CANADIAN NUCLEAR SOCIETY

bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

August 2002 Août

Vol. 23, No. 3

- Annual Conference
- Early Nuclear Power
- Steam Generator Conference
- Production of Cobalt 60
- Annual General Meeting
- New President

Contents

Cover Photo

The photograph on the cover is a partial view of the Bruce site showing Douglas Point in lower left, Bruce A in the background and the Bruce Heavy Water Plant in the centre. These facilities along with Pickering A, are the focus of Bill Morison's retrospective paper in this issue.

(Photo courtesy of Ontario Power Generation)

CANADIAN NUCLEAR SOCIETY

bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

ISSN 0714-7074

The *Bulletin of the Canadian Nuclear Society* is published four times a year by:
The Canadian Nuclear Society
480 University Avenue, Suite 200
Toronto, Ontario, Canada, M5G 1V2
Telephone (416) 977-7620
Fax (416) 977-8131
e-mail: cns-snc@on.aibn.com

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, free for 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 san frais pour les étudiants.

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

Associate Editor / Rédacteur associé
Ric Fluke — Tel. (416) 592-4110
Fax (416) 592-4930

The comments and opinions in the CNS Bulletin are those of the authors or of the editor and not necessarily those of the Canadian Nuclear Society. Unsigned articles can be attributed to the editor.

Printed by The Vincent Press Ltd., Peterborough, ON

Canada Post Publication Agreement #1722751

EDITORIAL

Where is the voice for nuclear?

The Kyoto Protocol has been very much in the news over the past few months - in particular the debate in Canada whether or not to ratify the accord.

Under that Protocol, which Canada signed (along with 83 other countries) in 1998, we would be obligated to reduce our "greenhouse gas" emissions to 6% below 1990 levels. Given that we are now emitting some 25% more GHG than in 1990 that implies a major reduction in the production of CO_2 and other GHG.

Since most of our production of CO_2 comes from the burning of fossil fuels it is understandable that producers and users of oil, gas and coal are fearful of such a commitment.

Over the past few years the federal government has had a "climate change " program, involving a secretariat and numerous working groups, and a package of inducements: to insulate buildings better, to increase energy efficiency, to develop "green" energy sources (meaning wind and solar), and other projects. From the working groups and, in particular, the "Analysis and Modelling Group", came earlier this year, a report titled *"A Discussion Paper on Canada's Contribution to Addressing Climate Change"* which presented four "options".

Not one of these "options" involved the expansion of nuclear power, despite its obvious advantage of being a proven, large-scale, GHG free, source of electricity. In fact the word "nuclear" does not appear anywhere in the report.

Where was the voice of nuclear energy in this exercise ? Where is it in the current debate ? The views of the oil and gas industry are very apparent, as are those of the other eight industry sectors studied (none of which included electricity generation).

There were a few nuclear people on the various "tables" that examined particular aspects of the GHG reduction challenge but, reportedly, the best they were able to achieve was to not have nuclear specifically excluded.

The role of nuclear power for the production of clean electricity is well know to all readers of the *CNS Bulletin.* Further, as has been shown in several very good papers by Romney Duffy and colleagues (a few of which we have reprinted), there is a great potential, technically and economically, in marrying nuclear power with the use of hydrogen for transportation. Since that sector is the source of over a third of our GHG such a development could lead to a significant reduction in our production of GHG (and other noxious gases). Both of these contributions have been ignored in the government's discussion papers.

For the sake of our environment and our economy this blindness must be overcome. Unfortunately, to date the Canadian nuclear community has been very inadequate in getting the message across.

Fred Boyd

IN THIS ISSUE

Much of this issue is drawn from or based on two major events, the **23rd CNS Annual Conference,** held in June, and the **6th CNS International Steam Generator Conference,** held a month earlier. There are reports on each of these gatherings and a few papers selected from them.

From the Annual Conference we have two technical papers and one of the three excellent reminiscent papers presented in the special "history" session at the Conference. The first technical paper is: **Reactor Physics Innovations in ACR-700 Design for Next CANDU Generation** by M.Ovanes, et al. The other is: **Cobalt-60 Production in CANDU Power Reactors** by G.R. Malkoske et al. Choosing one of the historical papers was difficult. Since there were several articles on NPD in the previous issue we chose the one by Bill Morison titled: **Early Development of Full Scale Nuclear Power in Ontario** in which he tells of the challenges of the rapidly growing nuclear program of the 1960s and 1970s.

Most of the papers at the Steam Generator were somewhat specialized. However, we believe that most readers will find the plenary presentation by J. Muscara, of the US Nuclear Regulatory Commission, interesting: **Research Perspectives on the Evaluation of Steam Generator Tube Integrity.** *We hope to present further papers from the both conferences in the following issue.*

The conclusion is included of Hughes Bonin's bilingual description of the **Nuclear Engineering Programs at RMC** which was begun in the last issue.

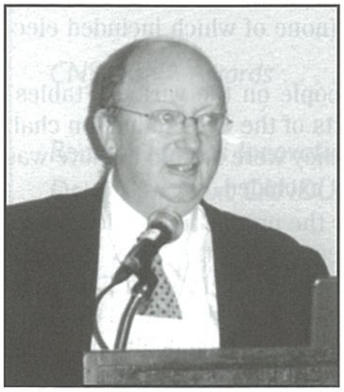
There is a shorter than usual section on **General News** with a few items you may not have seen elsewhere and a expanded section of **CNS News** in which we report on the Society's **Annual General Meeting** and provide a short note **Meet the President.**

Thanks to Keith Weaver we have two **Book reviews** and, of course, Jeremy Whitlock's particular view of affairs in **Endpoint**. Finally, the **Calendar** has been updated.

Enclosed as a supplement are the three winning papers from the CNS/CNA Student Conference held immediately prior to the Annual Conference.

We welcome feedback, be it comment, criticism, or contribution.

23rd CNS Annual Conference
—40 Years of Nuclear Power in Canada



Ken Talbot
Conference Chairman

Another very successful Annual Conference was held by the Canadian Nuclear Society in Toronto, June 2 to 5, 2002,with close to 300 attending.

The theme of this 23rd Annual Conference was: *"40 Years of Nuclear Power in Canada; Celebrating the Past, Looking to the Future".*

This was the third national nuclear meeting organized by the CNS. Over the previous two decades the annual gathering had been a joint effort of the Canadian Nuclear Association and the Society with the CNA taking on the major role. Earlier, prior to the formation of the CNS, the meetings had been solely a CNA affair.

The overall format this year was basically the same as the successful previous two with a combination of plenary sessions, in which senior members of the nuclear community provided overviews of various sectors of the nuclear program, and sets of parallel sessions in which some 80 technical papers were presented. Also, the CNS/CNA Student Conference was held on the Sunday, an arrangement that proved successful as it had the previous year.

David Jackson, left, presents his "CNS President's Award" to bob van Adel, president of Atomic Energy of Canada Limited, in recognition of 50 successful years of the company, at the 23rd CNS Annual Conference in Toronto, June 3, 2002.

A major change was using the banquet as the setting for the presentation of awards, from both the CNS and CNA. This innovation, augmented by a jazz band that played in the interludes and later, appeared to be popular with most of those attending (a number of whom showed that they still knew how to dance in the style of a few decades ago). *See a separate article in this issue of the* CNS Bulletin *for a story on the awards.*

The opening plenary session featured a line-up of speakers who provided current views of various segments of the nuclear power sector.

Pierre Charlebois, nuclear chief operating officer and chief nuclear engineer at Ontario Power Generation, began with an overview of OPG's nuclear program, noting that nuclear provides a major part of OPG's generation. The nuclear performance index has risen from 58% in 1997 to 83% in 2001, he reported. Augmented with a number of photographs he outlined some of the challenges imposed by the competitive electricity market which began in Ontario on May 1, 2002 Acknowledging that the refurbishment of Pickering A was behind schedule he commented that OPG had taken back direct management of the refurbishment program rather than relying on two major contractors. To a question he confirmed that the nuclear safety group was being spun off to a private company, noting that it also serves Bruce Power.

Duncan Hawthorne, CEO of Bruce Power, titled his address "The First Year and the Future". His company is investing $1.8 billion in the Bruce plants, he reported, primarily to bring two of the Bruce A units back into service. When that occurs Bruce will be largest electricity complex in Canada. After praising the Ontario government for de-regulating the electricity market he commented on the "human" element, relationship with the local communities and the staff. Through a profit sharing program most employees at Bruce received an extra $4,000 last year, he said.

Paul Thompson, of NB Power, provided an update on the proposed refurbishment of the Point Lepreau station, with reference to a similar presentation the previous year. After spending two years and $40 million on a scoping study NB Power decided to proceed to a detailed refurbishment plan, which is now underway.

Michel Rhéaume, of Hydro QuÈbec, presented a summary of the initial study for a similar refurbishment project, for the Gentilly 2 station. Noting that the fuel channels will probably need to be replaced about 2008 a study is underway to determine if an extended refurbishment to extend the life of the plant for a further 25 years would be justified. HQ is now in the middle of a four year study to assess the economic and technical feasibility of a major refurbishment. This study is scheduled to be completed by mid 2003 to be followed by a hear and a half of public consultation. Preliminary engineering work would proceed in parallel with the public hearings. Atomic Energy of Canada Limited has been engaged as the primary contractor for the reactor studies.


Michel Rhéaume

Gary Kugler, senior vice-president at Atomic Energy of Canada Limited, provided a summary of the nine CANDU units operating or under construction overseas. Four are operating in Korea, one each in Argentina and Romania. Two are under construction in China and one in Romania. The Qinshan project in China, he reported, is on schedule and budget with unit 1 expected to begin operation by the end of 2002. The Romanian government has indicated it wishes to complete units 3 and 4 at Cernavoda. Marketing activities are beginning in the UK and USA for the Advanced CANDU Reactor.


Grant Malkoske

The last two papers in the Plenary 1 session provided non-Canadian perspectives. **V.K. Chaturvedi,** chairman and managing director of Nuclear Power Corporation of India, presented a summary of his country's nuclear power program under the title *"Nuclear Power: The Sustainable Energy Option for India".* The electricity generating capacity in India is just over 100,000MWe. To support the current economic growth rate about 10,000 MWe additional will be needed annually. With limited coal and oil resources and most hydro already developed nuclear power is essential. There are now 14 power reactors operating, mostly 220 MWe PHWRs, based on the Douglas Point design but including two BWR units. An overall capacity factor of 85% was achieved in 2001. Construction is underway on eight units - four 220 MWe PHWRs; two 540 MWe PHWRs; and two 1,000 MWe VVER. Except for the last, being supplied from Russia, the units are all of Indian design and construction. A 500 MWe prototype fast breeder reactor is planned.

Closing the session, **Robert Lyon,** of the International Atomic Energy Agency (and formerly with AECL), gave a world view of heavy water power reactors, based on a recent IAEA report prepared by an international committee. Although HWRs represent only about 8% of the power reactors in the world they have been very successful, That led an IAEA working group to propose this compilation of the history, status and future directions for this type of plant.

The second plenary session, held on the Tuesday afternoon, was divided into two parts, one titled *"The Present and the Future",* followed by *"A Look at Canada's Nuclear History".*

Beginning the first part was a paper by **John Robson,** general manager McCLean Lake, COGEMA Resources Inc., on two topics, "Canadian Uranium, in the World Market" and "Production at McClean Lake". Canada is the world's largest uranium producer, he noted, providing about 1/3 of the total. With the spot price of uranium less than $10 (US) per pound many mines around the worlds have closed. Only the high grade of the Saskatchewan deposits combined with innovative production techniques have permitted Canadian mines to continue operation.

When the JEB mill at McCLean Lake started operation in 1999 it was the first new uranium mill in North America in two decades. It is designed to process ore from McClean Lake, Midwest and the new Cigar Lake mines.

Grant Malkoske, vice president MDS Nordion, and **Jean-Pierre Labrie,** general manger MMIR and isotope sales, AECL, jointly presented a paper on *"MAPLE Reactors for the Secure Supply of Medical Isotopes".* Malkoske began with his characteristic "upbeat" description of the benefits of radioisotopes. MDS Nordion, he stated, is the world's leading supplier of medical isotopes, providing the basis for over 34,000 nuclear medicine procedures every day. Labrie provided a description of the MAPLE reactors now under construction at the Chalk River Laboratories of AECL. To a question Labrie stated that the many problems that have delayed the start-up of the reactors have been overcome and commissioning is resuming.

In the final paper of this part session, **David Torgeson,** senior vice president at AECL, expounded on the features of the Advanced CANDU Reactor (ACR) (formerly CANDU NG) being developed by AECL. The target is a major reduction in capital cost, improved operability and enhanced safety margins. *(The ACR design is outlined in the paper "Reactor Physics Innovations in the ACR 700" reprinted in this issue of the* CNS Bulletin.)

The second part of plenary session II also had three papers - each providing a particular look at the history of nuclear power in Canada.

In his paper *"NPD, Canada's First Nuclear Power Station"* **Lorne McConnell,** former vice president Ontario Hydro and first superintendent of NPD, provided some insight into the beginnings of the country's nuclear power program. *(See the articles on the NPD Commemorative Plaque in this issue and those on NPD in the previous issue of the* CNS Bulletin, *Vol. 23, No. 2, May 2002.)*

Bob McDonald Luncheon Speaker

Bill Morison, also a former vice president of Ontario Hydro, picked up the history with a detailed description of the Douglas Point and Pickering A projects in his paper *"Early development of Full-Scale Nuclear Power in Ontario". (His paper is reprinted in this issue of the* CNS Bulletin.)

Ted Bazeley, formerly with AECL now with E.G. Bazeley & Associates, gave a history of a major part of the nuclear program in his paper entitled *"The Evolution of Procurement and Supply Conditions for CANDU Fuels".*

A third plenary session was held on the morning of the third day, on the topic *"Future Challenges and Opportunities"* with a somewhat eclectic mixture of presentations.

Dino Spagnolo, of AECL, began with a description of a new process for producing D_2O in a co-authored paper entitled *"Prototype CIRCE Plant - Industrial Demonstration of Heavy Water Production from Reformed Hydrogen Source".* The CIRCE (Combined Industrial Reforming and Catalytic Exchange) process offers the best prospect for commercialization, he stated. A prototype plant built at the Air Liquide Canada facility in Hamilton in 2000 has confirmed the design and its capability of enriching deuterium without compromising hydrogen production.

Tom Viglasky, director general, nuclear substance regulation, Canadian Nuclear Safety Commission, spoke on *"Risk Management in the CNSC Regulatory Program".* The Commission is moving to a risk informed approach to improve effectiveness and efficiency, he said. He outlined how the approach is being applied in one of his areas of responsibility - radioisotopes - by concentrating licensing and compliance efforts on those licensees posing the highest potential risk.

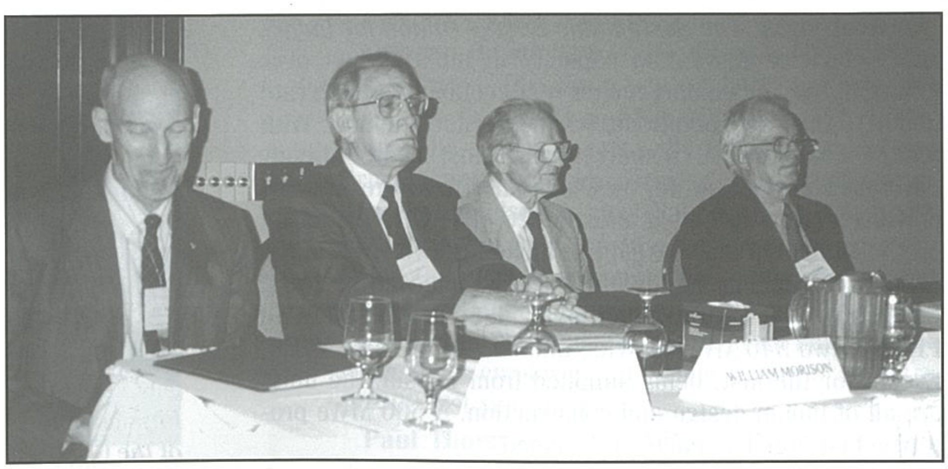
Myong-Jae Song, of Korea Hydro and Nuclear Power Co. Ltd., presented a paper on *"Update on Radioactive Waste and Spent Fuel Management in Korea".* Considerable research and development has been directed at the development of vitrification technology for the treatment of low and intermediate radioactive waste. A repository for these wastes is planned to be ready by 2008. For spent fuel a centralized interim storage facility is planned for 2016.

Bill Clarke, CEO of the Canadian Nuclear Association gave a brief report on current activities of his organization. A new communication program is being developed to be implemented later this year and considerable effort continues on regulatory matters, climate change and other issues. He noted the successful Winter Seminar held in Ottawa in February *(See Vol. 23, No. 2, May 2002, issue of the* CNS Bulletin.)

Then followed three very brief presentations. **Shayne Smith,** vice president Wardrop Engineering, provided an update on the continuing negotiations for a site for Iter, the large international thermonuclear project. **Adam McLean,** of the University of Toronto, reported on the successful bid by the CNS to host the next International Youth Nuclear Congress in Toronto in 2004. **Ken Smith,** UNECAN News and former president of the CNS, provided an update on Bill C-27, the *Nuclear Fuel Waste Act,* which, at that time was still being reviewed by a parliamentary committee. (It was subsequently passed and received Royal assent on June 13, 2002.) **Dave Shier,** of the Power Workers Union, spoke primarily about the developing relations between his union and Bruce Power.

Kevin Routledge, of NNC Canada Ltd., talked about the role of a nuclear service company, such as NNC, in the privatized nuclear industry operating in the UK.

The session closed with an interesting and animated panel on *"Opening the Electricity Market in Ontario - Nuclear Effects"* with representatives from the Independent Market Operator (IMO), Ontario Power Generation and Bruce Power. **Bruce Goulding,** CEO of the IMO, commented the market opening on May 1 had proceeded smoothly thanks to much planning and exercises. He noted that Ontario did not have much generation reserve. **Bruce**



The three speakers and chair of the special "history" session at the 23rd CNS Annual Conference, June 4, 2002 await the beginning time. Left to right: Ted Bazeley, Bill Morison, Lorne McConnell, Elgin Hortin (chair).

Boland, senior vice president OPG, commented on the pressure to control and plan outages. **Andrew Johnson,** vice president Bruce Power, insisted that there would be no compromise on safety, that commercial success and high safety performance were associated. The open market does, he noted, force more discipline.

On the social aspects there were two lunches and a banquet as part of the package along with generous morning and afternoon refreshments.

At the luncheon on the first day, **Hans Tammemmagi,** author, environmental consultant and former AECL researcher, spoke on the topic *"Can the Public Learn to Love Nuclear?"* His conclusion was probably not but the public can be convinced to accept nuclear power.

The other lunch, held on the third day, featured **Bob McDonald,** science broadcaster with the CBC, speaking on *"Science in the Third Millennium",* or, as he quipped, "2200 years of science in 25 minutes". He began with the story of Ertasthenes in Greece about 200 B.C., who estimated the diameter of the earth by examining the shadow of the sun in wells, and proceeded through Leonardo da Vinci., the application of steam, discovery of electricity, nuclear energy and the space probes around Mars. As an aside he commented that many, if not most, people associate the word "nuclear" with the "bomb".

As noted earlier the banquet, held on the evening of the second day, was the setting for the presentation of the several awards offered by the CNS and the CNA. *(See separate article.)* A jazz ensemble provided music in the interludes and continued after dinner, inducing many to show off their dancing skills.

During the Tuesday lunch period the North American Young Generation Network held a Professional Development Seminar.

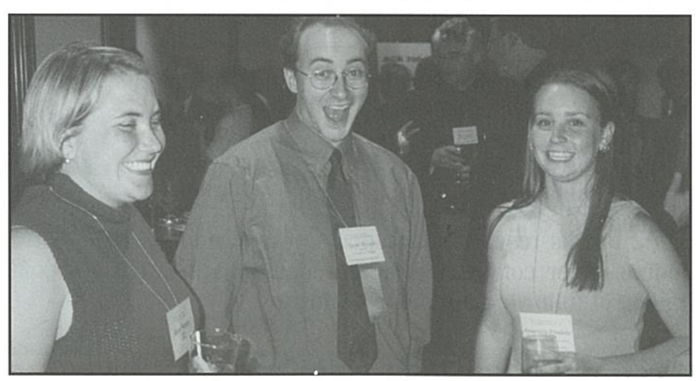
The conference was organized by a committee with Ken Talbot (of Bruce Power) as president and Ian Wilson (now CNS president) as executive chair. Other members included: Ken Smith, Martyn Walsh, Walter Thompson, Jeremy Whitlock, Eleodor Nichita, Roman Sejnoha, Margaret MacDonald, Jad Popovic, Jean Koclas, Claudia Lemieux, Ben Rouben, Denise Rouben, Denise Brien, Shirley Chapman, Gloria Niblock, Wenda Bourgeois, Lise Marshall, Veena Sharma.

Making the conference financially feasible many organizations provided sponsorship, including: AECL, Babcock& Wilcox Canada, Bruce Power, Cameco, CNA, Canatom NPM, Cogema, Framatome ANP Canada, GE Canada, Hydro QuÈbec, Lou Champagne Systems, NB Power, Nuclear Logistics Inc., OPG, OCI, Power Workers' Union, RCM Technologies, Stone &Webster, Summit Controls Ltd. Wardrop Engineering, Zircatec Precision Industries.

Plans are already underway for the 2003 conference. Anyone wishing information or willing to help should contact the CNS office.

A CD with most of the papers presented at the Conference is available from the CNS office.

Scenes from the Annual Conference reception



CNS / CNA Awards

In 2001 the Canadian Nuclear Association and the Canadian Nuclear Society decided to coordinate the various awards each organization gives to honour individuals and groups who have made significant contributions to the Canadian nuclear program. As a result a common award ceremony was held during the banquet of the 23rd CNS Annual Conference held in Toronto in June 2002. Following are the official citations.

In addition the prizes for the best papers at the **CNS / CNA Student Conference,** held June 2, 2002, immediately prior to the Annual Conference were presented at the same occasion. The winners were:

Best Undergraduate paper:
Sarah Attia, University of Toronto

Best Masters Level paper:
Mounia Berai, École Polytechnique

Best Doctoral Level paper:
Ibrahim Attieh, University of Tennessee

(Their winning papers are included as a supplement to this issue of the CNS Bulletin.)

CNS R. E. Jervis Award

This award was established in 1992 by former students of Prof. Robert E. Jervis of the University of Toronto and the CNS. The recipient must be a full-time graduate student at a Canadian university, who is pursuing research involving radiochemistry or the use of nuclear research rectors in applied chemistry or chemical engineering studies. Because no award was presented in 2001 three awards were granted.

Lt. Michael Walker, from the Royal Military College, was awarded the R.E. Jervis Award for 2001 for his studies assessing the properties of advanced polymer-based materials for potential application to the fabrication of metal-lined containers for the long-term storage of intermediate- and low-level waste.

Mr. Larry Unsworth was awarded the R.E. Jervis award for 2002 for neutron reflectometry and ellipsometric studies of the fundamental properties of monolayer films of ethylene glycol chemisorbed onto gold surfaces.

Mr. Tutun Nugraha was awarded the R.E. Jervis Award for 2002 for his research on aspects of behaviour of radioactive iodine under condensing steam conditions in a reactor containment following a reactor accident.

CNS Education and Communications Award

The Education/Communication Award was established by the CNS in 1997. This awards aims at recognizing the recipients for "significant achievements in improving the understanding of nuclear science and technology among educators, students and the public". The award is in the form of a certificate presented at the CNS Annual Conference.

Brent Lewis

The Education/Communication Award was awarded to **Adam McLean.** Adam is a very active member of the Canadian Nuclear Society. He is presently an engineering physics graduate student at the University of Toronto, yet has made time to serve on the CNS Council and work hard on education and outreach initiatives for the benefit of the Society and the public at large.

Some of his activities have included:

- Revitalizing the Toronto Branch of the CNS, of which he is the current Chair.
- Creating of the CNS "Business Card", listing educational contacts on the Internet and raising the profile of the CNS as an educational resource.
- Creating and maintaining extensive material under the Toronto Branch pages of the CNS web site on fusion and alternative energy sources, and on a Greenhouse Gas comparison spreadsheet.
- Contributing regularly and factually to the public cdn-nucl-l list server, speaking forcefully in favour of the nuclear option and unafraid to take on anti-nuclear criticism.
- Making interesting and innovative presentations to OPG staff, particularly students, on an introduction to nuclear, using for example Homer Simpson slides to demonstrate in an amusing and effective way what the nuclear industry is not.
- Pioneering the Ask an Expert! campaign, which will offer technical responses from CNS member volunteers to public and media questions.
- Being active on the Internet and Education subcommittees of the CNS, creating contacts with science organizations like Women in Engineering, Canada Wide Science Fair, Let's Talk Science
- Securing Toronto as the official host of the International Youth Nuclear Congress in 2004.

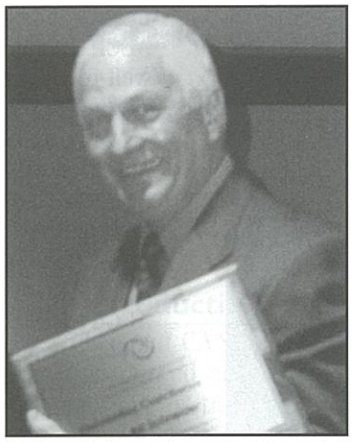
CNS Fellow

CNS members who have been designated "Fellows of the Canadian Nuclear Society" belong to a membership category established by the Society in 1993 to denote outstanding merit. The criteria for appointment as a CNS Fellow require extensive and outstanding service to the Society, and current

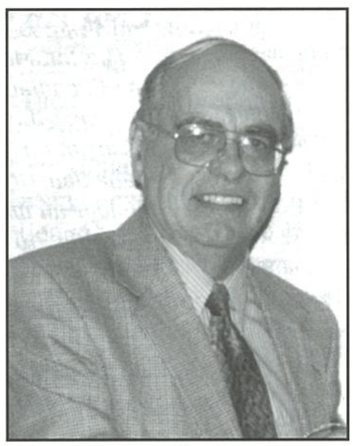
CNS membership of at least five years' standing. A further essential requirement is that the recipient must have demonstrated maturity of judgement and breadth of experience, as well as sustained contributions to the sciences and/or professions that relate to the advancement of nuclear technology in Canada, and outstanding technical capability. In the tradition of honorary membership categories of learned societies, CNS Fellows are entitled to add the letters "F.C.N.S." to letters denoting degrees and professional certifications following their name.

Dr. Brent J. Lewis, a professor at the Royal Military College was presented with a certificate acknowledging his designation as a Fellow of the Canadian Nuclear Society. Dr. Lewis completed his graduate studies at the University of Toronto and became a Research Scientist at the AECL Chalk River Laboratories in 1980, working in the area of fuel and fission-product-release behaviour. In 1988 he joined the teaching staff of the Royal Military College of Canada, where he is currently Professor in charge of the Chemical Engineering program at the undergraduate level. Over the years, he has supervised or co-supervised several 4th year Engineering Design Projects, Master's degree and doctoral theses, with many of his former students becoming successful members of the Canadian nuclear community. Dr. Lewis has acquired a solid reputation on the international scene, and has won several international awards in computer modelling of fission-product-release behaviour and in the measurement of radiation doses to the crews of high-altitude commercial and military aircraft. Dr. Lewis played a significant role in the development of two important computer codes: FORM 2.0, which has been adopted as a standard by the Canadian nuclear industry for the development of CANDU nuclear fuels, and PC-AIRE, which is about to become adopted as an industry standard by the Canadian, American and European airline industries.

Dr. Lewis is a Charter Member of the Canadian Nuclear Society. In addition to presenting numerous papers at various CNS conferences and encouraging his students to do so, he has been involved in the organization of a number of conferences. In 2001 he was the chairman of the 7th International CANDU Fuel.



Bill Schneider holds the plaque symbolizing the CNA Outstanding Contribution award presented to him June 4, 2002 during the CNS Annual Conference.



Ken Smith

Bal Kakaria

CNA Outstanding Contribution Award

The Outstanding Contribution Award was established in 1989 by the Canadian Nuclear Association. Criteria used in the selection procedure include but are not limited to individuals, organizations or parts of organizations who have either made a significant and obvious contribution to the nuclear industry over a long period of time and/or made a specific outstanding individual contribution that has had a significantly positive impact on the Canadian nuclear industry. Eligibility is not restricted to technical achievements. The individual or organization being nominated must be Canadian based. Members of the Canadian Nuclear Association office permanent staff can be nominated. In any given year, there can be more than one individual or organization receiving this award and will depend solely on the number and merits of the nominations. When more than one award is to be made, the selection committee will strive to ensure that the achievements being recognized are roughly equal in significance to maintain the integrity of the awards program. In the case of an individual receiving an award, that person is entitled to use the designation, "Fellow of the Canadian Nuclear Association". Three awards were made.

Bill Schneider

Bill Schneider began his engineering career in 1965 at Orenda Engines, and moved to Babcock & Wilcox in 1967. His career at B&W has encompassed design, development, and engineering service support for CANDU and PWR steam generators, involving fifteen different steam generator designs. His work has included overall concept development, and major performance programs on materials, steam separators, tube-support structures and other components.

His drive for perfection in nuclear steam-generator design has been a major contributor to the understanding and enhancement of B&W's nuclear products and services. As such, his contributions to the development and implementation of design concepts have had a direct impact on B&W's success in the very competitive international marketplace, where B&W has captured more than half of the U.S. market for replacement steam generators. In recognition of his contribution, Bill was recently chosen as the first Canadian recipient of B&W's Engineering Honours Award.

Bill has also been a strong supporter of the activities of the Canadian Nuclear Society, through his involvement in numerous Maintenance and Steam Generator conferences, becoming Chair of the Design & Materials Division, organizing a very successful CANDU Chemistry Course in 2000, and bringing to realization his ideas for a new CNS publication called C-News.

Ken Smith

During his extensive commitment to the Canadian nuclear industry, Ken Smith had a vari-

Al Kupcis, chairman at the Canadian Nuclear Association congratulates Stu Groom after presenting him with the Ian McRae Award at the awards banquet June 4, 2002 during the 23rd CNS Annual Conference.

ety of careers. He spent seven years at Chalk River on engineering R&D related to fuel channels for future reactor concepts, and another five years on the design, manufacturing development, and procurement of the Gentilly-1 fuel channels. For the next fifteen years, Ken held various project management and senior administration positions at AECL. He was AECL's Senior Project Engineer for Pickering A, and subsequently for Bruce A, with responsibility for the design/ construction and design/commissioning interface with Ontario Hydro. He led the development of AECL's first "work package reporting" system (WPRS), and was the primary author of engineering change notice (ECN) techniques for controlling the installation of the design changes on the multi-unit stations at Pickering A and Bruce A. This change-control methodology has been used effectively on all subsequent nuclear projects. He was heavily involved in assembling the project proposal estimates for the initial series of CANDU-6 projects. Ken subsequently spent five years with Energy Mines and Resources in Ottawa (now called Natural Resources Canada). His duties included adjustments to, and application of, the Canadian uranium export policy, plus the resolution of uranium trade issues at a time when the export policy was coming under fire from the USA and various European countries.

Following his retirement from full-time employment in 1991, Ken formed his own consulting company, and began the publication of a monthly newsletter, *UNECAN NEWS*, which is frequently referenced in international publications. He has earned a national and international reputation for presenting accurate information on developments within the Canadian nuclear and uranium industries. During this time he has been a very active Member of Council of the Canadian Nuclear Society, and served as President in 2000/2001. Since the CNS took over the organization of the Annual Conference, he has continuously served on the Annual Conference Organizing Committee.

Bal Kakaria

Bal Kakaria has had an outstanding career in the Canadian nuclear industry, a career that spanned more than 33 years with AECL. He served in a number of important positions, becoming well recognized by all the CANDU utilities and supplier organizations. Under Bal's leadership, AECL established itself in the growing refurbishment business and innovated both technically and in a willingness to find contractual models that serve the needs of both client and supplier. Under his direction, AECL invested in the design and assembly of modern fuel-channel inspection equipment, ensuring that CANDU utilities would have access to an essential service. He spearheaded programs in AECL to develop improved technology in large-scale fuel-channel replacement, while in parallel proposing risk-sharing utility agreements to mitigate uncertainties and ensure financial viability for refurbishment programs.

Bal played an active part in major AECL projects, such as Wolsong 2/3/4, Point Lepreau Refurbishment, Pickering A Return to Service, Bruce Return to Service, and Dry Spent Fuel Storage for G2, Cernavoda, and Korea. He has made a significant contribution to the establishment of the CANDU service industry, so that it can in turn support the long-term viability of CANDU reactor sales.

CNA Ian McRae Award

The Ian McRae Award of Merit was established in 1976 by the Canadian Nuclear Association in honour of the late Ian F. McRae, the first President of the Canadian Nuclear Association and Chairman of the Board of Directors of the Canadian General Electric Company Ltd. The purpose is to honour an individual for outstanding contributions, other than scientific, to nuclear energy in Canada.

Stu Groom

Stu Groom has thirty-seven years of experience in nuclear power plant operation and technical engineering support services related to metallurgical, mechanical, electrical and instrumentation and control aspects of plant operation and maintenance. During his career he has worked for Ontario Hydro, Canatom and New Brunswick Power. He has carried out the duties of shift supervisor, technical superintendent, technical manager, acting station manager, and chief nuclear engineer. He has been involved in COG activities since 1984 and is currently a member of the COG Board of Directors. He was also involved in the formation of the Waste Fuel Management Organization.

Mr. Groom has made significant contributions towards the success of Point Lepreau. He has also made important contributions to the industry by raising awareness and initiating and supporting R&D related to flow-assisted corrosion in CANDU outlet feeders and stress-corrosion cracking in feeder pipes. He has also provided a guiding role in bringing focus to the COG R&D pertaining to fuel channels and Steam generators. Throughout his career, Mr. Groom has shown unwavering support and devotion to the advancement of nuclear science and technology in Canada. He is admired for his inspiration, professionalism, expert judgement, and genuine concern for people. He has also been a strong advocate of information exchange and co-operation within the industry.

Reactor Physics Innovations in ACR-700 Design for Next CANDU Generation

by M. Ovanes, P.S.W. Chan and J. Mao[1]

***Ed. Note:** The following paper was presented at the 23rd CNS Annual Conference held in toronto, Ontario, June 2-5, 2002.*

ABSTRACT

ACR-700 is the "Next Generation" CANDU reactor, aimed at producing electrical power at a capital cost significantly less than that of the current reactor designs. A key element of cost reduction is the use of H_2O as coolant and Slightly Enriched Uranium fuel in a tight D_2O- moderated lattice. The innovations in the ACR core physics result in substantial improvements in economics, as well as significant enhancements in reactor controllability and waste reduction. Fuel design is chosen to balance fuel performance, cost, and reactor-physics characteristics. Full-core coolant-void reactivity in ACR-700 is about -3 mk. Power coefficient is substantially negative. Discharge fuel burn-up is about three times the current natural-uranium discharge burn-up. The result is a core design which provides a high degree of inherent safety with attractive power-production efficiency and stability.

1. Introduction

The Advanced CANDU Reactor 700 MWe-class (ACR-700) is the next CANDU generation, aimed at producing electrical power at a capital cost significantly less than that of the current reactor designs. Cost reduction of the ACR is achieved through the following innovations:

- reduce the inventory of D_2O by using H_2O as coolant and by using Slightly Enriched Uranium (SEU) fuel in a tight D_2O-moderated lattice,
- increase the maximum operating channel and bundle powers by using the CANFLEX® fuel bundle design,
- increase the overall reactor power output by flattening the radial channel power distribution,
- increase the thermal/electric conversion efficiency by operating at higher coolant pressure and temperature, and
- reduce the size of the reactor core and the reactor building.

The neutronic properties of the ACR have been specifically designed to ensure the improvements in economics are also accompanied by improvements in reactor controllability and waste reduction:

- a significant increase in the reliability and effectiveness of the Emergency Core Cooling (ECC) system by simplifying the interface between the ECC and the Heat Transport (HT) system since they are both now light-water systems,
- a substantial enhancement in reactor control by operating with significantly negative feedback in reactor power, and
- a factor-of-three reduction in the quantity of spent fuel-bundles per unit of electricity generated.

2. Physics Innovations to Achieve Slightly Negative Coolant-Void Reactivity

A CANDU reactor with H_2O coolant would have a high positive coolant-void reactivity at the current lattice pitch of 28.575 cm. The key parameter that determines the coolant-void reactivity is the moderator-to-fuel volume ratio in the lattice cell. The current CANDU reactor lattice has a large moderator-to-fuel ratio of 16.4, resulting in a well-moderated lattice that is optimized for the natural uranium (NU) fuel cycle. An effective way of reducing the coolant-void reactivity, for a CANDU reactor using H_2O coolant and SEU fuel, is to reduce the lattice pitch until an under-moderated lattice condition is reached. The lattice becomes under-moderated when the D_2O moderator volume alone cannot provide sufficient moderation to achieve maximum reactivity. The H_2O inside the fuel channel then functions as both coolant and moderator. Coolant-void reactivity is determined by the net result due to the loss of absorption (a positive reactivity change) and the loss of moderation (a negative reactivity change). Spatial and spectral changes of the neutron flux in the lattice cell due to voiding of the coolant, as well as the nuclide composition in the fuel, also affect the coolant-void reactivity.

Coolant-void reactivity in the ACR is a design parameter; lower values can be

1 Atomic Energy of Canada Limited, Mississauga, Ontario, Canada L5K 1B2

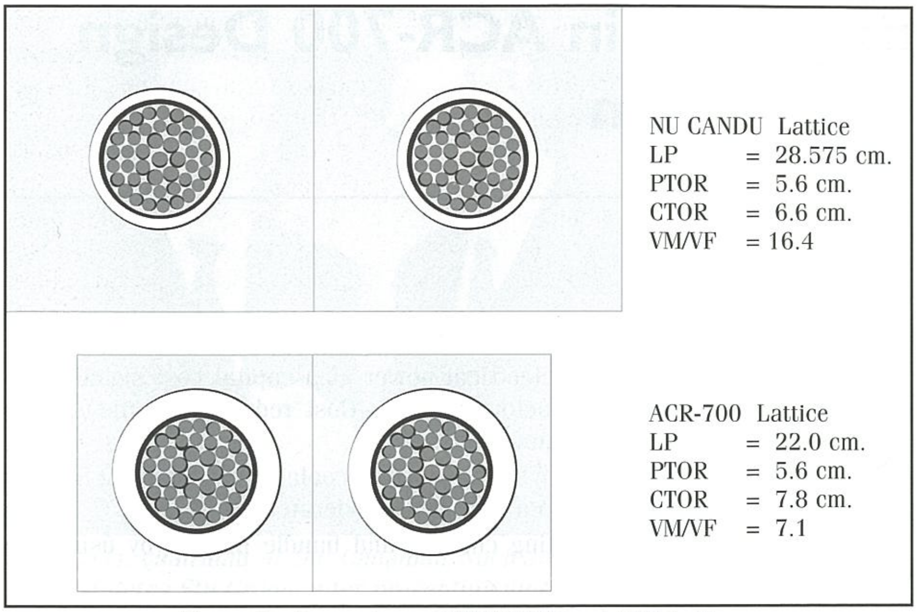


Figure 1: Comparison of NU CANDU and ACR Lattice

achieved mainly by reducing the lattice pitch. A survey study of the relationship between coolant-void reactivity and the moderator-to-fuel volume ratio was conducted using the lattice code WIMS-IST (WIMS-AECL version 2-5d) with the ENDF/B-VI nuclear data library [1]. It was determined that a moderator-to-fuel volume ratio of less than 6.0 is required to achieve a slightly negative coolant void reactivity. This would require the reduction of the lattice pitch from the current value of 28.575 cm to 20 cm.

The space requirements between feeders in adjacent fuel channels in a CANDU reactor determine the minimum lattice pitch that is permissible. A detailed engineering assessment recommended a minimum lattice pitch of 22 cm, giving a moderator-to-fuel volume ratio of 8.4. This ratio can be further reduced to 7.1 by displacing more moderator from this lattice cell by increasing the calandria tube outside radius from the current value of 6.6 cm to 7.8 cm. This is considered to be the maximum calandria tube size that still retains the necessary tube-sheet ligament strength required for a robust core mechanical design. The separation between adjacent calandria tubes is adequate for the installation of interstitial in-core reactivity control devices. However, the coolant-void reactivity is about +7 mk, which is higher than the CVR design target of -3 mk.

Using a small quantity of burnable poison in the central pin of a CANDU fuel bundle can further reduce the coolant-void reactivity. There is an increase in the thermal neutron flux towards the centre of the fuel bundle upon voiding of the coolant. Depending on the amount of burnable poison incorporated in the central fuel pin, this increase in neutron absorption could generate a negative reactivity component strong enough to reduce the overall coolant-void reactivity from a slightly positive value to a slightly negative value. The fuel enrichment and the burnable poison concentration can be tailored to meet the design targets of discharge fuel burn-up and coolant-void reactivity. The current ACR fuel design uses uniform 2.0% SEU fuel elements except the central element, which uses natural uranium fuel containing 4.6 wt% of the burnable poison Dysprosium. This fuel design gives a core-averaged discharge burn-up of 20.5 MWd/kgU and a coolant-void reactivity of -3 mk, based on full-core fuel management simulations using the RFSP-IST [2] code with WIMS-IST lattice parameters.

Figure 1 shows the dimensions of the lattice pitch (LP), pressure tube (PT), calandria tube (CT), and the moderator-to-fuel volume ratio (VM/VF) in NU CANDU and ACR lattices. The small ACR lattice results in a highly compact reactor core. The savings in D_2O cost is clearly demonstrated in *Figure 2,* which compares the size of this compact ACR core with those for other CANDU designs. The current reference ACR-700 core has 284 fuel channels producing 731 MWe inside a 5.20-metre-diameter calandria shell. This is much smaller than the 7.6-metre-diameter calandria shell that is required to accommodate 380 fuel channels in the current NU CANDU 6 reactor, which produces 728 MWe.

The compact lattice and slightly negative coolant-void reactivity result in strong negative power feedback, exceptional stability, and other benign neutronic characteristics for all sizes of ACR reactors currently under consideration.

3. MCNP Simulations

The WIMS [3] lattice code was originally developed as a general-purpose code for reactor lattice-cell calculations for a wide range of reactor systems, including both thermal and fast reactors, and both rod & plate fuel geometries in regular arrays or bundle clusters. Various versions of the WIMS lattice code have been used successfully to design

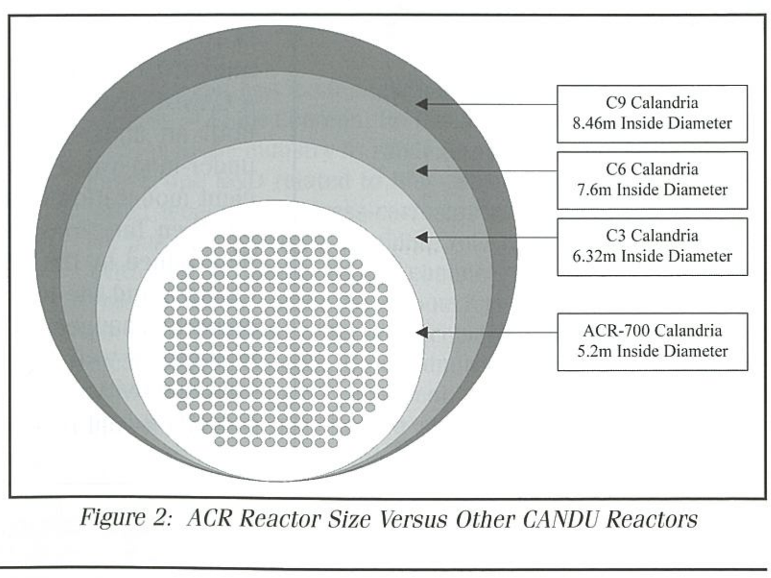


Figure 2: ACR Reactor Size Versus Other CANDU Reactors

Table 1: Reactivity Coefficients in ACR-700

Parameter	Value
Moderator Temperature (including density) effect	-0.024 (mk/(C)
Coolant Temperature (including density) effect	-0.010 (mk/(C)
Fuel Temperature effect (from 687 to 787 (C)	-0.014 (mk/ (C)
Boron increased from 0 to 5 ppm in Moderator	-2.1 (mk/ppm)
Power Coefficient (95% -105% full power)	-0.07 mk/% power
Reactivity change from 0% to 100% full power	-8.0 mk
CT and PT gap filled with H2O Coolant	-0.24 mk/channel
CT and PT gap filled with D2O Moderator	+0.08 mk/channel
Full-core Coolant-Void Reactivity	-3 mk

the SGHWR and the FUGEN reactors, where the reactor core physics characteristics are similar to those in ACR. Therefore, it is expected that WIMS-IST will be adequate for the design of the ACR. While precise experiments will be required to determine the absolute accuracy of the coolant-void reactivity calculated by WIMS-IST, it is desirable to confirm, at least qualitatively at the conceptual design stage, the WIMS-IST results by supplementing them with results obtained from a more rigorous code, such as the Monte Carlo code MCNP [4].

Figure 3 shows the neutron spectra averaged over the fuel and coolant regions inside the pressure tube with and without the H_2O coolant. These results were calculated with MCNP using nuclide densities calculated by WIMS-IST for the ACR lattice cell at mid-burnup. The neutron spectrum "hardens" when the coolant is lost and the dips at low epithermal neutron energies become more pronounced. *Figure 4* shows a general increase in the fast and epithermal neutron flux in the moderator region as a result of increased escape of fast neutrons from the voided channel, and an associated decrease in the thermal neutron flux due to the lack of moderation.

The dips in the spectra in *Figure 3* are attributed to absorption effects in different Uranium and Plutonium isotopes at specific neutron energies. *Figure 5* shows the large resonance absorption cross section of ^{238}U between 1 eV and 1 keV, while Figure 6 shows the prominent broad resonance of ^{239}Pu fission cross section centred at 0.3 eV. The behaviours of these cross sections have a major influence on the coolant-void reactivity in the ACR lattice.

The MCNP results show that the ACR lattice is under-moderated at the nominal operating conditions. Voiding of the H_2O coolant removes its moderation effect, which renders the lattice even more under-moderated. The shift in neutron spectrum upon coolant voiding increases the absorption in ^{238}U in the resonance region. There is also a significant reduction of the fission-yield in ^{239}Pu due to the decrease in neutron flux near 0.3 eV. These negative reactivity effects reduce the overall coolant-void reactivity in the lattice cell that would be expected from the loss of substantial absorption in the H_2O coolant.

Survey calculations using MCNP and WIMS-IST indicated that the ACR is an effective plutonium burner and that slightly negative coolant-void reactivity could be achieved in ACR using various plutonium-driven fuel cycles without the need for burnable poison. These include the MOX, Tandem and Thorium fuel cycles. The on-line fuelling capability of ACR allows full-core implementation of these advanced fuel cycles with consistently benign physics characteristics.

4. Reactivity Effects in ACR-700

Table 1 summarizes the major reactivity effects in the ACR-700 core, based on WIMS-IST lattice-cell calculations

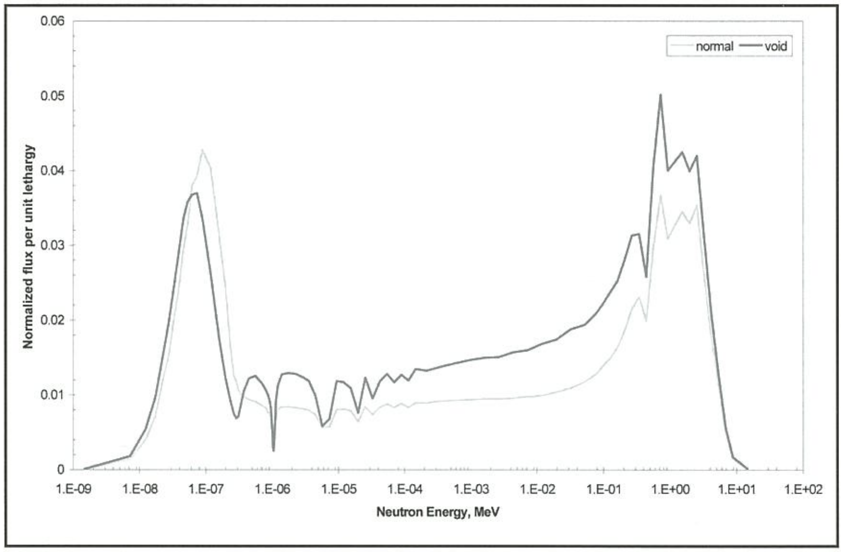


Figure 3: Neutron Flux Averaged over Fuel and Coolant within the Pressure Tube (MCNP Model)

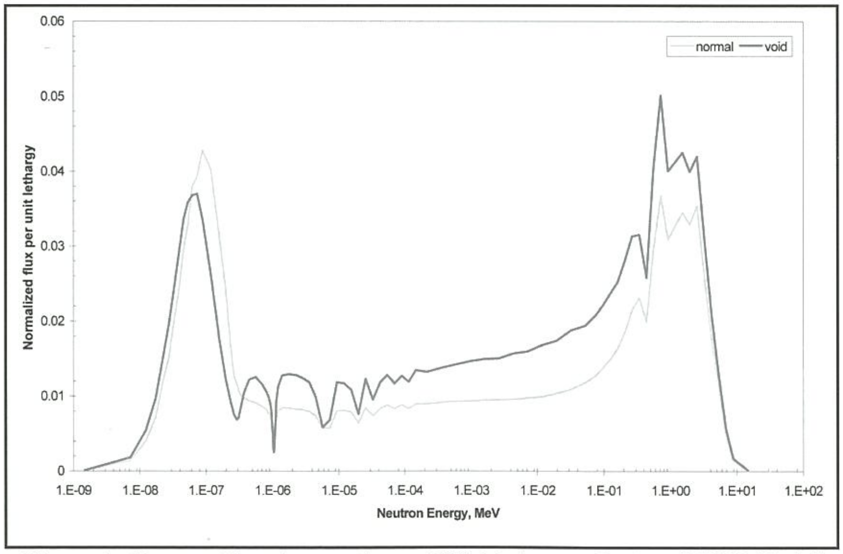


Figure 4: Neutron Flux Averaged over D2O Moderator Region (MCNP Model)

Table 2: Design Characteristics of ACR-700 Core

Parameter	Value
Number of Fuel Channels	284
Number of Bundles per Channel	12
Reactor Thermal Power Output	1982 MW (th)
Gross Electrical Power Output	731 MW (e)
Lattice Pitch (Square)	22 cm
Coolant (Average)	H2O @ 300 oC
Moderator (Average)	D2O @ 80 oC
Fuel Type	43-element CANFLEX
Enrichment of CANFLEX SEU Fuel	2.0 wt% ^{235}U + Central NU pin with 4.6 wt% Dy
Radial Form Factor	0.93
Core-Average Discharge Fuel Burn-up	20.5 MW.d/kg U
Maximum Fuel Element Burn-up	26 MW.d/kg U
Fuelling Scheme	2-bundle-shift
Fuel Bundles Required per Full Power Day	5.8
Channel Visits per Full Power Day	2.9
Maximum Time-Average Channel Power	7.5 MW(th)
Maximum Time-Average Bundle Power	874 kW(th)
Maximum Instantaneous Channel Power	7.8 MW(th)
Maximum Instantaneous Bundle Power	900 kW(th)
Maximum Instantaneous Linear Element Rating	51 kW/m

at mid-burnup. Each ppm of natural boron in the moderator is worth about -2.1 mk. The fuel-temperature and moderator-temperature reactivity coefficients are -0.014 mk/°C, and -0.024 mk/°C, respectively. The coolant-temperature coefficient is also slightly negative, about -0.010 mk/°C.

The reactivity change due to an increase in reactor power is the combined effect due to the increase in coolant temperature and the increase in fuel temperature. A thermalhydraulic code was used to calculate the core-averaged coolant temperature (including density effect) and fuel temperature at various power levels using the time-average power shape. The reactivities corresponding to these power levels were calculated by WIMS-IST for the mid-burnup fuel lattice using the appropriate fuel and coolant temperatures. The reactivity change from 0% power to 100% power in ACR is estimated to be about -8.0 mk. Between 95 % and 105 % power levels, the power coefficient is about -0.07 mk/% full power. Detailed coupled neutronic-thermalhydraulic simulations will be conducted at a later stage to determine the power coefficient more accurately. However, the magnitude of the negative power coefficient is sufficient to guarantee smooth power control during normal reactor operation, but it is not strong enough to interfere with the reactor control system.

Flooding the gap between the calandria tube and the pressure tube with H_2O coolant will result in a reactivity injection of -0.24 mk per channel. Therefore, a pressure tube that developed a leak while at power will cause a noticeable reduction in core power, in addition to a local reduction caused by increased neutron absorption in the gap. In-core LOCA will not cause a power excursion in the ACR. Instead, it could shut down the reactor automatically. However, flooding the gap between the calandria tube and the pressure tube with D_2O moderator will result in a reactivity injection of +0.08 mk per channel. This will cause a small increase in reactor power, which will be quickly terminated by the control system. Full-core coolant-void reactivity is about -3 mk. This slightly negative coolant-void reactivity will result in an automatic power decline under hypothetical LOCA conditions even without the intervention of the safety systems. However, the shutdown systems in ACR are based on traditional CANDU systems, designed to quickly terminate much more severe power transients.

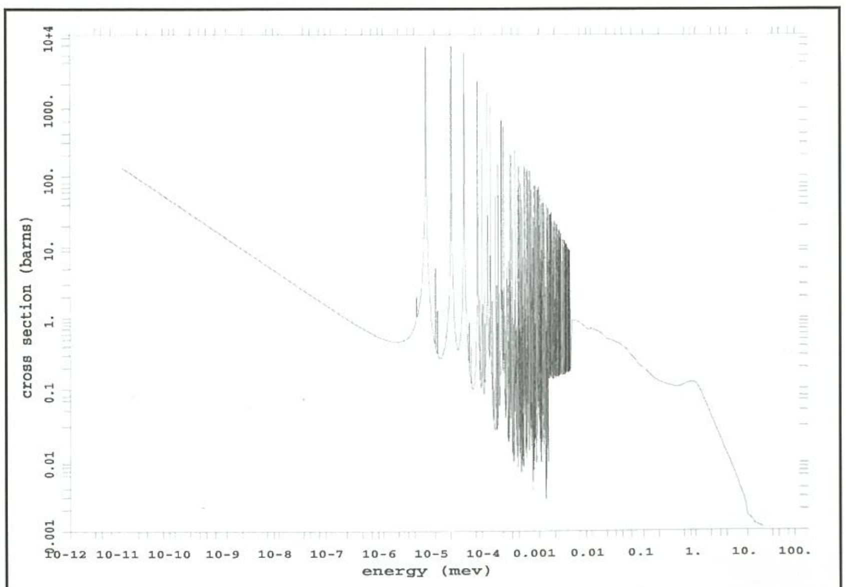


Figure 5: Absorption Cross Section of ^{238}U

5. Design Characteristics of ACR-700 Core

The primary characteristics of the ACR-700 design are summarized in *Table 2.* The stable flat radial flux profile enables the ACR to operate at a very high radial power form factor (average-to-peak ratio) of 0.93. *Figure 7* shows the bundle-power profile in channel J-9 operating at a maximum time-average channel power of 7.5 MW(th). The corresponding linear element ratings in each fuel ring of the CANFLEX bundle are shown in *Figure 8.* The ACR-700 axial power shape is slightly skewed towards the coolant inlet end. Thermalhydraulic assessments show that the ACR axial power shape gives higher Critical Channel

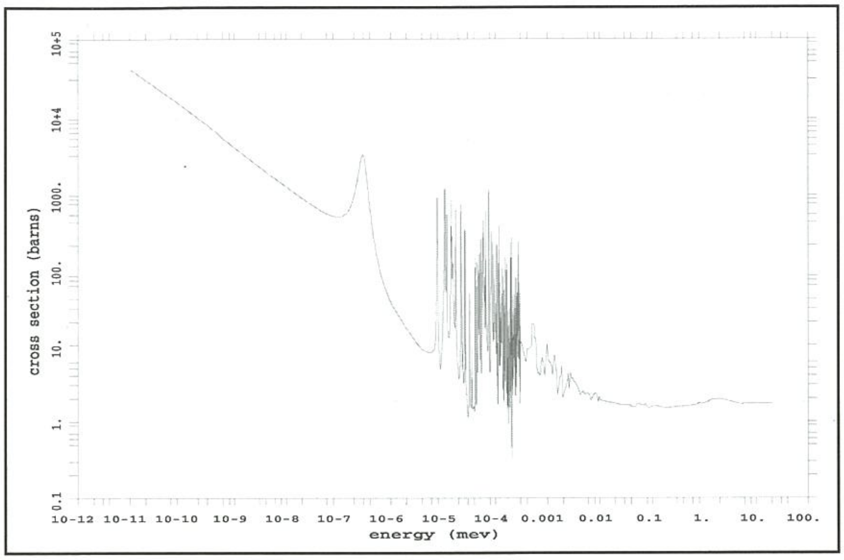


Figure 6: Fission Cross Section of ^{239}Pu

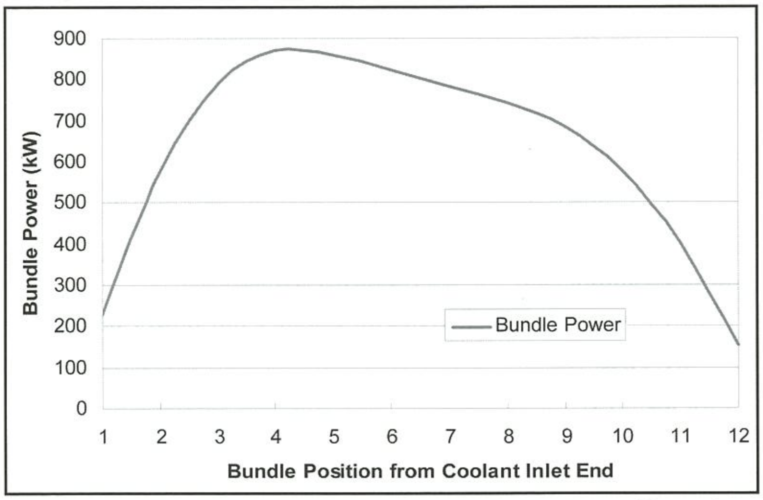


Figure 7: Bundle-Power Profile for 7.5 MW High-Power Channel

Power (CCP) than that for a center-peaked power shape in a NU CANDU. The ACR-700 is expected to operate with a maximum instantaneous channel power of 7.8 MW(th) and a maximum bundle power of 900 kW(th), while retaining acceptable margin to dryout. The CANFLEX fuel design allows ACR to operate at these power levels with fuel element ratings about 10 to 15% lower than those in current CANDU designs. Moreover, subtle design changes have been made to the ACR fuel elements to assure good performance at extended burn-up.

The target discharge fuel burn-up in ACR is 20.5 MW.d/kg(U), about three times the current NU burn-up. The fuelling requirement is 5.8 bundles per full power day, less than 3 channel-visits per full power day using a 2-bundle-shift refuelling scheme. The ACR fuel-handling system can readily meet this requirement.

The nominal and full-core voided thermal flux distributions across the ACR-700 core, at time t=0, 0.01, 0.02 and 0.03 second of a LOCA transient, are presented in *Figure 9*. The ACR lattice is nominally under-moderated in the core region. Voiding of coolant in the core region further reduces the moderation effect in the core and increases the migration of fast neutrons towards the reflector region. The increase in neutron flux in the reflector during a LOCA increases the reactor leakage, which further reduces the coolant-void reactivity. Reducing the reflector thickness enhances the leakage effect, resulting in further reduction of the coolant-void reactivity. Hence, the reflector thickness is another independent parameter, which can be used to fine-tune the coolant-void reactivity at the conceptual design stage.

The LOCA simulations were performed using the 3-D diffusion code DONJON [5], with WIMS-IST-generated lattice cross sections using the ENDF-B/VI library. It is clear that there is a global shift in the reactor power/flux distributions from the central region towards the edge (reflector region) during a full-core LOCA in the ACR core. Detailed simulations (about 100 calculations) for the first 0.01 sec of a LOCA transient confirmed our believe that there will be a rapid rise of thermal neutron flux in the ACR reflector region (by about 20%) for a short period at the onset LOCA because of the increased thermalization of the fast neutrons in the reflector. This increase in the thermal flux in the reflector region is an unique feature that can be used to generate fast neutronic trip signals to scram the reactor upon a postulated LOCA. While this is not a requirement for the safety of the ACR which is designed for negative coolant-void reactivity, the availability of the fast neutronic trips further enhances its safety. Simulation results show that the reactor power starts to drop spontaneously after LOCA before the actuation of the safety systems, and there is no significant risk to the fuel whether the reactor is tripped at 1 sec., 2 sec. or 3 seconds based on slow process signals, such as high temperature, low pressure or low flow.

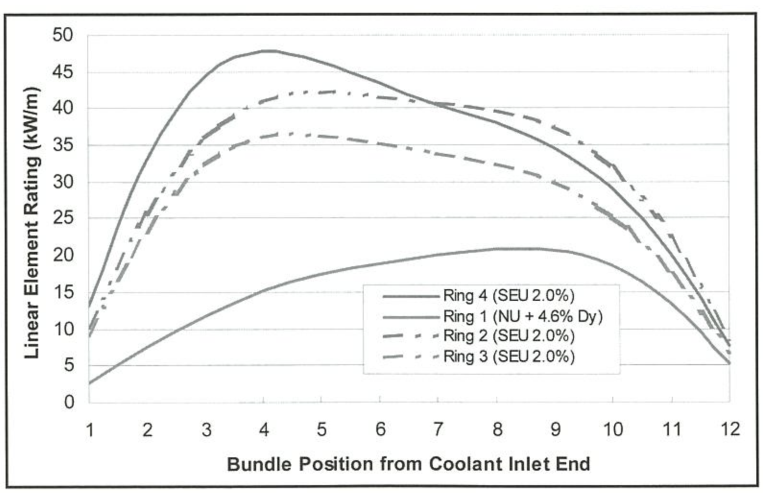


Figure 8: Element Ratings for 7.5 MW High-Power Channel

6.0 Control and Safety Systems in ACR-700

The current ACR-700 concept includes nine mechanical zone control assemblies, arranged in three symmetrical rows of three assemblies each. The central row is on the reactor axial centerline. Each assembly is divided into two independently movable segments. The SDS2 consists of eight liquid poison injection tubes, four in the upper reflector region and the other four in the bottom reflector region. The end-view and the plane-view of the zone-control assemblies and liquid-poison injection tubes are shown in *Figures 10 and 11*, respectively. The layout of SDS1 has not been finalized at this stage. There are no adjuster rods in the current design.

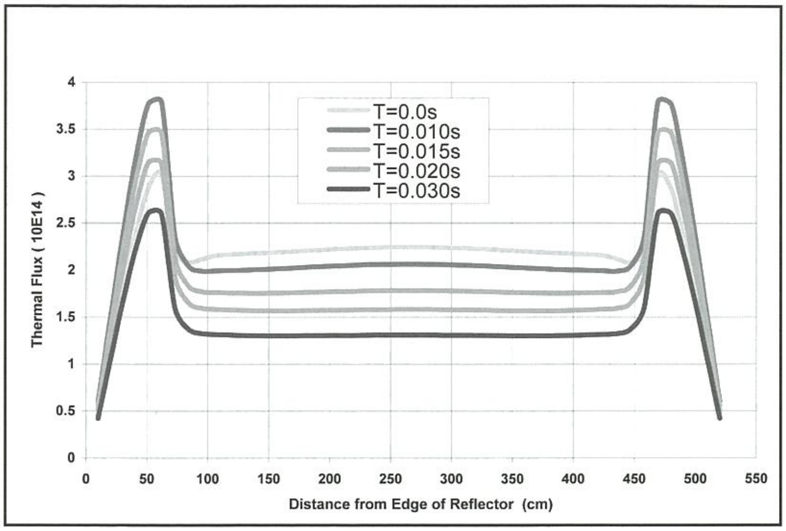


Figure 9: Effect of Coolant Voiding on Radial Thermal-Neutron-Flux Distribution in ACR-700 Core (WIMS-IST/DONJON Simulations)

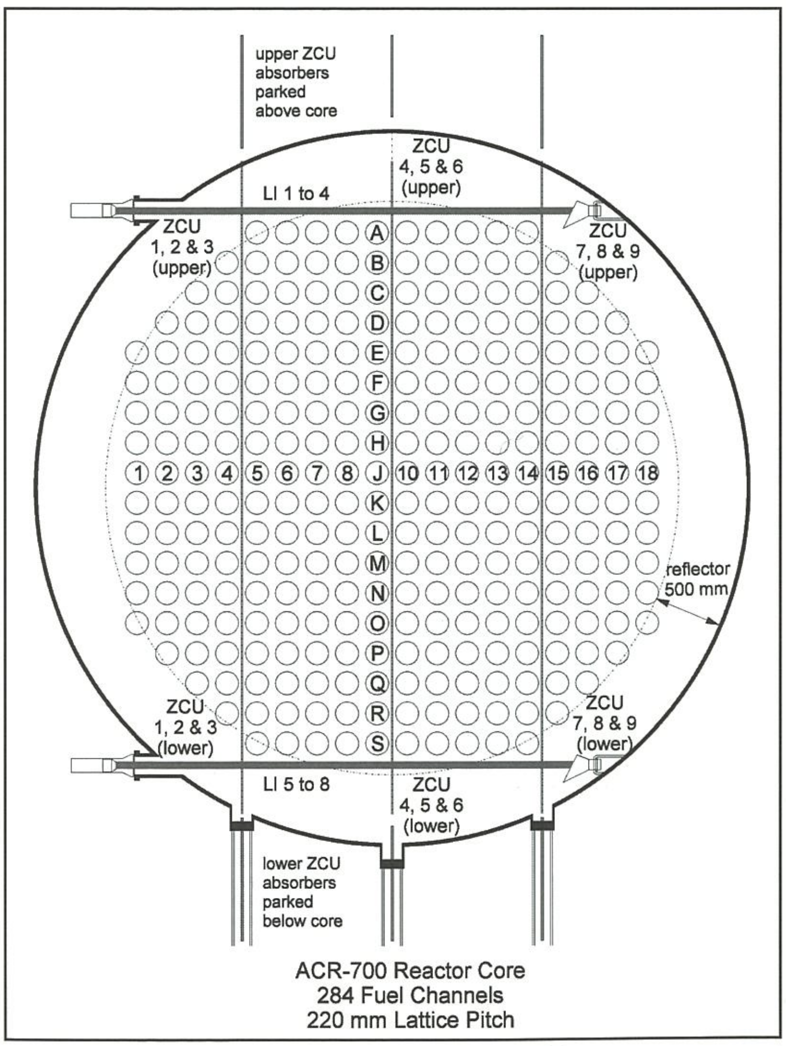


Figure 10: End-View of ACR-700

The tight neutronic coupling in a small core results in exceptional stability in the ACR. Preliminary assessments show that ACR is more stable than NU CANDU-6 for all harmonics except the first axial mode. The small sub-criticality for the first axial mode is due to the flattened axial flux distribution in ACR. However, preliminary analysis has shown that all harmonic modes, including the first axial mode, are stable at 100% power in the ACR.

The current ACR zone-control system layout has a total reactivity worth of 9 mk. Assuming that the zone controllers operate nominally at 50% insertion, approximately ± 3 mk will be available for the following operations:

- perform bulk- and spatial-control functions,
- provide about 12 minutes of xenon override time,
- reduce power from 100% to 75% and hold indefinitely, and
- provide reactivity for about 7 full-power days without refuelling.

Not all of the zone controllers are needed for bulk and spatial control purposes at any given time. For example, the three assemblies in the middle row will be used mainly for bulk reactivity control. Most of the spatial-control functions can be accomplished by using the four corner assemblies. The current layout can be configured in many ways to optimize the operation of the control system. The final layout of the zone control system will be determined at a later stage depending on the design specifications of the control system.

The liquid-poison injection tubes in the ACR traverse the calandria in the upper and lower reflector regions only. These are the ideal locations for the liquid-poison injection tubes because the neutron flux level is high and the locations are easily accessible. The SDS2 system is designed to inject enough liquid poison (concentrated gadolinium nitrate solution) to blanket the entire reflector region within one second after actuation. RFSP calculations indicate that this is equivalent to the injection of -50 mk within one second, sufficient to quickly shut down all postulated accidents. SDS2 contains enough poison to guarantee a system reactivity lower than -150 mk after thorough mixing of the poison with the entire moderator system. This is more than sufficient to keep the reactor shut down under all foreseeable conditions.

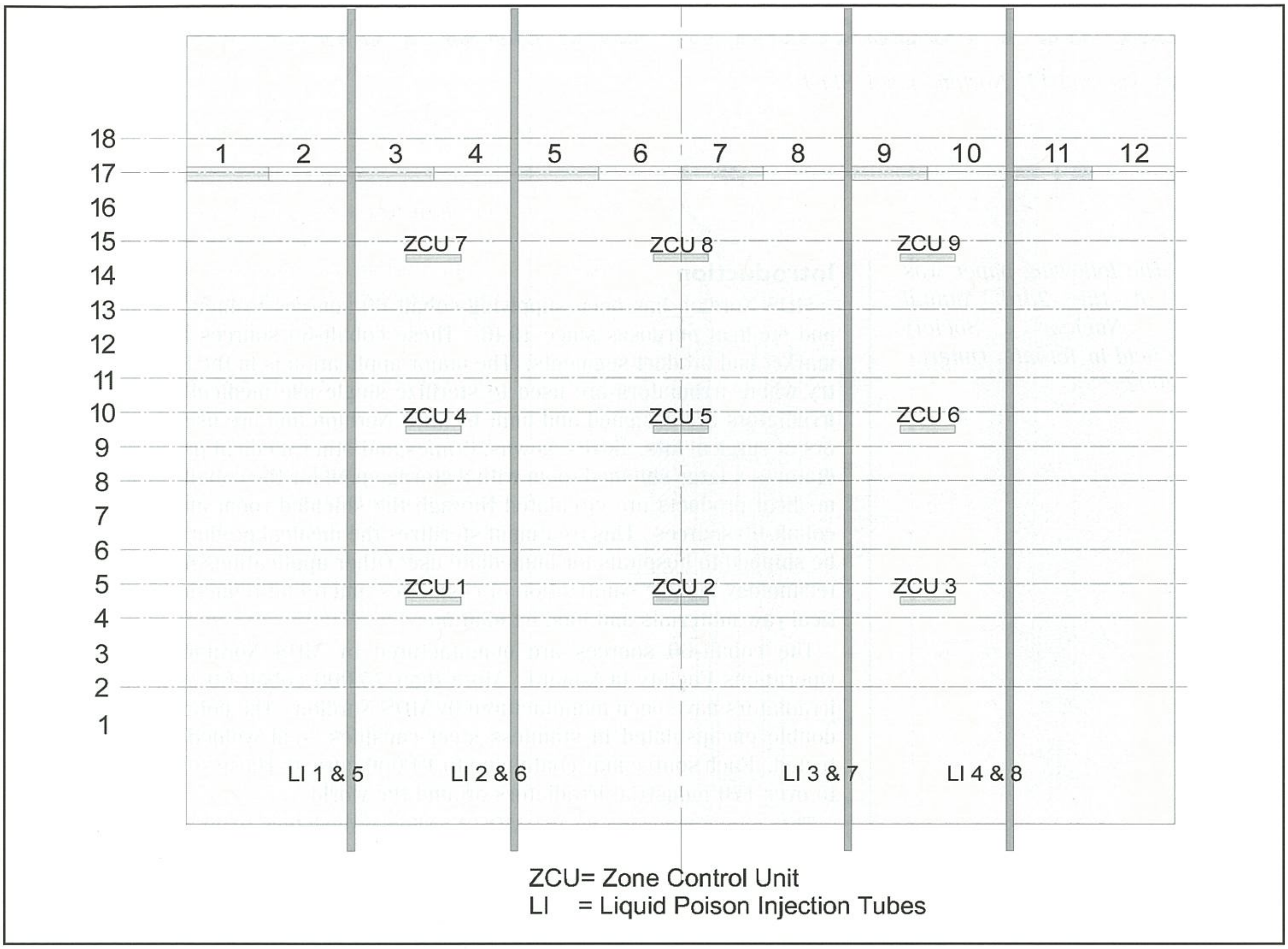


Figure 11: ACR-700 Reactivity-Mechanism Plan View

The design of SDS1 has not yet been finalized. However, its performance will be comparable to that of SDS2. Because of the small size of the ACR core, conventional shutoff rod drives can readily achieve this requirement. The final design of SDS1 will be optimized to meet this modest requirement in the most efficient way.

7.0 Conclusions

ACR achieves substantial reduction in capital cost by using H_2O coolant, SEU fuel, and a tight D_2O-moderated lattice. The use of the CANFLEX fuel-bundle design and the flat flux and power distributions enable ACR to operate at higher channel and bundle powers with no risk in fuel failure. The tight neutronic coupling in a small core results in exceptional stability, which is further enhanced by a substantial negative power coefficient. The discharge fuel burn-up in ACR is targeted at 20.5 MW.d/kg(U), resulting in a significant reduction in spent fuel volume per unit of energy produced.

References:

1. J.V. Donnelly, "WIMS-CRNL, A User's Manual for the CRNL Version of WIMS", AECL-8955, 1986 January
2. B. Rouben, "Overview of Current RFSP-Code Capabilities for CANDU Core Analysis", Transactions of the American Nuclear Society, TANSAO 72, 339, 1995
3. J.R. Askew, F.J. Fayers and P.B. Kemshell, "A General Description of the Lattice Code WIMS", Journal of the British Nuclear Engineering Society, 5:564-585, 1966.
4. J.F. Briesmeister, " MCNP- A General Monte Carlo N-Particle Transport Code", LA-12625-M, Version 4B, 1997 March.
5. E. Varin, A. HÈbert, R. Roy and J. Koclas, "A User's Guide for DONJON Version 2.01", IGE-208, …cole Polytechnique de MontrÈal, Institut de gÈnie nuclÈaire, 2000 May.

Cobalt-60 Production in CANDU Power Reactors

by G.R. Malkoske and J.L. Norton[1] and J. Slack[2]

Ed. Note: The following paper was presented at the 23rd Annual Canadian Nuclear Society Conference held in Toronto, Ontario, June 2-5, 2002

Introduction

MDS Nordion has been supplying cobalt-60 sources to industry for industrial and medical purposes since 1946. These cobalt-60 sources are used in many market and product segments. The major application is in the health care industry where irradiators are used to sterilize single use medical products. These irradiators are designed and built by MDS Nordion and are used by manufacturers of surgical kits, gloves, gowns, drapes and other medical products. The irradiator is a large shielded room with a storage pool for the cobalt-60 sources. The medical products are circulated through the shielded room and exposed to the cobalt-60 sources. This treatment sterilizes the medical products which can then be shipped to hospitals for immediate use. Other applications for this irradiation technology include sanitization of cosmetics, microbial reduction of pharmaceutical raw materials and food irradiation.

The cobalt-60 sources are manufactured by MDS Nordion in their Cobalt Operations Facility in Kanata. More than 75,000 cobalt-60 sources for use in irradiators have been manufactured by MDS Nordion. The cobalt-60 sources are double encapsulated in stainless steel capsules, seal welded and helium leak tested. Each source may contain up to 14,000 curies. These sources are shipped to over 170 industrial irradiators around the world.

This paper focusses on the MDS Nordion proprietary technology used to produce the cobalt-60 isotope in CANDU reactors.

Almost 55 years ago MDS Nordion and Atomic Energy of Canada developed the process for manufacturing cobalt-60 at the Chalk River Labs, in Ontario, Canada.

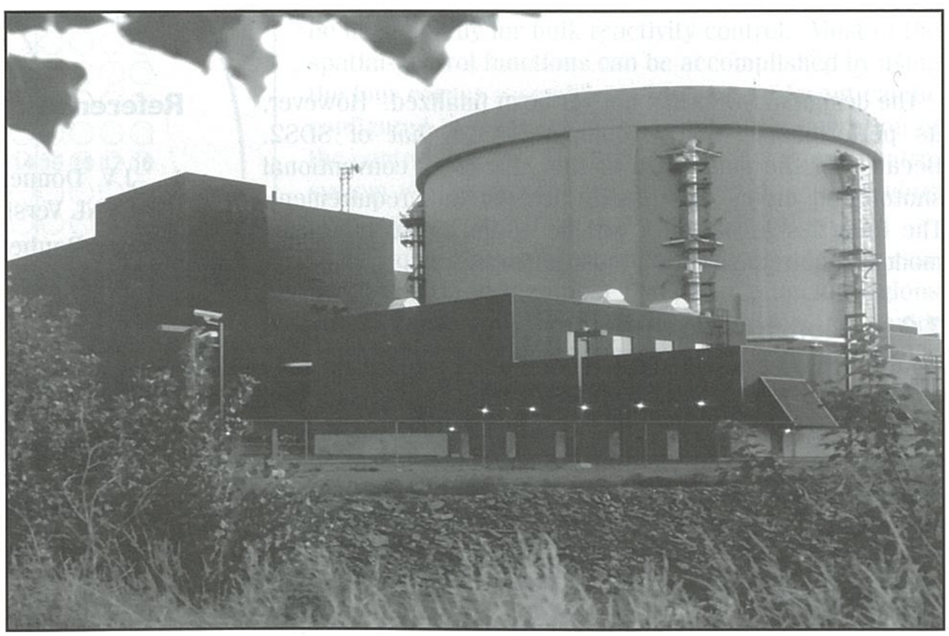


Figure 1: Gentilly 2

1 MDS Nordion, Kanata, Ontario

2 Atomic Energy of Canada Limited, Chalk River, Ontario

A cobalt-59 target was introduced into a research reactor where the cobalt-59 atom absorbed one neutron to become cobalt-60. Once the cobalt-60 material was removed from the research reactor it was encapsulated in stainless steel and seal welded using a Tungsten Inert Gas weld. The first cobalt-60 sources manufactured using material from the Chalk River Labs were used in cancer therapy machines. Today the majority of the cancer therapy cobalt-60 sources used in the world are manufactured using material from the NRU reactor in Chalk River.

The same technology that was used for producing cobalt-60 in a research reactor was then adapted and transferred for use in a CANDU power reactor. In the early 1970s, in co-operation with Ontario Power Generation (formerly Ontario Hydro), bulk cobalt-60 production was initiated in the four Pickering A CANDU reactors located east of Toronto. This was the first full scale production of millions of curies of cobalt-60 per year.

As the demand and acceptance of sterilization of medical products grew, MDS Nordion expanded its bulk supply by installing the proprietary Canadian technology in additional CANDUs. Over the years MDS Nordion has partnered with CANDU reactor owners to produce cobalt-60 at various sites. CANDU reactors that have, or are still producing cobalt-60, include Pickering A, Pickering B, Gentilly 2, Embalse in Argentina, and Bruce B. *(Fig. 1)*

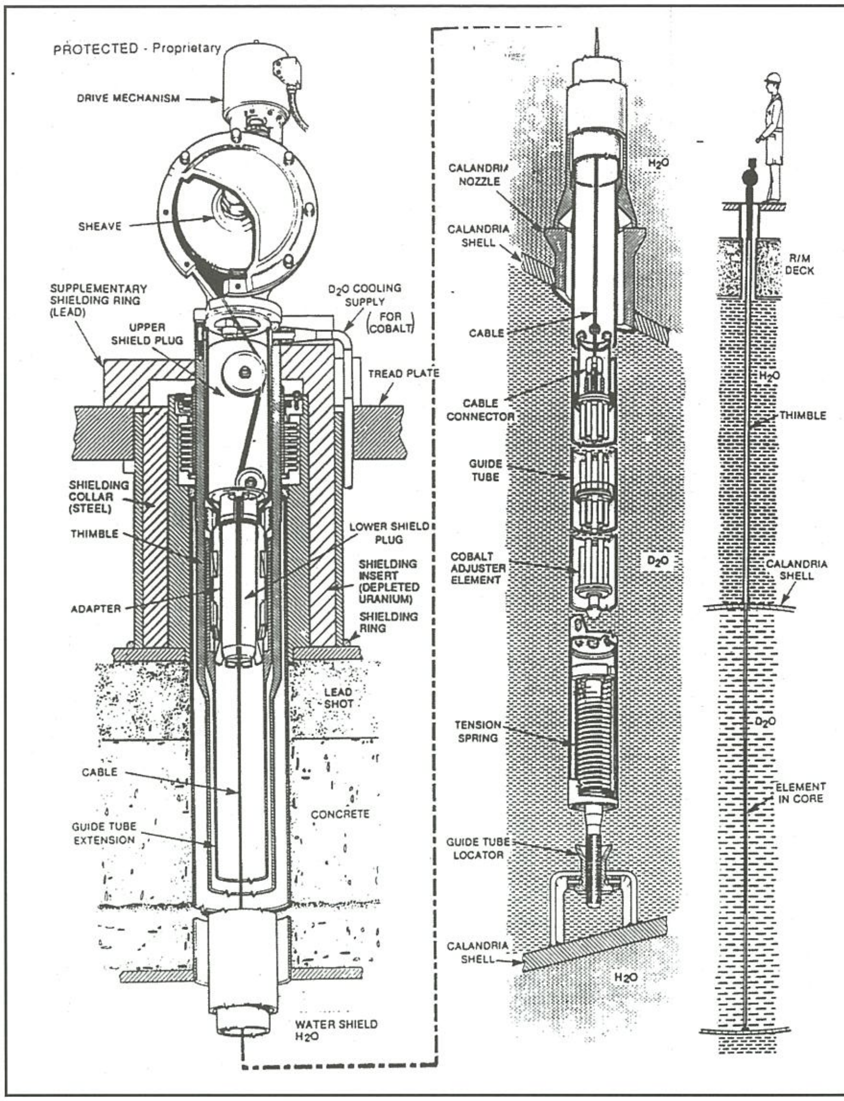


Figure 2: Cobalt Adjuster Unit

AECL's CANDU Reactor

AECL's CANDU Reactor is unique among the power reactors of the world, being heavy water moderated and fuelled with natural uranium. They are also designed and supplied with stainless steel adjusters as part of the reactor regulating system, which is to shape the neutron flux to optimize reactor power and fuel burn-up, and to provide excess reactivity needed to overcome xenon-135 poisoning following a reduction of power. The reactor is designed to develop full power output with all of the adjuster elements in the core.

For cobalt-60 production, the reactor's full complement of stainless steel adjusters is replaced with neutronically equivalent cobalt-59 adjusters, which are essentially invisible to reactor operation. With its very high neutron flux and optimized fuel burn-up, CANDU has a very high cobalt-60 production rate in a relatively short time making it an excellent vehicle for bulk cobalt-60 production.

Prior to a utility engaging in Cobalt-60 production, and notwithstanding the obvious initial change in licensing requirements and submissions, there are many engineering design considerations and requirements for the production of cobalt-60 in CANDU which must be assessed. These include operator and public safety, minimum impact on station efficiency and reactor operations, shielding requirements during reactor operation with cobalt-60 adjusters, removal of the cobalt-60 adjusters from core, transportation within the station, and finally the processing and shipment off-site. Execution of the above mentioned results in the design and supply of the specialized equipment required for the production and handling of Cobalt Adjuster Rods.

CANDU Reactors currently produce many millions of curies per year of Cobalt-60 for MDS Nordion's use in industry and commerce. Following the removal and replacement of stainless steel adjusters with cobalt adjusters, the cobalt adjusters are removed from the reactor at approximately two year irradiation intervals, and transported to the remote Secondary Irradiated Fuel Bay (SIFB) for storage and processing. In the SIFB the cobalt adjusters are disassembled and the individual cobalt bundles prepared for offsite shipment to MDS Nordion in their

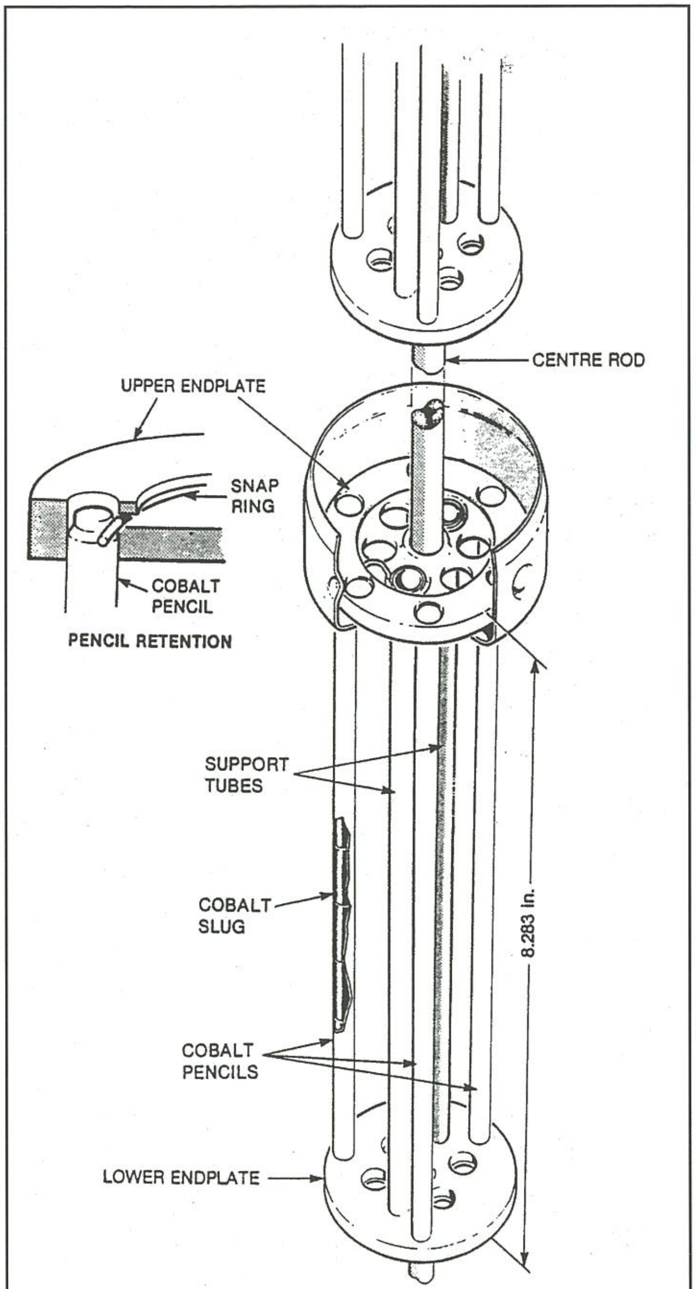


Figure 3: Cobalt Bundle Assembly

purpose built and licensed transportation flasks.

In compliance with the above and to facilitate cobalt production, the Cobalt Adjuster Element Processing System (CAEPS) was designed to permit the replacement of all of the cobalt adjuster rods during routine reactor maintenance shutdowns. The cobalt removal and transfer equipment was designed to be used intensively for relatively short periods of time and to function quickly and reliably so that the limited time "window" available for the replacement process would not be missed. The cobalt removal and transfer system is mechanized extensively in order to minimize labour and operator skills required. The system is designed for high productivity, to minimize the demands upon the station maintenance staff during the critical maintenance interval, and to increase the profitability of the operation.

Cobalt Adjusters

As previously stated a set of cobalt adjuster rods are provided in the reactor as part of the Reactor Regulating System (RRS). *Fig. 2* shows an overall view of a cobalt adjuster unit converted from a standard stainless steel adjuster. Initially, the design provided for D_2O cooling of the adjuster to address perceived thermal requirements. However, D_2O cooling has since been demonstrated as unnecessary and the system valved out.

The requirements for flux flattening in the core result in a number of different types of adjuster rods. Each cobalt adjuster rod assembly consists of a number of bundles, each bundle containing up to six cobalt pencils. The adjuster rods are assembled from standard design components. Only the centre rod and stainless steel cable lengths are special for each adjuster application, as determined by the number of bundles required due to its location in the reactor.

The cobalt bundle assembly *(Fig. 3)* is the basic building block of an adjuster rod. It consists of two circular endplates held apart by two welded support tubes. The plates feature an outer ring of holes, which are precisely aligned so that one to six pencils can be inserted into them as required. Once inserted, the pencils are held in position by a snap ring, secured by a groove in the upper end plate and a shoulder on the bottom end plate.

The pencils are seal-welded zircaloy tubes filled with cobalt slugs. They are standardized components, made to suit service conditions as well as reactor requirements. The cobalt in the pencils constitutes the bulk of neutron absorbing material, the rest of the adjuster assembly being built mostly of zircaloy and designed for the smallest practical neutron absorption. The pencil and bundle lengths are matched so that the pencils, acting in compression, add to the bending structural stiffness of the bundle assembly.

The cobalt bundles, loaded with pencils as required, are threaded onto the center rod in a sequence to match the negative reactivity requirements for each adjuster type, due to its particular location in the reactor core. A special nut is screwed onto the upper end of the center rod. To provide a shoulder for a compression spring to apply tension to the center rod. The cobalt bundles are thus kept under reasonable constant load despite varying tolerance and thermal expansion effects. The upper nut and lower fitting on the center rod are designed to permit tensioning, and the lower fitting is designed to rupture the center rod at the bottom rivet for disassembling the element in the SIFB.

Removal of Cobalt Adjusters from the Reactor

General

Heavily shielding apparatus is required to safely discharge and transfer the irradiated cobalt adjusters from the reactor adjuster position to the designated section of the SIFB. Prior to commencing the cobalt production program, and as a primary requirement, the reactivity mecha-

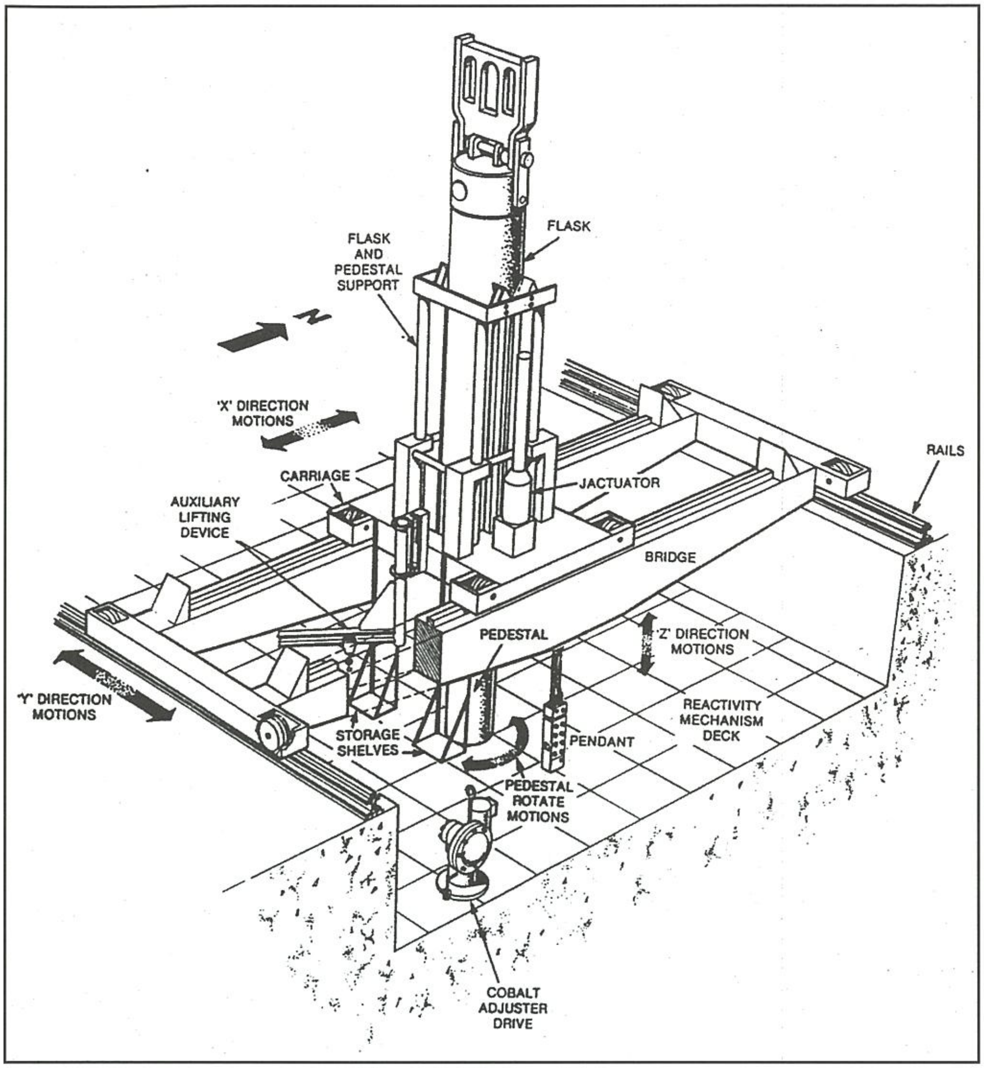


Figure 4: Flask positioner

nism decks were provided with extra shielding to facilitate the handling of the irradiated cobalt elements.

The following items of CAEPS equipment are supplied or are used to safely unload the cobalt adjusters from the reactor, transport them to the SIFB and process them in the SIFB.

1. Flask and Pedestal
2. Reactor Building Crane (existing)
3. Flask Positioner
4. Transporter/Erector
5. Discharge Port
6. Element Processing and Handling in the Bay

Flask and Pedestal

The flask was designed to safely contain one irradiated cobalt adjuster on its suspension cable plus the lower shield plug. The flask shielding is sufficient as to give a surface contact dose rate on the outside of the flask of 50 mR/h or less during normal operations. Special appendages on the flask permit its safe transport by the reactor building crane and the CAEPS transporter/erector.

The CAEPS pedestal is designed to bridge the gap between the adjuster thimble and the flask, and provide a shielded passage for the cobalt adjuster during its removal from the reactor. The pedestal is dimensioned such that it fits within the confines of adjacent Reactivity Control Units which are closely pitched on the reactivity mechanism deck. The pedestal is mounted in and positioned around the adjuster thimble by the positioner. The shielding provided by the pedestal is designed to minimize man-rem exposure to the operator. Auxiliary shielding blocks are used to improve local shielding effectiveness within the space restrictions caused by adjacent Reactivity Control Unit mechanisms and which vary from position to position. The number and complexity of assembling these is minimized so as to not impede the cobalt adjuster discharge process. Both the flask and pedestal are capable of being used in turn on all reactor units as required.

Flask Positioner

The CAEPS flask positioner *(Fig. 4)* is designed to accept, carry and position the flask and pedestal at each of the adjuster thimble positions on the reactivity mechanism deck. Its high accuracy of positioning of the pedestal is essential to avoid damaging the thimble when lowering the pedestal into the deck. The flask positioner is very similar to a crane and runs on rails located approximately 3 meters above the reactivity mechanism deck. Due to the use of the positioner in the cobalt adjuster replacement process, only a few CAEPS operations require the use of the overhead reactor building crane.

Transporter/Erector

After each irradiated Cobalt Adjuster Rod is removed from the reactor into the CAEPS flask, the boiler room crane is used to lift the flask from the positioner and to lower it into the Transporter/Erector. The Transporter/Erector is comprised of a simple tractor drawn carriage on which a mechanized cradle is mounted to support and elevate the CAEPS flask. The Transporter/Erector is used to safely transport the CAEPS flask, containing the cobalt adjuster rod, between the reactor building and the secondary irradiated fuel bay (SIFB). It is thus designed to function both indoors and outdoors and travel anywhere within the reactor site.

The Transporter/Erector is equipped with an integral erecting mechanism which is fully power operated and fail safe to prevent any uncontrolled or unintended movement of the flask during any operation. Stabilizing devices are provided on the Transporter/Erector, to ensure the basic stability of the Transporter/Erector whenever the flask is in a partially or fully raised position. The stabilizers are equipped with interlocks to the elevating mechanism such that no erecting or lowering motion can be effected unless the Transporter/Erector is fully stabilized.

At the SIFB, and depending upon the reactor site configuration, the positioning of the flask onto the discharge port is performed by the SIFB service crane and/or the Transporter/Erector. The Transporter/Erector is required to park, be stabilized, and then erect the flask to the vertical position. The flask is then held vertical by the crane or the Transporter/Erector until discharging of the cobalt adjuster into the bay via the discharge port is complete.

The handling and processing of cobalt adjusters are carried out at such depth in the SIFB as to provide sufficient water shielding and minimize radiation hazards to cobalt operations personnel. The equipment involved is primarily comprised of the discharge port, and cobalt adjuster storage and processing equipment.

Discharge Port

The cobalt discharge port is located in the SIFB cobalt discharge slot. The port provides shielding when the cobalt adjuster is lowered from the flask into the SIFB cobalt slot. The top section of the port is designed to allow the flask to be located and mounted to it. The cobalt then passes through a centrally located bore in the discharge port.

Beneath the discharge port resides the discharge trough, it is used to accept and provide visual confirmation that the cobalt adjuster has been fully lowered from the flask. From the discharge trough, the cobalt adjuster is transferred to the storage rack via the transfer arm and monorail trolley, where it awaits processing.

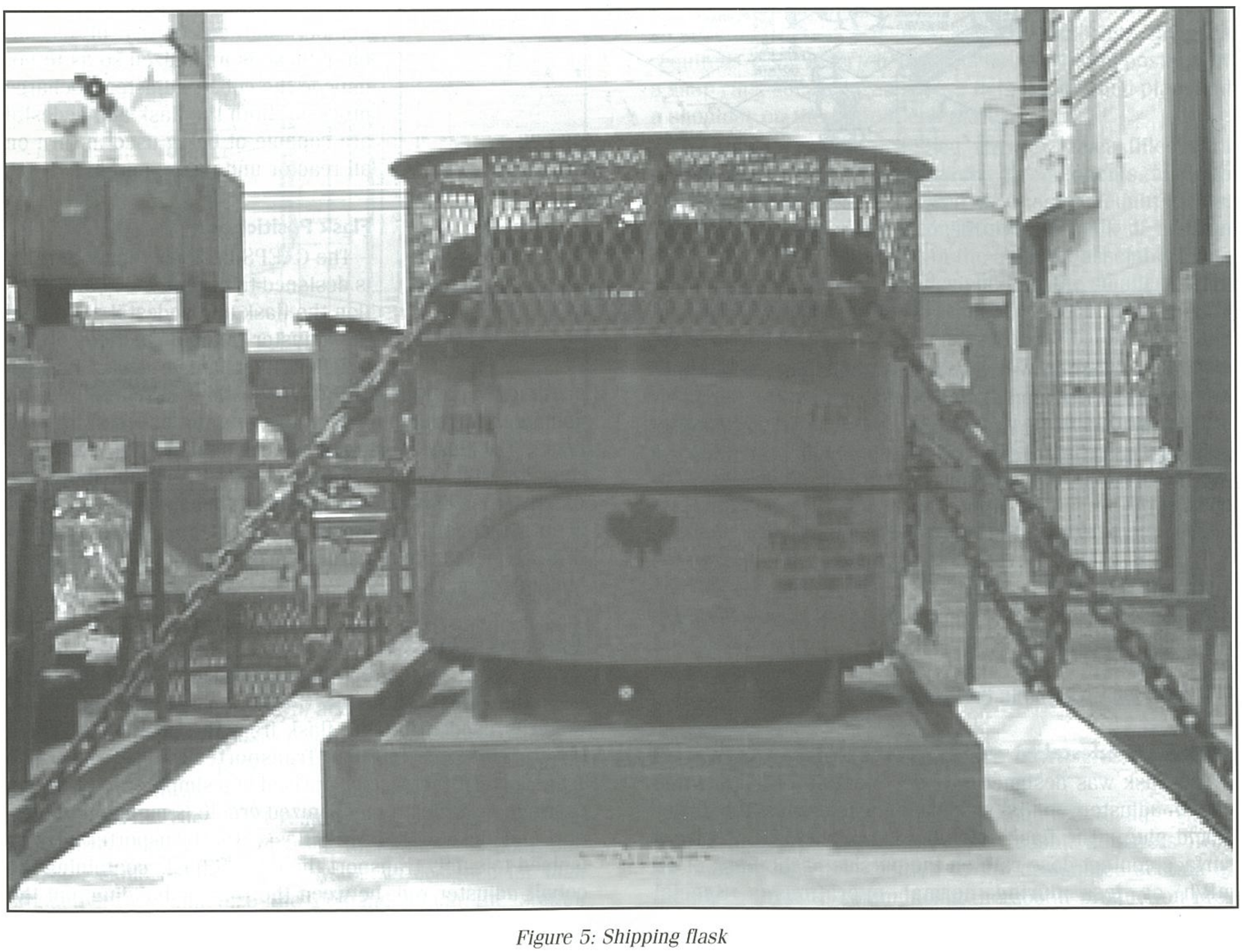


Figure 5: Shipping flask

Cobalt Adjuster Processing Equipment

The Cobalt Adjuster Processing Equipment is comprised of the Inspection Table, Bundle Separator, Center Rod Muncher and Control Panel.

Inspection Table

The inspection table provides an area for inspection of the cobalt bundles and storage for individual bundles and bundle carriers. In addition, the table provides support for the bundle separator, hydraulic cylinders, tubing and in case of separator malfunction, a manual adjuster cone cutting facility.

The table rests on the bay bottom and is secured to the edge of the bay by two straps. A cut-out at one end of the table provides for containment of the catenary hoses that connect the valve panel to the inspection table/bundle separator assembly hydraulics.

Bundle Separator

The bundle separator grips the cobalt adjuster assembly head cup and lower cone, placing the adjuster centre rod in tension. The tensile force applied is sufficient to fracture the centre rod at a designed weak point located at the lower cone area of the center rod. The fractured centre rod allows the adjuster to be disassembled into cobalt bundles and waste component.

A rotating shaft anchors the bundle separator to the inspection table. A hydraulic cylinder bolted to the inspection table enables the separator to be rotated from a horizontal to near vertical position for easy acceptance of the cobalt adjuster rod from the storage rack and monorail. The hydraulic cylinders and controlex cable of the separator inspection table assembly are remotely operated from the control panel located at the edge of the bay.

Centre Rod Muncher

The muncher, located on the bay bottom adjacent to the inspection table, consists of a pedestal, cutter assembly, storage bin, catenary hoses and a controlex cable. The storage bin receives adjuster waste components resulting from the adjusters disassembly.

The waste components from the bundle separator are discharged into the bin via a chute system located at the end of the bundle separator and under the inspection table. In addition, the bin receives lengths of the adjuster centre rod and cable fed through the cutter assembly. The cutter assembly is actuated by a double acting water operated piston, controlled from the control panel. The controlex cable actuates an indicator on the control panel which shows the position of the cutter assembly.

Control Panel

The operation of the bundle separator/inspection table and centre rod muncher hydraulics are manually initiated from the control panel. The working medium of the hydraulic system is demineralised water taken from and recirculated to the SIFB.

In addition, two controlex cable levers are located on the panel, one for operating the bundle shuffler control valve, and the second for position indication of the muncher cutter. The hand lever operated control valve of the muncher is also located on the panel.

Cobalt Bundle Shipping

After the individual cobalt bundles have been removed from the adjuster rod assembly, inspected, and measured for their curie content, they are placed in MDSN's F231 shipping flask *(Fig. 5)* for transportation to MDSN's processing facility in Kanata, Ontario. MDSN's F231 shipping flask, as used for transporting the cobalt, is a purpose built flask which is licensed by the CNSC for the transportation of up to 400,000 curies of cobalt 60.

Summary

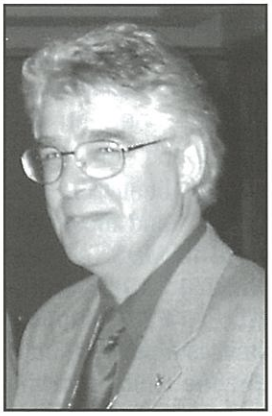
The technology for cobalt-60 production in CANDU reactors, designed and developed by MDS Nordion and Atomic Energy of Canada, has been safely, economically and successfully employed in CANDU reactors with over 195 reactor years of production.

Today over forty percent of the world's disposable medical supplies are made safer through sterilization using cobalt-60 sources from MDS Nordion. Over the past 40 years, MDS Nordion with its CANDU reactor owner partners, has safely and realiably shipped more than 500 million curies of cobalt-60 sources to customers around the world.

MDS Nordion is presently adding three more CANDU power reactors to its supply chain. These three additional cobalt producing CANDU's will help supplement the ability of the health care industry to provide safe, sterile, medical disposable products to people around the world. As new applications for cobalt-60 are identified, and the demand for bulk cobalt-60 increases, MDS Nordion and AECL continue to identify additional CANDU reactor owners who recognize the mutual benefits of cobalt-60 production.

4th CNS International Steam Generator Conference

—specialized event draws delegates from many countries



Marc Leger

Bob Tapping

Steam generator specialists from ten countries joined their Canadian counterparts May 5 to 8, 2002, for the ***4th CNS International Steam Generator Conference.*** About 130 delegates attended this meeting at the Marriott Eaton Hotel in Toronto, Ontario that focussed on a very critical component of nuclear power plants.

Following a pleasant reception on the Sunday evening the conference began in earnest early the next morning with a short opening address by Paul Spekkens, of Ontario Power Generation, followed by the "plenary lecture", presented by Joe Muscara, of the US Nuclear Regulatory Commission, on *"Research Perspectives on the Evaluation of Steam Generator tube Integrity"* (which is reprinted in this issue of the *CNS Bulletin).*

Then the conference delegates got down to work, listening and questioning the presentation of 33 papers on all aspects of steam generator integrity. The scope is indicated in the titles of the sessions:

- Life Management Strategies, Replacement Strategies, and Regulatory Issues
- Operational Experience
- Vibration, Fretting and Fatigue
- Thermalhydraulics, fouling and Cleaning
- Inspection Advancements and Experience, and Fitness for Service
- Materials, Corrosion and Chemistry Control

These presentations were augmented by a Poster Session with 21 entrants. To enhance the review of these excellent papers by delegates a social period was held on the late afternoon of the first day in the poster room, with wine, cheese, beer and pretzels as inducements. After long deliberation by a panel of judges, the poster by Peter Angell of Atomic Energy of Canada Limited was judged the best of the posters presented.

A booklet of abstracts was provided at the conference. A CD is being prepared with full papers plus the questions and answers that followed each presentation. That will be sent to all delegates and will be available from the CNS office.

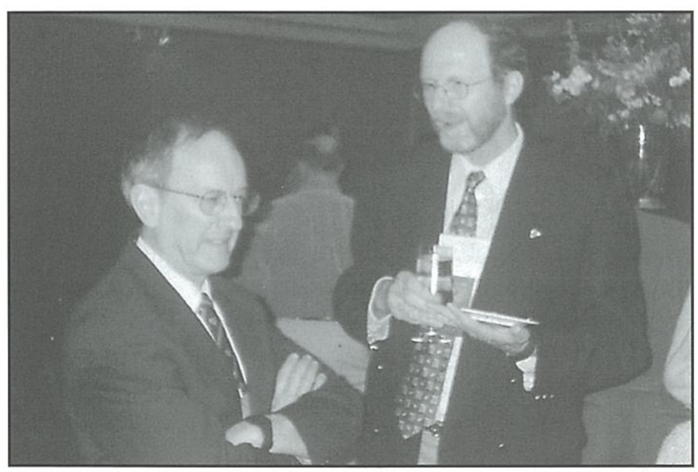
Luncheons were served each day and Babcock & Wilcox Canada (again as at previous conferences) offered a tour of their plant in Cambridge, Ontario, followed by an excellent dinner. With a bus trip each way of over an hour it was a long evening, but a very enjoyable and informative one for those who participated.

The CNS Steam Generator conferences have been held every four years since they were initiated in1990. Delegates to this fourth conference obviously thought they were worthwhile with preliminary discussions about the fifth conference in 2006.

The conference was organized by a committee chaired by Marc Leger of AECL, with Victor Murphy, Ed Price, Bill Schneider and Denise Rouben as members.

The technical program was put together by a separate committee chaired by Bob Tapping of AECL, with both Canadian and overseas members. From Canada: C. Daniel (OPG), E. Price (retired), C. Taylor, C. Turner, G. Wolgemuth (all AECL), P. King and W. Schneider (Babcock & Wilcox Canada), and A. Brennenstuhl (Kinectrics). Overseas members were: J. Muscara (USA), S. Oder and J. Daret (France), H-S. Chung (Korea) and W. Zhang (China).

A number of organizations supported the conference as sponsors, including: AECL, Babcock & Wilcox Canada, COG, Hydro QuÈbec, Kinectrics Inc., OPG, Bruce Power, NB Power, Framatome ANP Canada.



Victor Murphy (AECL) and Michel Pettigrew (École Polytechnique) confer during the reception for the 4th CNS International Steam Generator Conference, May 5, 2002.

Research Perspectives on the Evaluation of Steam Generator Tube Integrity

by J. Muscara[1] and D. R. Diercks, S. Majumdar, D. S. Kupperman, S. Bakhtiari, W. J. Shack[2]

***Ed. Note:** The following paper is the text of the paper presented as the "plenary lecture" at the 4th CNS International Steam Generator Conference held in Toronto, Ontario, May 5 to 8, 2002*

Abstract

Industry efforts have been largely successful in managing degradation of steam generator tubes due to wastage, pitting, and denting, but fretting, stress corrosions cracking (SCC) and intergranular attack have proved more difficult to manage. Although steam generator replacements are proceeding, there is substantial industry interest in operating with degraded steam generators, and significant numbers of plants will continue to do so. In most cases degradation of steam generator tubing by stress corrosion cracking is still managed by "plug or repair on detection," because current NDE techniques for characterization of flaws and the knowledge of SCC crack growth rates are not accurate enough to permit continued operation.

Replacement generators with improved designs and materials have performed well to date, but previous experience with the appearance of some types of SCC in Alloy 600 after 10 years or more of operation and laboratory results suggest additional understanding of corrosion performance of these materials is needed. This paper reviews some of the historical background that underlies current steam generator degradation management strategies and outlines some of the additional research that must be done to provide more effective management of degradation in current generators and provide greater assurance of satisfactory performance in replacement steam generators.

1. Introduction

Steam generators have historically been among the most troublesome of the major components in commercial pressurized water reactor (PWR) nuclear power plants around the world. They have been described as the "weak link"1 in the PWR design, and their premature deterioration has been characterized as "one of the most persistent challenges facing utilities with pressurized water reactors."[2] For the past decade or more, steam generator problems in the United States have ranked only behind refueling outages as the most significant contributor to lost power generation.[3] To date, various forms of degradation have resulted in the repair (by plugging, sleeving, or rerolling) of more than 275,000 tubes worldwide. Through July 2000, 168 steam generators in 57 PWRs around the world had been replaced because of severe tube degradation, including 79 steam generators in 25 U.S. plants.[3] Replacements are continuing in both the U.S. and abroad. Beyond the reliability and economic issues facing utilities, steam generator problems raise potentially significant regulatory issues both in terms of performance under design basis operating and accident conditions and under severe-accident conditions.

2. Corrosion Degradation of Steam Generator Tubes

Corrosion problems have afflicted steam generators from the very introduction of the PWR technology. Shippingport, the first commercial PWR operated in the United States, developed leaking cracks in two Type 304 stainless steel (SS) steam generator tubes as early as 1957, after only 150 h of full-power operation.4-6 The cracks were attributed to stress corrosion cracking (SCC) produced by free caustic in the secondary water and steam blanketing of the tubes at the top inlet portion of the steam generator, leading to concentration of the caustic. The leaking tubes were plugged, and the use of a modified sodium phosphate water chemistry was instituted to control secondary water pH.

Because austenitic SS steam generator tubes were found to be susceptible to SCC from both chlorides and free caustic, the decision was made in the late 1960s to instead use Alloy 600 tubes in the United States and most of Europe and Alloy 800 tubes in Germany.1 The decision to use Alloy 600 was made on the basis of its known high resistance to chloride attack, based largely on petrochemical plant experience. However, the decision to use Alloy 600 ignored the work of Coriou et al.7,8 which showed as long ago as 1959 that this and similar nickel-base alloys were subject to stress corrosion cracking in deionized water at 300-350°C.

Because Alloy 600 is subject to cracking at high caustic concentrations, early steam generators with Alloy 600 tubes used phosphate additions to the secondary water to provide a buffering capability. This was based on prior experience with fossil-fired boilers. However, rapid caustic cracking was observed in several early steam generators. This problem was successfully controlled by reducing the sodium-to-phosphate molar ratio, but severe tube wastage problems were almost immediately experienced. By the early-to-mid 1970's, wastage was by far the leading cause of tube plugging in the U.S.

1 US Nuclear Regulatory Commission, Washington D.C.
2 Argonne National Laboratory, Chicago. IL.

In response to the tube wastage problem, most U.S. plants switched to all volatile water treatment (AVT) around 1974. In this approach, ammonia, morpholine or similar additions were added to control pH, and hydrazine or similar additions were added for oxygen scavenging. Effective use of AVT water chemistry requires very high purity levels in the feedwater, since no buffering agents are present to prevent excessive acidic or caustic conditions in regions of impurity concentration. It should be noted that once-through steam generators have always used AVT water chemistry to avoid the deposition of chemical solids on tube surfaces in their boil-dry design.

The wide-spread change to AVT water chemistry resulted in a dramatic decrease in tube plugging due to wastage, but this problem was soon replaced by severe tube denting problems in many plants. Tube denting was eventually brought under control by improved controls on feedwater chemistry, improved condenser integrity to eliminate the inleakage of oxygen and other impurities, and, in some cases, the use of condensate polishers or boric acid additions.

Since about 1980, steam generator tube degradation in the U.S, and elsewhere has been dominated by stress corrosion cracking. Unlike wastage and denting, which occur exclusively on the secondary side (outer diameter) of the tubes, stress corrosion cracking can occur on either the primary or secondary side. Primary water stress corrosion cracking (PWSCC) is most likely to occur at regions of high residual stress, as at the tube expansion transition at and immediately above the tubesheet, at U–bends (particularly the small-radius U-bends on the inner-row tubes, and in tube regions deformed by secondary–side denting at the tube support plates.

A number of design changes have been implemented over the years to address the PWSCC issue. These include shot peening or rotopeening of the ID surfaces of the tubes in the roll transition zone to produce compressive residual stresses, improved processes for expanding the tubes into the tubesheet to reduce residual stresses in this region, and in–situ thermal treatment of U-bends on older plants and thermally treated U–bends in newer plants to reduce residual stresses in this region. All of these processes have proven at least somewhat beneficial, but PWSCC continues to be a problem in PWR steam generators.

Outer-diameter stress corrosion cracking (ODSCC) and intergranular attack (IGA) commonly occur in crevices or under corrosion product scales, where conditions are such that incomplete wetting by secondary water occurs, and the consequent alternate wetting and drying result in substantial local buildup of corrosive species. Such locations include the tube support plate crevice, the region near the top of the tube sheet, free span areas under corrosion products or deposits, and regions under sludge build–up. Calculations of local crevice chemistry predict concentration factors approaching 10^8 and crevice pH values ranging from < 2 to > 10 at operating temperatures, depending upon the impurity species in the secondary water. Again, remedial actions have been taken over the years to address this problem. However, ODSCC, like PWSCC, continues to be a leading cause of steam generator tube plugging and repair.

In the 1980s, PWSCC and ODSCC problems were almost entirely confined to lowtemperature mill annealed (LTMA) tubing found in Westinghouse steam generators. However, starting about 1990, SCC problems also began to significantly affect the high-temperature mill annealed (HTMA) tubes used in the Combustion Engineering steam generators.[3,9,10] More recently, SCC is increasingly observed in Babcock & Wilcox steam generators, which use tubes that have been stress relieved (SR) after a similar high-temperature 1065-1090°C mill anneal.[3]

Around 1980 for replacement units and in the mid-1980s for the new Model D-5 and Model F steam generators, Westinghouse began using thermally treated (TT) Alloy 600 tubing, which has a microstructure more resistant to SCC, and the oldest of these units (e.g., Surry 1 and 2) have operated for 20 years with virtually no SCC.3 However, numerous SCC failures have been observed in Alloy 600 TT mechanical plugs, an effect attributed to certain susceptible heats of material,[11–17] and PWSCC of the Alloy 600 TT tubes in the Ulchin 1 and 2 steam generators in Korea has led to extensive tube sleeving.[18–20] Recent work suggests that the tube cracking at Ulchin may be associated with an undesirable distribution of precipitated carbides in the microstructure. (Ref. 21)

Since about 1989, thermally treated Alloy 690 has been the tubing material of choice for most replacement steam generators, although Alloy 800 is still being used in Canada, Spain, and Germany. After up to 13 years of service, no incidents of SCC have been reported for any Alloy 690 tubes in the field. While laboratory studies have also been unable to produce SCC in Alloy 690 in primary water chemistries, Alloy 690 has been shown to be susceptible to SCC in environments that contain lead, reduced sulfur and slightly oxidizing mild acids.[22–26]

New designs have sought to minimize the presence of built–in crevices and the importance of good water chemistry is now recognized by the industry. However, the new designs have not eliminated crevices at the top of the tube sheet, in the obtuse angle of the egg crate support, and at the lines of contact with the tubes with the supports. Without remedial actions, aggressive conditions could develop with time as deposits accumulate.[26] The expectations raised by the good performance of Alloy 690 in the field to date, should be tempered by the observation that in many cases the occurrence of significant SCC in Alloy 600 steam generators has taken more than ten years.[26]

3. Steam Generator Integrity

3.1 Nondestructive Evaluation

To ensure the integrity of steam generator tubing, it is important to be able to detect and characterize the degradation. Up to the early 70s, the inservice inspection of PWR steam generators was carried out using single-frequency eddy current (EC) bobbin coils. This inspection technology was adequate for detection of volumetric degradations but not for cracks. Part of the problem was a low signal–to–noise ratio for cracks, and in the late 70's, two-frequency EC equipment was introduced to help reduce noise signals from probe wobble and the tube support plate.

By the mid-80s, additional modes of degradation such as pitting and intergranular attack (IGA) had to be addressed. Pancake coils were introduced in the 80's to improve detection of IGA in the tube sheet crevice. In addition, three–frequency mixing of bobbin coil signals was introduced to improve flaw detection. Dodd and Deeds[27] showed how to eliminate the tube support plate (TSP) signal by using magnitude and phase at different frequencies in a leastsquare analysis of data. Steam generator inservice inspection (ISI) guidelines were introduced by EPRI that included qualification requirements for techniques and analysts that focussed on performance with a requirement that the inspector demonstrate an 80% probability of detection (POD) for flaws > 60% throughwall rather than mere adherence to procedures.

By 1990, motorized rotating pancake coils (MRPC) with single or multiple probe heads and isometric displays of the eddy current response were being used to supplement bobbin coil inspections. The 90's saw extensive use of MRPC for better characterization of cracks in Ubends, TSP, and the roll transition zone (RTZ). In addition to the extensive use for supplementary inspections in locations susceptible to cracking, MRPC were used for primary examinations in some cases such as the detection of circumferential cracking. Differential MRPC designs like the +Point probe were introduced to provide improved signal to noise ratios in many cases.

Despite improvements in detection capability, sizing, however, is still a problem in many cases. Different expert observers analyzing the same data can produce high variable estimates of crack size.

Array probes have long held the promise of more robust detection and characterization capabilities for circumferential and axial cracks with speeds comparable to those obtained by bobbin coils. Analysis of the output of such probes requires substantial computation efforts, but modern developments in computers and software suggest that wider use of array probes is likely to occur as new models are being developed in Canada, Japan, and the US.

An independent assessment of steam generator inspection reliability has been developed through an NDE round–robin on a steam generator mockup at Argonne National Laboratory. The purpose of the round robin was to assess the current state of SG tubing ISI reliability by determine the probability of detection (POD) as function of flaw size or severity and assessing flaw sizing capability. Eleven teams have participated in analyzing bobbin coil and rotating coil mock-up data collected by qualified industry personnel. The mockup contains hundreds of cracks and simulations of the artifacts such as corrosion deposits, tube support plates, etc. that make detection and characterization of cracks more difficult in operating steam generators than in most laboratory situations. An expert group from ISI vendors, utilities, EPRI, ANL, and the NRC have reviewed the signals from the laboratory grown cracks used in the mockup to ensure that they provide reasonable simulations of those obtained from field cracks. The number of tubes inspected and number of teams in the round robin were intended to provide better statistical data on the probability of detection (POD) and characterization accuracy than is currently available from industry performance demonstration programs. The results of the round robin will be discussed in another paper at this conference.[28] They show that good probability of detection can be achieved for deep flaws. The level of success in detection of SCC did vary with flaw location, and there is a possibility of having a deep crack with a weak MRPC signal that would not be called a crack by analysts.

3.2 Failure Models for Steam Generator Tubes

Extensive work by NRC[30] and industry[31,32] during the 70's and 80's has developed and verified models for failure of flawed steam generator tubes under normal operating temperature (300°C) and pressures up to the failure of unflawed tubes (10,000–11,000 psi). Failure of steam generator tubes under such conditions is controlled by the flow stress of the material. A significant body of failure data on flawed steam generator tubes currently exists and has been the basis for the development of various flow stress models.

Most of this work focused on the potential for tube failure during design basis accidents like a main steam line break (MSLB). Risk assessment studies,[33] however, show that a significant portion of the risk due to steam generator tube failures is associated with tube failures due to severe accidents, during which tube temperatures can increase to 650–750°C. Under such conditions the strength

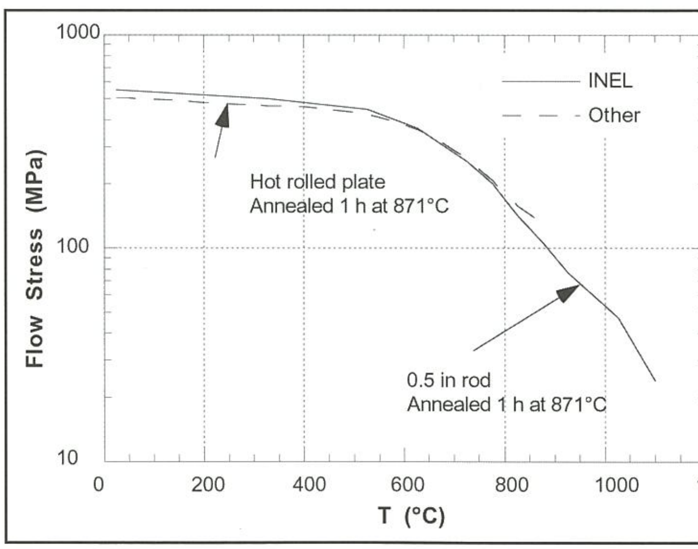


Figure 1: At high temperatures the flow stress of Alloy 600 decreases markedly and creep effects become significant.

of Alloy 600 decreases significantly as shown in Fig. 1, and creep becomes a potential failure mechanism for the tubes and the potential for increased leakage through flaws due to opening of existing throughwall flaws by creep deformation must be considered.

The research program at ANL has developed a data base, correlations and methodologies for predicting the failure of flawed and unflawed steam generator tubes under severe–accident conditions.[34] It is well known[35] that high-temperature failure is controlled by thermal creep at low strain rates and by flow stress at high strain rates. In the most structurally challenging severe accidents, the coolant pressure remains high (e.g., close to the safety relief set point) whereas the temperature of the tubes rises at rates varying from 5–10°C/min. Tests have shown that under these conditions, tube failure is best described by a creep model.[34]

Such models can also be extended to consider the potential for the failure of repaired tubes under severe accident conditions. Analyses and tests have been performed to study the behavior of tubes repaired by the Electrosleeve™ process under severe–accident conditions.[36]

Stress corrosion cracks on the primary side and due to high caustic concentrations on the secondary are mainly planar in nature. The cracks of primary interest at present, particularly on the secondary side, are segmented and have many ligaments between small segments of the crack. These cracks behave differently structurally from planar cracks. Tubes with these kinds of cracks exhibit higher burst pressures than one would predict using the correlations based on a planar bounding crack.

Mechanistic approaches to prediction of failure require the characterization of flaw geometries. In some cases it is possible to develop empirically based Alternate Repair Criteria (ARC) that do not explicitly consider flaw geometry. For example, in the case of ODSCC in Westinghouse steam generators with drilled-hole tube support plates, Generic Letter 95-05 provides repair criteria in terms of the peak bobbin coil voltage that do not explicitly address crack length or depth. Such empirical approaches presume that the crack geometries in the tubes used to develop the data base for the empirical correlation are representative of those actually encountered in reactor.

The USNRC Advisory Committee on Reactor Safeguards has suggested that a better understanding of the potential for damage progression as a result of the dynamic processes associated with depressurization during a main steam line break or other type of accident is needed.[37] They suggested that the bending and vibration of the tubes that could be involved might induce crack growth, tube leakage and tube burst outside the range previously considered in safety analyses.

4. Regulatory Guidance

Regulatory guidance for steam generator tube plugging and repair was developed in the 1970s (Reg. Guide 1.121, Bases for Plugging Degraded PWR Steam Generator Tubes). This guidance was based on deterministic depth–based plugging criteria that did, however, attempt to account for degradation growth and NDE uncertainty. The specific estimates for degradation growth and NDE uncertainty in Reg. Guide 1.121 were based on engineering judgment. Because the uncertainties associated with the integrity assessments are strongly dependent on the specific mode of degradation, regulatory guidance has changed with time from deterministic depth-based plugging criteria that apply to all flaw types toward performance-based risk-informed degradation-specific plugging criteria. One example of such guidance is Generic Letter 95–05, which as noted previously, provides plugging and repair criteria for a specific degradation, ODSCC at tube support plates in Westinghouse steam generators with drilled–hole tube support plates. The NRC staff has considered more broadly applicable performance-based risk-informed guidance in DG–1074, *Steam Generator Tube Integrity*, and such an approach is reflected in current industry guidance for tube integrity assessments (NEI 97–06).

One major outcome of the regulatory activity over the past 10 years to improve the effectiveness of regulatory requirements to assure steam generator integrity is the development and implementation of two key concepts, condition monitoring and operational assessment. Condition monitoring is an assessment of the current state of the steam generator relative to the performance criteria of structural integrity. An operational assessment is an attempt to assess what will be the state of the generator relative to the structural integrity performance criteria at the end of the next inspection cycle. The predictions of the operational assessment from the previous cycle can be compared with the results of the condition monitoring assessment to verify the adequacy of the methods and data used to perform the operational assessment.

The reliability of such assessments and projections depends critically on the reliability of the NDE techniques used to establish the flaw distribution, both in terms of flaw detection and characterization, the capability to assess the impact of these flaws on the structural integrity of the tubes, and the ability to predict crack initiation, evolution, and growth. In most cases degradation of steam generator tubing by stress corrosion cracking is still managed by "plug or repair on detection," because current NDE techniques for characterization of flaws are not accurate enough to permit continued operation. This is very conservative in many cases, since flaws <40% throughwall (or even deeper, short flaws) have little impact on tube integrity. On the other hand, current inspection technologies and procedures can miss flaws that will lead to steam generator tube ruptures.

5. Ongoing and Future Research

5.1 NDE Round Robin

Although the initial NDE round–robin on a steam generator mockup at Argonne National Laboratory has been completed, some NDE round robin activities are continuing. The mockup has been reconfigured with additional flawed tubes added and some flawed tubes removed for fractographic examination. The reconfigured mock-up has been scanned using an array probe called the X-probe. Experts from AECL, RDTech, and Framatome Technology Inc. participated in the exercise. The data collected were kept at Argonne, and training examples have been prepared from these data. A round robin exercise with the X-probe data collected from the mock-up is being developed.

In addition, a team from Mitsubishi Heavy Industries scanned about half of the mock-up using their 24-coil eddy current array probe. Although there are differences between the Xprobe array and the MHI array with respect to coil design and analysis software, overall, i t appears that the performance of the two arrays with respect to detection of mock-up flaws was comparable. A round robin that includes the MHI array has not yet been planned.

A round robin exercise on sizing is also underway. It is based on selected samples from the steam generator mockup at ANL. Most participants are expected to use phase analysis of +Point data.

5.2 Advanced NDE

To reduce some of the subjectivity of the analysis of EC data and to better cope with the huge amount of data produced by rotating and array coils, there is ongoing research in the development of advanced modern imaging and analysis algorithms[39]. Codes have been developed that permit more efficient and flexible analyses of rotating coil data. Simplification of interpretation of data is provided though improved enhanced visualization and automated analysis methodologies. It is now possible to produce NDE profiles of large sections of tubing in a fraction of the time that is needed for manual analysis.

Manual analysis of multiple frequency eddy current data is a tedious and challenging process. Signal distortion by interference from internal/external artifacts in the vicinity of a flaw further complicates discriminating of flaw signals from noise. In comparison to high–speed bobbin coil inspections, high-resolution multi-coil rotating and array probes generate enormous amounts of data over comparable scan lengths. Rotating probe ISI of SG tubing is thus generally restricted to areas that are historically predisposed to known damage mechanisms and sections of particular interest that are flagged by the initial bobbin coil examinations. More extensive application of such probes for improving NDE reliability rests in part on automating various stages of the data screening process. Computer-aided data analysis is the only viable way to overcome many of the challenges associated with reliable processing of data acquired with high-resolution probes.

In order to characterize flaws in a SG, a variety of characterization methods are being examined. An automated imaging and analysis algorithm for the analysis of RPC data has been developed. The basic elements of the algorithm include automated calibration of the data, filtering and deconvolution to improve the signal to noise ratio, use of a rule-based expert system to classify indications, and the use of multifrequency, multiparameter correlations for flaw size.

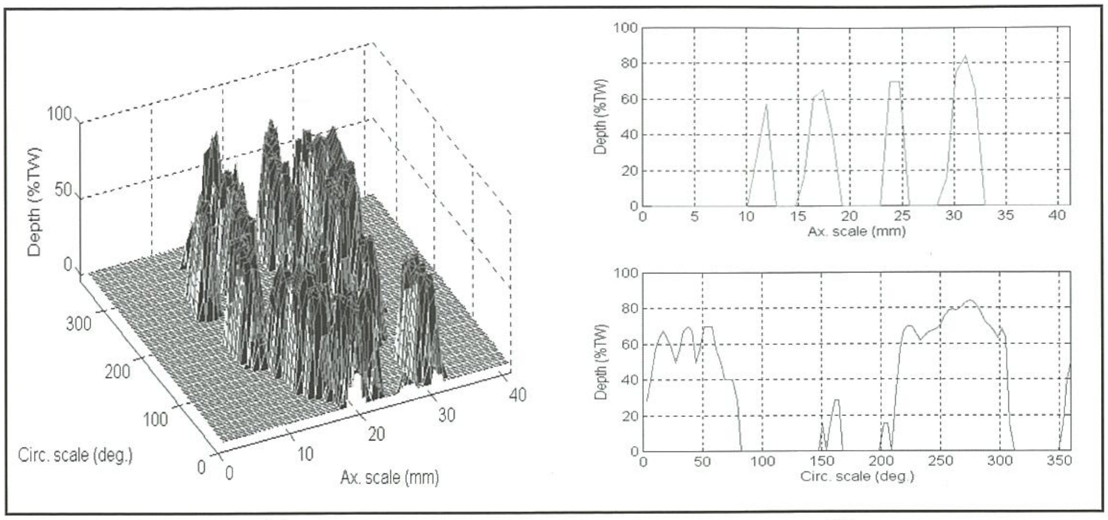
The method also provides a graphical display that helps visualize cracking especially in cases like the roll transition where geometry greatly complicates analysis. The results can be presented directly in terms of depth profiles as a percentage of the tube wall thickness. Reconstruction of helically scanned data into C-scan format allows for the observation of sizing results from any azimuth and elevation view angle and for any axial or circumferential cross section of the tube. Typical examples of the graphical display are shown in Figs. 2a and 2 b.

In the development of the multiparameter algorithm the results from the algorithm have been compared to fractographic results on a wide variety of SCC cracks and EDM and laser–cut notches. To provide an objective benchmark, however, additional SCC cracks were produced and used for a blind test of the predictions of the algorithm against fractographic measurements of the crack geometry. Examples of the comparison of the NDE results with fractographic measurements are shown in Fig. 3.

Array probes are another area of active interest. The X-Probe from RDTech is a transmitreceive eddy current array of three rows of pancake coils. The number of coils in the row varies with tube diameter. The transmit coil establishes the eddy current while receive coils read flaw created disruptions in currents, represented as phase and amplitude variations in the voltage plane. The array can travel through tubing at speeds comparable to bobbin coils, while still providing spatial and orientation information for both axial and circumferential cracks. Mitsubishi Heavy Industries of Japan has developed a 24 channel design using thin film pickup coils.[40] As in the case of the ANL multiparameter algorithm, color displays are used to help analysts visualize and interpret data. Figures 4a and 4b show X-Probe and +Point 3D signal amplitude plots for a flaw from the mockup. The tube axis is from lower left to upper right. Figure 4c-d show the corresponding 3D image generated by the Argonne multiparameter algorithm. Note that the array probe image represents a signal amplitude profile while the Argonne multiparameter image is a depth profile. For mock-up cracks, the quality of images from the MHI array are comparable to those generated by the X-Probe though in some cases the MHI array exhibited higher spatial resolution in the circumferential direction.

5.3 Structural Integrity

As noted previously, well-established criteria for predicting ligament rupture and unstable burst pressures of tubes with relatively long rectangular flaws exist. Some modifications of these criteria have been made for short and deep flaws [34]. Although we can currently predict with some



(a) (b)

Figure 2: (a) Lab-grown circumferential ODSCC ≈360° staggered cracking with maximum depth > 0% TW. (b) Axial or circumferential cross-sections can be taken to get profiles of the crack.

confidence failure pressures of tubes with flaws that are rectangular in shape, such a morphology is not characteristic of much of the cracking that is currently being observed in steam generators. Stress corrosion cracks in steam generator tubes are generally non-planar, ligamented, and can have highly complex geometry. Procedures for predicting ligament rupture for such complex cracks, using an "equivalent rectangular crack" approach (Fig. 5), has been developed[36,38]. Limited tests at ANL on steam generator tubes with laboratory generated stress corrosion cracks have shown the usefulness of such an approach. The use of the "equivalent rectangular crack" to predict leak rates through laboratory generated stress corrosion cracks has also proven to be promising. Additional leak rate and failure tests on tubes with stress corrosion cracks that are generated in the laboratory as well as on pulled tubes from a retired SG are needed to further validate the approach.

5.4 Materials Degradation

Although the performance of Alloy 690TT tubing has been excellent to date, further work is needed to characterize its potential for SCC. As stated previously, laboratory studies have shown Alloy 690TT is susceptible to SCC in the presence of soluble lead, reduced sulfur, and in mildly acidic and slightly oxidizing solutions and cracking may be aggravated by the presence of chlorides or sulfates.[26,41] These mildly acidic conditions are particularly relevant because molar ratio control as well as sea water contamination can produce mildly acidic crevices in steam generators.

It has been observed that concentrations of lead in the ppm range in mildly acidic, neutral, and alkaline environments produce or substantially accelerate the SCC of Alloy 690.[22,42] Despite efforts to reduce lead contamination, it still persists in deposits inside steam generators in ranges substantially greater than the levels required to produce SCC in the laboratory. However, this Pb contamination has not yet produced SCC in the field, and the reasons are unclear.[26]

Sulfur in the form of sulfides is another contaminant that is known to accelerate SCC in Alloy 690 TT, based on experiments in alkaline solutions. Sulfur is sometimes introduced as sulfates as feedwater contamination or in resin fines. These sulfates, in turn, can be reduced to sulfides either by hydrazine or by direct reaction with Alloy 690TT, and this reduction process and its consequences have not been adequately characterized.[26]

Additional research is needed to address these and other issues. The crevice chemistries at various locations in steam generators must be determined, and the chemistry of Pbcontaining deposits and their possible relationship to the occurrence of SCC should be evaluated. In addition, the conditions under which lower-valence sulfur compounds can form in crevice environments due to reactions with hydrazine or with Alloy 690 requires further study. In all of these studies, it is desirable to conduct the tests in the appropriate crevice chemistry environments. It is worth noting that except for model boiler studies, most of the corrosion testing in support of understanding secondary side corrosion has been conducted in single phase liquid water, whereas the environment on the tube surfaces where corrosion occurs is a combination of water, water/steam interface, and steam.[26]

Finally, studies on the behavior of Alloy 600 are still important, even though replacement steam generators are using Alloy 690 tubes. We have extensive and very valuable field experience with Alloy 600 that can be coupled with laboratory data. The knowledge gained in this coupling process can provide a bridge between laboratory data and expected field behavior for Alloy 690. The two alloys should be studied under similar conditions, and a better understanding of crack initiation, evolution, and growth under realistic crevice chemistry conditions is needed for both materials.

6. Observations and Recommendations

6.1 NDE

There is a need for a more robust screening of SG tubing. The development of array probes, which have better resolution than bobbin coils and enable rapid detection of both axial and circumferential cracks, may be the route to improved screening.

The industry has developed inspection technologies, performance demonstration and qualification programs that have improved the effectiveness and reliability of steam generator inspection programs, but improvements are needed in inspection guidelines and performance demonstration required to qualify techniques and analysts. The current acceptance criterion is intended to ensure at least an 80% detection rate for flaws > 60% throughwall. This implies that up to 20% of such flaws could be missed.

Currently, there are no passing criteria for sizing. Qualification for sizing is needed using sample sets with realistic cracks and other flaws. Until better sizing can be achieved, degradation of steam generator tubing by stress corrosion cracking may have to be managed by "plug or repair on detection,"

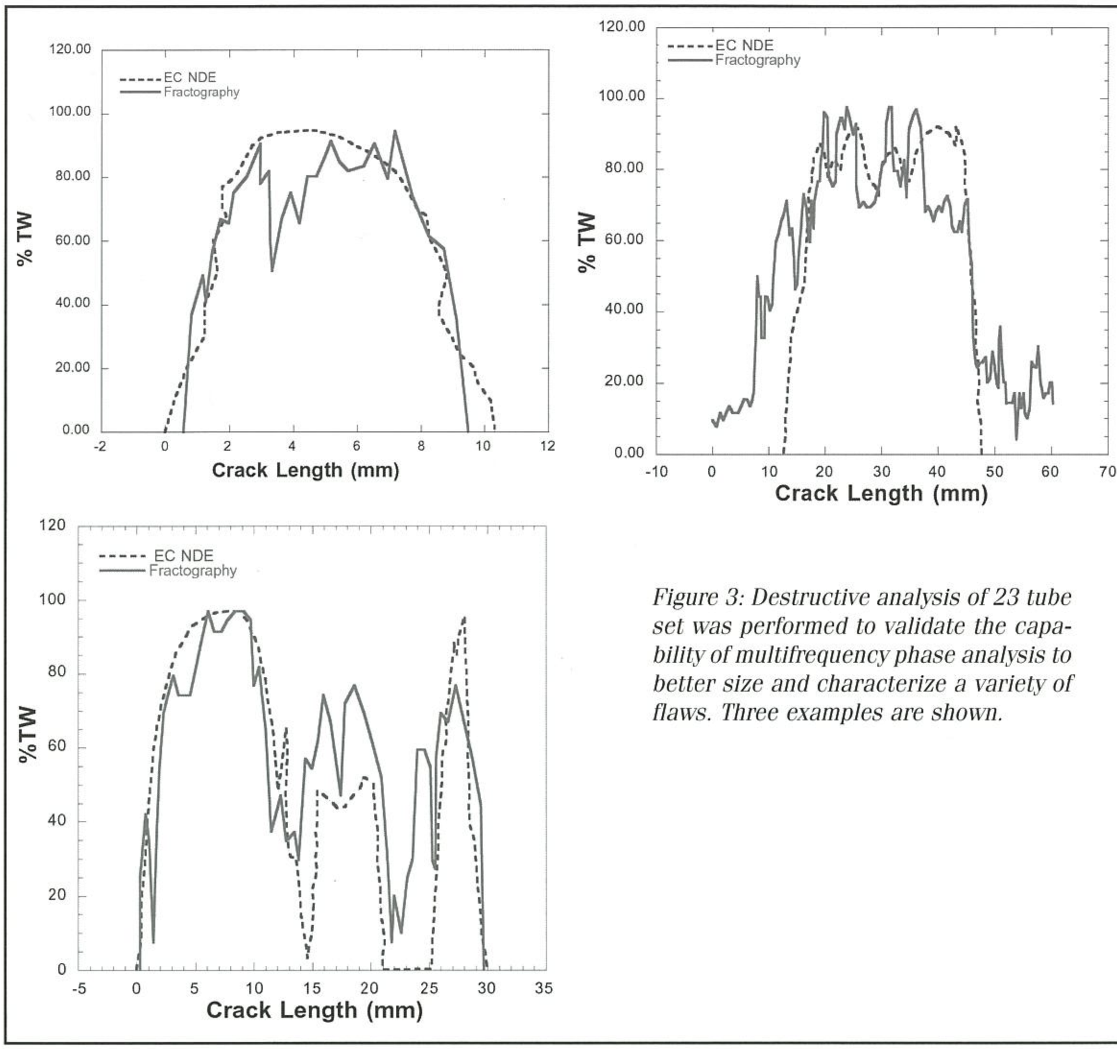


Figure 3: Destructive analysis of 23 tube set was performed to validate the capability of multifrequency phase analysis to better size and characterize a variety of flaws. Three examples are shown.

Replacement SGs with 690 tubing may require a different approach to ISI. In general larger samples are needed for early detection of developing degradation. Thus it may be preferable to have 100% sampling rather than the 15-20% currently being proposed. The use of smaller samples is typically justified by an argument that it is a fleet of generators that are being inspected, not a single generator. However, susceptibility is likely to be very dependent on particular chemistries and circumstances that it is not clear that the whole collection of generators can be considered as a single population. The larger inspection sample could be balanced by a lower frequency of inspection only in early years of operation. In addition, a higher POD for smaller flaws is needed for early detection.

6.2 Integrity

Currently, reliable correlations for predicting structural integrity and leakage of tubes with single well-defined rectangular cracks or notches are available. These models can be used to conduct conservative calculations by replacing actual cracks by bounding rectangular cracks. However, these evaluations can sometimes be overly conservative. To obtain more realistic assessments, these models have to be extended and/or modified.

The "equivalent rectangular crack" appears to be a reasonable approach towards a more realistic description of planar cracks with irregular shapes.[36,38] The current approach projects the crack depth profile as measured from NDE on to a single plane and treats the crack as a planar crack. But tests show that such planar cracks tend to have lower ligament rupture and burst pressures and higher leak rates compared to cracks that are non-planar and segmented separated by ligaments. A key to developing more realistic rupture and leak rate criteria is to determine the behavior of such ligaments as a function of their size and width.

An interesting recent observation made on deep stress corrosion cracks is the significant time-dependent increase of leakage under constant pressure hold, indicating an increase of throughwall crack length due to time-dependent ligament rupture. Such behavior has been observed in tests at room temperature as well as at 282°C - a temperature regime where timedependent creep deformation is generally accepted to be negligible. Such a time-dependent behavior under constant pressure suggests that the ligament rupture pressure of deep cracks under a constantly rising pressure test may be dependent on the pressurization rate. An analogous effect of pressurization rate on ligament rupture pressure has also been observed for deep planar

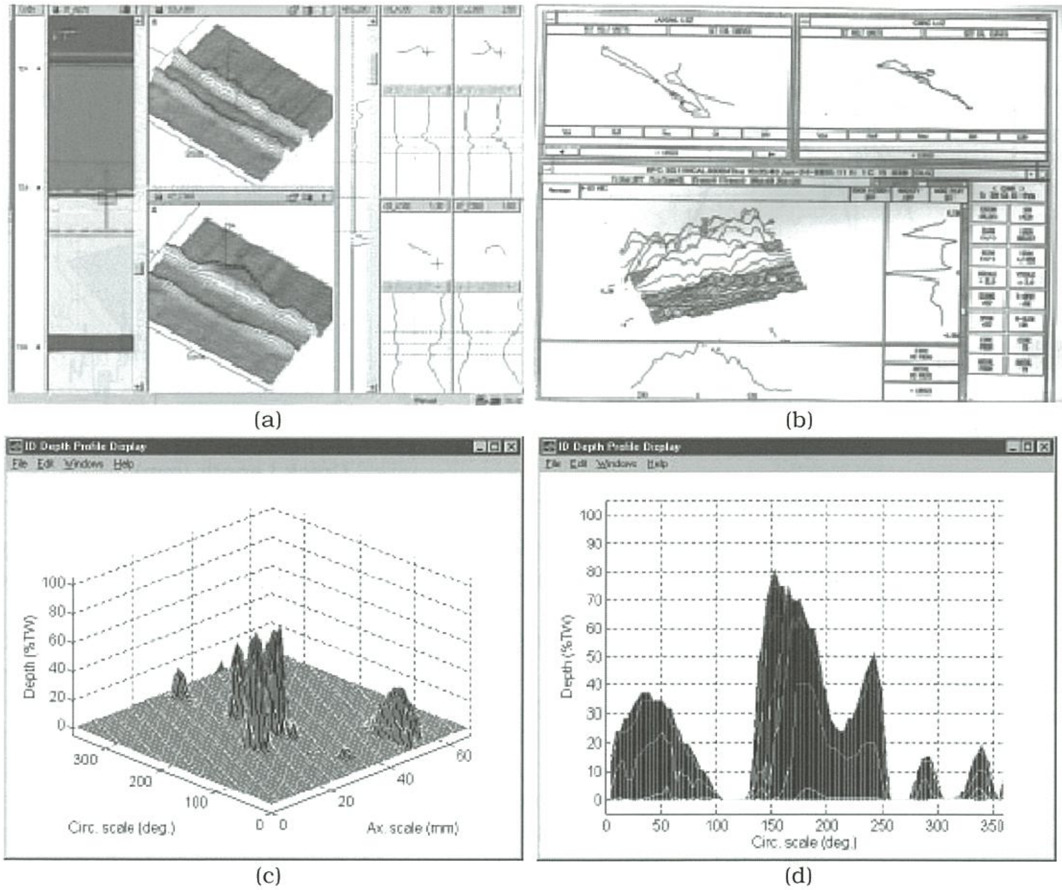


Figure 4: (a) X-Probe 3D image of eddy current signal amplitude as function of position around a test section in tube sheet simulation level of NRC steam generator mock-up; (b) +Point 3D image of eddy current signal amplitude as function of position around same mock-up test section; (c) Argonne multi-parameter algorithm generated 3D plot of depth vs position around same mock-up test section; (d) Projection of results from Argonne multiparameter algorithm onto the cross section.

machined notches with variable ligament width. Currently, we have no model to account for such time-dependent ligament rupture phenomenon.

To select an appropriate integrity model used in the operational assessment, we need to better predict how flaws develop, evolve, and grow from more complex infant cracks to planar cracks. Again, the behavior of ligaments under pressure and corrosive environment is the key to developing such predictive models.

Nucleation and early growth of stress corrosion cracks are controlled by various factors – some of them are mechanical (e.g., stress), some are environmental (e.g., temperature), some are chemical (e.g., pH) and some are metallurgical (e.g., carbide morphology). Currently, the complex interactions between these various factors are not clearly understood. Also, crack morphology during this period can be very complex (e.g., cellular cracks rather than a single dominant crack). As a result, mechanistic models for predicting crack initiation are currently lacking, and empirical models based on stress are often used for predicting crack initiation. With continued service exposure, often a dominant single crack emerges for which the mechanical component of the crack driving force becomes controlling. Fracture mechanicsbased models can then be used to calculate the growth of such cracks, and crack growth rate data for alloy 600 under primary and secondary water environments have been generated for this purpose.

6.3 Materials Degradation

As noted previously service experience to date with thermally treated Alloy 690 has been good. After up to 13 years of service, no incidents of SCC have been reported in operating steam generators. However, although laboratory studies have also been unable to produce SCC in Alloy 690 in primary water chemistries, numerous studies have demonstrated the ability to crack this alloy under conditions that approximate chemistries that could occur under crevice conditions on the secondary side of steam generators. In addition, it should be noted that widespread instances of SCC with Alloy 600 tubes did not occur until after ≈10 years of service. The situation has some similarity to that in the late '60s when Alloy 600 was thought to be the solution to steam generator corrosion problems. Although designs and water chemistry controls have improved and Alloy 690 is clearly a more resistant material, it should not be assumed that the SCC problem in PWR steam generators has been permanently solved through this choice of material.

Studies of Alloy 600 behavior are still important, even though replacement steam generators use Alloy 690 tubes. There is extensive field experience with Alloy 600 that can be coupled with laboratory data to help understand and validate the relation between laboratory data and behavior in actual steam generators. This information can be used to provide a bridge between laboratory data and field behavior for Alloy 690.

Substantial progress is being made in improving NDE capability and developing a better understanding of the structural behavior of flawed tubes. However, we still need

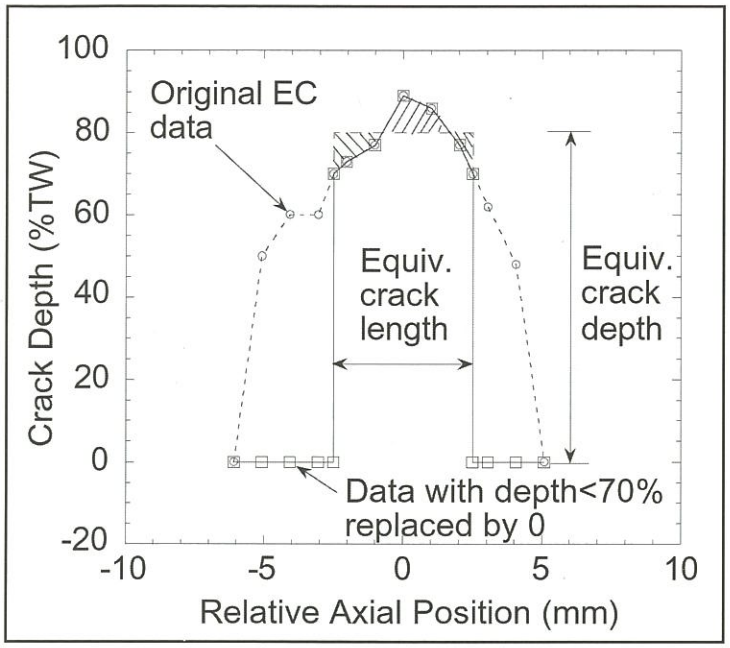


Figure 5: "Equivalent rectangular crack" methods are promising, but more validation work on a wider variety of crack geometries is needed.

to gain a better understanding of crack initiation, evolution, and growth under realistic crevice chemistry conditions for both Alloy 600 and 690 to carry out more realistic operational assessments of steam generator integrity.

References

1. J. M. Gras, *Stress Corrosion Cracking of Steam Generator Tubing Materials,* pp. 411- 432 in Proc. Parkins Symp. on Fundamental Aspects of Stress Corrosion Cracking, S. M. Bruemmer et al., eds., The Minerals, Metals, & Materials Society, Warrendale, P A (1992).
2. J. Douglas, "Solutions for Steam Generators," EPRI Journal (May/June 1995), pp. 28- 34.
3. "Steam Generator Progress Report, Revision 15," 1000805, Electric Power Research Institute, Palo Alto, CA (November 2000)
4. W. J. Singley, I. H. Welinsky. S. F. Whirl, and H. A. Klein, *Stress Corrosion of Stainless Steel and Boiler Water Treatment at Shippingport Atomic Power Station,* pp. 748-768 in Proc. Amer. Power Conf., Vol. XXI (1959).
5. I. H. Welinsky, W. F. Brindley, W. E. Berry, and S. F. Whirl, *Final Evaluation of Shippingport Power Station's Stainless Steel Generator after Five Years,* pp. 1-13 in Proc. Symp. on High Purity Water Corrosion of Metals, 23rd NACE Conf., National Association of Corrosion Engineers (1968).
6. C. F. Cheng, *Intergranular Stress-Assisted Corrosion Cracking of Austenitic Alloys in Water-Cooled Nuclear Reactors,* J. Nucl. Mater., Vol. 56 (1975), pp. 11-33.
7. H. Coriou, L. Grall, and S. Vettier, "Corrosion sous de l'Inconel 600 dans l'eau à haute temperature," 3ème Colloque de métallurgie sur la corrosion, Saclay, North Holland Publishing Co., Amsterdam (1959), pp. 161-169.
8. H. Coriou. L. Grall, C. Mahieu, and M. Pelras, "Sensitivity to stress corrosion and intergranular attack of high nickel austenitic alloys," Corrosion, Vol. 22 (1966), pp. 280-290.
9. *Operation with Steam Generator Tubes Seriously Degraded,* NRC Information Notice 92-80, U.S. Nuclear Regulatory Commission, Washington, DC (December 7, 1992).
10. *Inservice Inspection Deficiencies Result in Severely Degraded Steam Generator Tubes,* NRC Information Notice 94-88, U.S. Nuclear Regulatory Commission, Washington, DC (December 23, 1994).
11. *Potential Failure of Westinghouse Steam Generator Tube Mechanical Plugs,* NRC Information Notice 89-33, U.S. Nuclear Regulatory Commission, Washington, DC (March 23, 1989).
12. *Failure of Westinghouse Steam Generator Tube Mechanical Plugs,* NRC Bulletin 89-01, U.S. Nuclear Regulatory Commission, Washington, DC (May 15, 1989).
13. *Failure of Westinghouse Steam Generator Tube Mechanical Plugs,* NRC Bulletin 89-01, Supplement 1, U.S. Nuclear Regulatory Commission, Washington, DC (November 14, 1990).
14. *Failure of Westinghouse Steam Generator Tube Mechanical Plugs,* NRC Bulletin 89-01, Supplement 2, U.S. Nuclear Regulatory Commission, Washington, DC (June 28, 1991).
15. *Unanticipated Crack in a Particular Heat of Alloy 600 Used for Westinghouse Mechanical Plugs for Steam Generator Tubes,* NRC Information Notice 94-87, U.S. Nuclear Regulatory Commission, Washington, DC (December 22, 1994).
16. *Circumferential Cracking of Steam Generator Tubes,* NRC Generic Letter 95-03, U. S. Nuclear Regulatory Commission, Washington, DC (April 28, 1995).
17. *Potential for Stress Corrosion Cracking in Steam Generator Tube Plugs Supplied by Babcock and Wilcox,* NRC Information Notice 89-65, U.S. Nuclear Regulatory Commission, Washington, DC (September 8, 1989).
18. "KEPCO Intensifies Eddy Current Examination of Ulchin Steam Tubes," Nucleonics Week, Vol. 40, No. 16 (April 22, 1999). p. 17.
19. "More Tube Sleeving at Ulchin may Delay Steam Generator Replacement," Nucleonics Week, Vol. 41, No. 14 (April 6, 2000). pp. 4-5.
20. "Public Pressure May Prompt KEPCO to Replace Ulchiin Steam Generators," Nucleonics Week, Vol. 41, No. 18 (May 4, 2000). p. 12.

21. J. S. Kim and S. S. Hwang, "PWSCC of Thermally Treated Alloy 600 Pulled from a Korean Plant," Nuclear Eng, and Design (in press).
22. *Stress Corrosion of Alloys 600 and 690 in Acidic Sulfate Solutions at Elevated Temperatures,* EPRI Report NP-3943, Electric Power Research Institute, Palo Alto, CA (October 1983).
23. K. Norring, J. Engstrom, and P. Norberg, *Intergranular Stress Corrosion Cracking in Steam Generator Tubing—Testing of Alloy 690 and Alloy 600 Tubes,* pp. 587-593 in Proc. 3rd Intl. Symp. on Environmental Degradation of Materials in Nuclear Power systems—Water Reactors, Traverse City, MI, August 30-September 3, 1987, G. J. Theus and J. R. Weeks, eds., The Metallurgical Society, Warrendale, PA (1988).
24. F. Vaillant, D. Buisine, and B. Prieux, "Comparative Behavior of Alloys 600, 690, and 800," pp. 219-231 in *Proc. 7th Intl. Symp. On Environmental Degradation of Materials in Nuclear Power Systems,* Breckenridge, CO (August 1995).
25. W. H. Cullen, "Review of IGA, IGSCC, and Wastage of Alloys 600 and 690 in High-Temperature Acidified Solutions," pp. 273-304 in *Control of Corrosion on the Secondary Side of Steam Generators,* National Association of Corrosion Engineers, Houston, TX (1996).
26. R. W. Staehle and J. A. Gorman, *Quantitative Assessment of Submodes of Stress Corrosion Cracking on the Secondary Side of Steam Generator Tubing in PWRs,* NUREG/CR–xxx, Argonne National Laboratory, Argonne, IL, to be published.
27. C. V. Dodd and W. E. Deeds, "In–Service Inspection of Steam–Generator Tubing Using Multifrequency Eddy–Current Techniques," *Eddy–Current Characterization of Materials and Structures,* ASTM STP 722, G. Birnbaum and G. Free, Eds., American Society for Testing and Materials, 1981, pp. 229–239.
28. D. S. Kupperman, J. Muscara, S. Bakhtiari, J. Y. Park and W. J. Shack, "Eddy Current Analysis Round Robin Using the NRC Steam Generator Mockup," Fourth International Steam Generator Conference, May 5-8, 2002, Toronto, Canada
29. D. S. Kupperman, S. Bakhtiari, W. J. Shack, J. Y. Park, and S. Majumdar, "Evaluation of Eddy Current Reliability from Steam Generator Mock-Up Round Robin," NUREG/CRxxxx, ANL-01/22, Argonne National Laboratory, Argonne IL, to be published.
30. R. J. Kurtz, R. A. Clark, L. R. Bradley, W. M. Bowen, P. G. Doctor, R. H. Ferris, and F. A. Simonen, *Steam Generator Tube Integrity Program/Steam Generator Group Project, Final Project Summary Report,* NUREG/CR–5117, PNNL, Richland, WA, May 1990.
31. B. Flesch and B. Cochet, "Crack stability criteria in steam generator tubes," *Int. Cong. on Pressure Vessel Technology,* Beijing, Sept. 1988.
32. B. Cochet, J. Engstrom, and B. Flesch, "PWR steam generator tube and tube support plate plugging criteria," Paper 4.1, *Steam generator tubes mechanical, LBRB, and probabilistic studies,* EDF, France, 1990.
33. SGTR Severe Accident Working Group, "Risk Assessment of Severe Accident-Induced Steam Generator Tube Rupture," NUREG-1570, U.S. Nuclear Regulatory Commission, Washington DC, 1998.
34. S. Majumdar, W. J. Shack, D. R. Diercks, K. Mruk, J. Franklin, and L. Knoblich, "Failure Behavior of Internally Pressurized Flawed and Unflawed Steam Generator Tubing at High temperatures – Experiments and Comparison with Model Predictions," NUREG/CR-6575, Argonne National Laboratory, Argonne IL, 1998.
35. I. Finnie and W. R. Heller, *Creep of Engineering Materials,* New York, McGraw-Hill, 1959.
36. S. Majumdar, K. Kasza, and J. Franklin,"Pressure and Leak-Rate Tests and Models for Predicting Failure of Flawed Steam Generator Tubes," NUREG/CR-6664, Argonne National Laboratory, Argonne IL 60439, 2000.
37. Voltage-based Repair Criteria, A Report to the Advisory Committee on Reactor Safeguards From Its Ad Hoc Subcommittee on a Differing Professional Opinion, NUREG–1740. March 2001.
38. J. Begley, Docket No. 50-361, Steam Generator Runtime Analysis for Cycle 9, San Onofre Nuclear Generating Station, Unit 2, Sept 25, 1997
39. S. Bakhtiari and D. S. Kupperman, Advanced NDE for Steam Generator Tubing, NUREG/CR-6638;ANL-99/9, January 2000.
40. MHI Presentation at the 20th Annual EPRI Steam Generator NDE Workshop in Orlando, Florida, July 9-11, 2001.
41. L. zur Nedden, J. Stubbe, and E. Pierson, "Effect of Simulated Outage Conditions in Acid Environment Containing Copper on Corrosion of Steam Generator Tubes," pp. 91-99 in Proc. Eighth Intl. Symp. On Environmental Degradation of Materials in Nuclear Power Systems—Water Reactors, American Nuclear Society, La Grange Park, IL (1997).
42. M. Helie, L. Lambert, and Santarini, "Some Considerations About the Possible Mechanisms of Lead Assisted Stress Corrosion Cracking of Steam Generator Tubing, pp. 247-258 in Proc. Seventh Intl. Symp. On Environmental Degradation of Materials in Nuclear Power Systems—Water Reactors, American Nuclear Society, La Grange Park, IL (1995).

CNS/CNA 26th Student Conference
2 June 2002
Winning undergraduate paper

Radiolytic Formation of Organic Iodides from Organic Compounds Released from Ripolin Paint

by Sarah Attia, Greg J. Evans[1]

Abstract

The impact of a serious nuclear reactor accident is governed to a large extent by the possible release of airborne organic iodides to the environment. This research examines the identification and behavior of organic iodides formed in the containment due to the release of organic compounds from Ripolin paint, into the aqueous phase, following a nuclear reactor accident. A bench scale apparatus installed in the irradiation chamber of a Gammacell was used to analyze the formation of organic iodides. Iodo-organics, transferred to the gas phase above irradiated aqueous samples, were analyzed using a Thermal Desorption method coupled with gas chromatography and mass spectrometry. Detailed studies of the identity of the organic compounds released and the organic iodides formed were conducted. The effects of parameters such as irradiation dose were also examined. All the organic iodides formed, under radiolytic conditions, were identified as iodo-alkanes. The organic compounds that were released from the Ripolin paint, such as methyl isobutyl ketone, were found to decompose, by a series of reactions, to produce the organic iodides. The precursor organic compounds and the organic iodides formed were observed to consist of the same alkyl group. These results indicate that organic compounds released from surface paints directly influence the formation of radiolytic organic iodide.

Introduction

During the normal operation of a nuclear reactor fission of Uranium-235 takes place, producing several iodine radioisotopes. For the evaluation of reactor safety, radioiodine is of significant interest due to its high fission yield, its potential volatility, and its radiobiological .hazard. It is therefore important that the behavior of radioiodine, under reactor accident conditions, be fully understood.

In the event of a reactor accident, radioactive materials from the reactor core may be released into the containment area. Under accident conditions the iodine released from the fuel, into containment, is expected to be in the form of cesium iodide (CsI). The iodine dissolves in water, in the form of molecular iodine (I-), and settles in the sump at the bottom of the containment. If I^- remains in the aqueous phase, it can be easily contained in the system. However, I^- is involved in a series of chemical and radiolytic reactions and can subsequently be oxidized to forms such as molecular iodine (I_2), organic iodides (RI), and atomic iodine (I). The behavior of the dissolved iodine, following a reactor accident, depends on the radiation chemistry that exists within the containment structure.

The major effect of low energy transfer radiation, such as Cobalt-60, on water is the production of highly reactive free radicals and molecular products. The radiolysis products are listed below:

$$H_2O - ã, â^- \rightarrow OH, e^-, H, H_2, H_2O_2, H^+ \quad (1)$$

The most important of these radicals are OH, e^-, and H. The effect of radiation on iodine chemistry is indirect, through the reaction of the water radiolysis products with iodine species. The following reactions take place:

Oxidation of I^- by the hydroxyl radical

$$I^- + OH \rightarrow I + OH^- \quad (2)$$

Where I is in rapid equilibrium with I_2^-

$$I + I^- \leftrightarrow I_2^- \quad (3)$$

In containment, organic compounds can have a substantial impact on iodine volatility. Following a nuclear reactor accident, large quantities of water-soluble organic impurities are leached into the containment atmosphere from various surface paints. The radiation chemistry of aqueous systems containing organic compounds involves the reaction of water radiolysis products with organic solutes. This area of iodine behavior is still not fully understood. These organic solutes may react with molecular iodine to form a variety of organic iodides.

$$R + OH \rightarrow \rightarrow R^* + products \quad (4)$$

1 Department of Chemical Engineering & Applied Chemistry, University of Toronto, Toronto, Ontario.

$$R^*/R'^* + I_2 \rightarrow RI/R'I + I \quad (7)$$

$$R^*/R'^* + I \rightarrow RI/R'I \quad (8)$$

The details of the reactions involved in the decomposition of the organic compounds to form the alkyl radicals, and subsequently the organic iodides, requires further research.

Effect of Irradiation Time on the Organic Compounds and Organic Iodide Formation

A relationship exists between the decomposition of the organic solvents, their release from the paint surfaces, and the formation of organic iodides under radiolytic conditions. To.this end, the behavior of the organic compounds over a range of irradiation times was examined. Experiments were performed with irradiation time ranging form 0 to 24 hours.

Of the organic compounds in the iodine-paint irradiated sample, methyl isobutyl ketone (MIBK) had the greatest yield. The concentration of MIBK was observed to decrease over the first 24 hours of irradiation, with the most significant drop occurring in the first five hours of irradiation. To further understand these observations, this experiment was repeated using pure MIBK sample (in place of the paint sample). In this case, the MIBK in the system was observed to be completely eliminated in the first ten hours of irradiation, much faster than in the case of the paint samples. This difference in behavior suggests that the mechanisms involved with the decomposition of the organic solvents released from the paint samples is much more complex than the behavior of pure organic compounds under radiolytic conditions.

A similar analysis of the duration of formation of organic iodides, over a range of irradiation times, was conducted. The organic iodides were detected throughout the 24 hours of irradiation time. These results show that the significant organic compound (MIBK) quickly decreases in abundance in the first five hours of irradiation, while organic iodides continue to be detected beyond that time.

From the identification of the organic iodides and the organic compounds in the system, and the analysis of the behavior of MIBK over a range of irradiation times, a number of interpretations can be made. The organic impurities produced by the reaction of water radiolysis products with organic solutes (such as MIBK), can react to form other organic compounds (such as 2 methyl propanal and butanal). Both the products and the precursor may be involved in the radiolytic reactions to produce organic iodides. Further study of this topic is required in order to determine the complex reaction mechanism involved.

Conclusions

This research investigated the formation of organic iodides through the radiolytic reaction of molecular iodine and organic compounds, leached into the containment area, from Ripolin paint. The work done in this study was a significant step in a very important research area. The types of organic iodides formed and the precursor organic compounds that contribute to their formation were identified. All the organic iodides detected were identified as iodo-alkanes. Organic compounds that are released from Ripolin paint decompose to produce iodo-alkanes. The precursor organic compounds and the alkane iodides consist of the same alkyl group. The analysis of the behavior of the organic iodide and their precursor organic compounds, over different irradiation times, suggests that a complex reaction mechanism is involved. The organic radicals (produced from the organic compounds) go through a series of reactions before forming organic iodides.

The results of this study will be incorporated in the method development for further research in this area. Specifically, the results can be used as a basis for tests involving the measurement of organic iodide formation. These results will also assist in developing and validating models describing the formation of organic iodides in containment following reactor accidents.

References

1. Spinks, J., & Woods, R. *An Introduction to Radiation Chemistry.* John Wiley and Sons Inc., NewYork, 1990.
2. Sunaryo, G., Katsumura, Y., and Ishigure, K. *Radiation Physical Chemistry.* 44 (3), 273-280.
3. Wren, J. *The Chemistry of Iodine in Containment.* AECL, Atomic Energy of Canada Ltd. (1999)
4. Woods, R., & Pikaev, K. *Applied Radiation Chemistry.* John Wiley and Sons Inc., NewYork, 1994.
5. Taghipour, F. Radiolytic *Organic Iodide Formation under Nuclear reactor Accident Conditions.* Environ. Sci. Technol. 2000, 34, 3012-3017.
6. Wren, J. *The Interaction of Iodine with Organic Material in Containment.* AECL, Atomic Energy of Canada Ltd. (1998)
7. Taghipour, F. *The Impact of Organic Compounds on Iodine Behavior Under reactor Accident Conditions.* PhD thesis. Graduate Department of Chemical Engineering and Applied Chemistry, University of Toronto, 1998.
8. Wren, J., Sagert, N., and Sims, H. *Modeling of Iodine Chemistry: The LIRIC Database.* Proc. 3 rd CSNI Workshop on Iodine Aspects of Severe Accident Managements, Japan, 1991
9. Wren, J. *Dissolution of Organic Solvents from Painted Surfaces into Water.* Can J. Chem. Vol 78, 2000, pg 464 -473.
10. Evans, G., *An Experimental Assessment of Iodine Petitioning and Speciation in Relation to Nuclear Reactor Accident.* PhD thesis, University of Toronto, 1988.
11. Belval-Haltier, E., Taylor, O. *Iodine Volatile Species Production from Painted Surfaces of the reactor Containment, during a Severe Accident.* Proc. CSNI

Workshop on Iodine Aspects of Severe Accident Managements, Finland, 1999

12. Fluke, R., Ball, J., Dickinson, S., Sims, H., Evans, G. *Iodine Behavior in Containment, Quantifying the Effect of Organic Reactions"*, ACEX TR-B-04, 1997.
13. Funke, F. *Data Analysis and Modeling of Organic Iodide Production on Painted Surfaces.* Proc. CSNI Workshop on Iodine Aspects of Severe Accident Managements, Finland, 1999.
14. Kupferschmidt, W., Buttazone, J., Evans, G., Ford, B., Palson, A., Portman, R., Sanipelli, G.,. *Iodine Chemistry in the presence of Vinyl Surfaces.* Proc. 3rd CSNI Workshop on Iodine Aspects of Severe Accident Managements, Japan, 1991.
15. Ono, S., Fujita, N. *Radio-chemical effect on the Formation of Inorganic and Organic Species in Aqueous Phase.* Water Chemistry for Nuclear Reactor Systems 4, London, 177-182, 1986.
16. Wren, J., Ball, J., and Glowa, G. *Studies on the Effects of Organic Painted Surfaces on pH and Organic Iodide Formation.* Proc. CSNI Workshop on Iodine Aspects of Severe Accident Managements, Finland, 1999.
17. Lambourne, R. *"Solvents, Thinner and Diluents, Paints and Surface Coatings: Theory and Practice"* 2nd Edition, Woodhead Publishing Limited, 1999.
18. Stoye, D., and Freitag, W. *"Paints, Coatings and Solvents"*, 2nd edition, Wiley VCH, 1991.
19. Ashmore, C., Baston, G., Dean, T., Dickonson, S., Matcham, A., Sims, H. *Experimental Studies of Organic Iodide Production.* Proc. CSNI Workshop on Iodine Aspects of Severe Accident Managements, Finland, 1999.
20. Taghipour, F., Evans, G. *Iodine Behavior Under Conditions relating to Nuclear Reactor Accidents.* University of Toronto, 1998.

CNS/CNA 26th Student Conference
2 June 2002
Winning doctoral level paper

An Adaptive General Multigroup Method

by Ibrahim K. Attieh, Ronald E. Pevey[1]

I. Introduction

In the multigroup transport equation, the subdivision of the continuous energy domain is approximated using a finite number of energy groups. The generation of group cross sections is predominantly performed using the traditional multigroup method (1). A new approach is presented that sheds the traditional definition of energy groups. The new method allows an energy to have partial membership in more than one group, which allows the assumed group spectral shape to adapt to problem-dependent conditions. It will be applicable in criticality safety studies because it allows for a more accurate fission neutron spectrum and spatial variation in the flux spectrum inside a homogenous material.

I. Discussion

For an infinite homogeneous medium, with no fission and a constant neutron source, the transport equation is

$$\Sigma_t(E)\Phi(E) = \int_0^\infty dE' \Sigma_s(E' \to E)\Phi(E') + S(E) \quad (1)$$

To transform the equation into coupled multigroup equations, the flux $\Phi(E)$ is approximated by

$$\Phi(E) = \Psi(E) * \sum_{g=1}^{G} \phi_g f_g(E) \quad (2)$$

where $\Psi(E)$ is an assumed spectrum shape, and $f_g(E)$ is the group g membership function. By substituting Equation 2 into Equation 1, we obtain:

$$\Sigma_t(E)\Psi(E)\sum_g \phi_g f_g(E) = \int_0^\infty dE' \Sigma_s(E' \to E)\Psi(E')\sum_g \phi_g f_g(E') + S(E) \quad (3)$$

To obtain the coupled multigroup equations, we multiply this equation by each group membership function and integrate over energy for each group, which reduces to

$$\int_0^\infty \Sigma_t(E)\Psi(E)\sum_g \Phi_g f_g(E) f_k(E) dE = \int_0^\infty f_k(E) dE \int_0^\infty dE' \Sigma_s(E' \to E)\Psi(E')\sum_{g'} \Phi_{g'} f_{g'}(E') + \int_0^\infty f_k(E) S(E) dE \quad (4)$$

1 University of tennessee, Knoxville, TN

For group k, for example, this gives us:

$$\sum_{g=1}^{G}\Phi_g\Sigma_{tkg} = \sum_{g=1}^{G}\Phi_g\Sigma_{skg} + S_k \qquad (5)$$

where

$$\Sigma_{tgk} = \Sigma_{tkg} = \int_0^\infty \Sigma_t(E)\Psi(E)f_g(E)f_k(E)dE \qquad (6)$$

$$\Sigma_{skg} = \int_0^\infty f_k(E)dE\int_0^\infty f_g(E')\Sigma_s(E'\rightarrow E)\Psi(E')dE' \qquad (7)$$

$$S_k = \int_0 S(E)f_k(E)dE \qquad (8)$$

In the traditional multigroup method, $f_g(E)$ is a rectangular membership function with magnitude of $1/\Psi_g$ over the domain of group g, where the group cross sections are defined such that

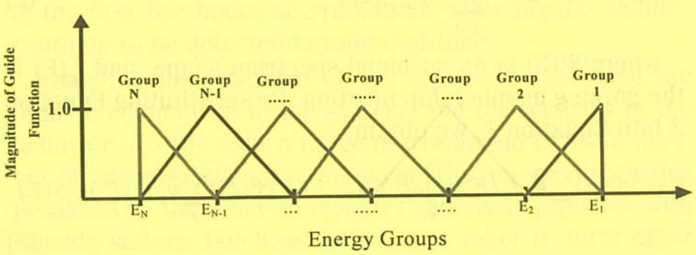
$$\Psi_g \equiv \int_{E_g}^{E_{g-1}} dE\Psi(E) \qquad (9)$$

$$\Sigma_{tgk} = \begin{cases} \dfrac{\int_{E_g}^{E_{g-1}} dE\,\Sigma_T(E)\Psi(E)}{\Psi_g}, & k = g \\ 0, & k \neq g \end{cases} \qquad (10)$$

$$\Sigma_{sgg'} \equiv \frac{\int_{E_g}^{E_{g-1}} dE \int_{E_{g'}}^{E_{g'-1}} dE'\Sigma_s(E'\rightarrow E)\Psi(E')}{\Psi_{g'}} \qquad (11)$$

For this research, we use the generalized form (Equations 5-8) and investigate the use of "chapeau" functions (shown in Figure 1) for the group membership functions.

Figure 1: Chapeau Membership Functions for Generalized Multigroup



In the resulting multigroup equations, the group-to-group total cross sections are restricted to the current group and adjacent neighbors, e.g. with four groups the matrix relation would be:

$$\begin{bmatrix} \Sigma_{t11}-\Sigma_{s11} & \Sigma_{t21}-\Sigma_{s21} & 0 & 0 \\ \Sigma_{t12}-\Sigma_{s12} & \Sigma_{t22}-\Sigma_{s22} & \Sigma_{t32}-\Sigma_{s32} & 0 \\ -\Sigma_{s13} & \Sigma_{t23}-\Sigma_{s23} & \Sigma_{t33}-\Sigma_{s33} & \Sigma_{t34}-\Sigma_{s43} \\ -\Sigma_{s14} & -\Sigma_{s24} & \Sigma_{t34}-\Sigma_{s34} & \Sigma_{t44}-\Sigma_{s44} \end{bmatrix} \begin{bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \end{bmatrix} = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{bmatrix} \qquad (12)$$

2. Example

To demonstrate the new method's robustness, an example problem was calculated. The problem consists of an infinite medium of ^{238}U with a constant neutron source emitting 1 neutron/second/unit volume with 500 eV energy. The neutron slowing down rate at 400 eV energy (calculated to be 0.22123 +/- 0.00013 using a Monte Carlo method) was calculated using both the traditional histogram and the chapeau group membership functions using a $1/(E^*\Sigma_T)$ assumed spectrum shape. The number of groups was varied from 4 to 1024. This is a challenging problem because there is a 78% loss of neutrons over a very small energy range due the presence of absorption resonances and the small energy loss per collision.

3. Results and Conclusion

The resulting errors in the escape probabilities are shown in Figure 2. It is observed that the new method is generally more accurate than the traditional method. With 4 groups, the new method is within 7% of the true solution as opposed to the 28% for the traditional method. At 32 groups, the error for the new method is 0.8% compared to 3.35%. For 64 groups, both methods have converged to within the uncertainty of the true solution, which is about 0.1%. Hence the new method shows promise as an improved way or representing the energy dimension.

In the near future, this method is going to be applied to criticality safety, shielding, and reactor problems. The authors feel that the new method will have its greatest impact in criticality safety studies because it allows for a more accurate fission neutron spectrum (i.e., line segments vs. histogram) and spatial variation in the flux spectrum inside a homogenous material.

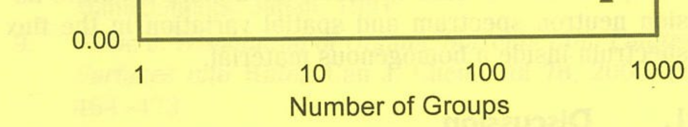


Figure 2: Error in the Estimation of Escape Probability vs. Number of Energy Groups for Different Methods of Calculating Group Cross Sections

4. Reference:

[1] D.E. Cullen, "Nuclear Cross Section Preparation", in Y. Ronen, Ed., CRC Handbook of Nuclear Reactor Calculations I, CRC Press, Boca Raton, FL (1986)

Mr. Attieh has informed the CNS Bulletin that he is revising this paper. Anyone wishing an updated version should contact him at < iattieh@utk.edu >

Acknowedgement: The first author would like to thank Distinguished Professor Robert E. Uhrig for providing funds for his Ph.D. research.

CNS/CNA 26th Student Conference
2 June 2002
Winning graduate level paper

Caractérisation des configurations des écoulements diphasiques par la détermination simultanée des composantes complexes de l'impédance électrique

by M. Berdaï et A. Teyssedou[1]

Ed. Note: Unfortunately only the Abstract of Ms. Berdai's paper was available at the time of publication, but is presented in both official languages as submitted.

Dans ce papier on présente une étude préliminaire, sur la distribution du champ électrique et des lignes équipotentielles dans un système de mesure du taux de vide, utilisant la méthode de l'impédance.

Les méthodes de mesure du taux de vide basées sur le comportement électrique du milieu, ont été jusqu'au présent développées, soit en déterminant la partie réelle ou la partie imaginaire de l'impédance du milieu.

Dans ce travail, on propose de caractériser la structure de l'écoulement diphasique, par la mesure simultanée des composantes active et réactive de l'impédance.

Pour bien comprendre la variation de ces éléments en fonction de la configuration de l'écoulement (écoulement par bulles, par bouchons, annulaire, etc.), nous avons développé un programme de calcul qui permet la simulation de leurs comportements. Ainsi la génération des configurations d'écoulement connues, nous permettra d'établir une technique objective pour l'identification des configurations des écoulements.

Dans cette étape préliminaire, nous présentons les résultats obtenus pour des écoulements par bulles, par bouchons, agités et annulaires, ainsi que leurs transitions.

Ces résultats montrent que les distributions du champ et du potentiel électrique sont fortement affectées par la configuration de l'écoulement. Pour différentes fréquences d'excitation utilisées, ceci ce traduit par des composantes actives et réactives dépendantes du type de configurations.

Comme continuation de ce travail, on envisage la caractérisation des écoulements diphasiques, par la méthode de la fonction densité de probabilité ("PDF"), conjointement avec une machine neuronale.

1 Institut de génie nucléaire, Département de génie physique, École Polytechnique de Montréal

This paper presents a preliminary study on the distribution of the potential and electrical field in a void fraction measurement system based on the impedance method.

Most of the techniques used to measure the void fraction based on the electrical behavior of the medium, have been until now developed by determining independently the real or the imaginary part of the impedance.

This work proposes to characterize two-phase flow patterns by simultaneously determining both the active and reactive components of the electrical impedance.

In order to better understand the variation of these components, according to the configuration of two-phase flows (bubbly, slug, annular, etc.), we have developed a program that is able to calculate and simulate the changes in impedance for different two-phase flow topologies. This technique allows the generation of predetermined two-phase flow patterns, to be carried out.

Thus, it should be possible to establish an objective technique for the correct identification of two-phase flow structures.

As a preliminary stage, we present herewith, the results obtained for the following flow configurations: bubbly, slug, churn and annular, as well as the corresponding transitions.

The present results show that the potential and electrical field distributions are strongly affected by the configuration of the flow. It can be also observed that depending on the excitation frequency used, both reactive and active components of the total electrical impedance depend strongly on the two-phase topology.

The continuation of this work will be oriented to developing an objective method to characterize two-phase flow patterns using the aforementioned results in conjunction with the Probability Density Function technique (PDF) and a neuronal machine.

The Nuclear Engineering Programmes at the Royal Military College of Canada

Part II

by Hugues W. Bonin

Following is the second part of Prof. Bonin's article. The first part was published in the May 2002 issue of the CNS Bulletin, Vol. 23, No. 2.

In order to conclude this article, let's look at some of the research projects on-going at RMC in nuclear science and engineering. The reader will notice than most of them involve more than one professor, and often teaming nuclear professors with colleagues specialized in other disciplines such as polymer engineering, metallurgical engineering, and chemistry. Some of these research projects involve researchers from the Defence Research Establishments, other federal and provincial agencies, and, of course, experts from the nuclear industry. Several thesis research topics are usually available to graduate students within each one of these projects. The list of projects is indicative of the nuclear research activity at present at RMC, and new topics are frequently added to the list.

In nuclear engineering, Dr. William S. Andrews, (the very first Ph.D. graduate at RMC) has the following research interests: the application of artificial intelligence and neural networks to nuclear systems (with Dr. Brent. J. Lewis), the modelling of the dispersion of aerosols in the atmosphere from transient point sources, which includes the dispersion of air-borne radioactive contaminants. He is also working on a contract to determine the extent of contamination by depleted uranium of Canadian peacekeeping troops.

Dr. Bennett's interests are mainly in neutron radiography and in radiation measurement and instrumentation. With several graduate students over the years, he designed the neutron radiography facility based on the SLOWPOKE-2 reactor, which constitutes a first for this type of facility. More recently, with LCdr Lloyd Cosby, he conceived and implemented a new computer-based control console for RMC's SLOWPOKE-2 reactor. He is also involved with Dr. Lewis in the radiation dose measurement program for high altitude aircrews.

Dr. Hugues W. Bonin is involved in several research projects. With Dr. Van Tam Bui, a colleague specialized in polymer engineering, he conducts research on many aspects of the interaction of radiation with advanced polymers. The main project to-date is the design of containers made of polymer-based composite materials for the long-term storage of radioactive materials, such as high-level radioactive waste (and spent nuclear fuel), and low- and intermediate-level radioactive waste. This research has concentrated in

Les Programmes De Génie Nucléaire Du Collège Militaire Royal Du Canada

II^me Partie

par Hugues W. Bonin

Ici nous présentons le deuxième partie de l'article par le professeur Bonin. Nous avons présenté le premier partie dans le numéro Vol. 23, No. 2 de la CNS Bulletin.

En guise de conclusion, examinons de plus près quelques-uns des projets de recherche en science et en génie nucléaires au CMR. Le lecteur notera que la plupart des projets impliquent plus d'un professeur, souvent mettant en équipe des professeurs en nucléaire avec certains de leurs collègues spécialisés dans d'autres domaines comme le génie des polymères, la métallurgie et la chimie. Certains des projets impliquent aussi des chercheurs des Centres de Recherche de la Défense, de certaines autres agences des gouvernements fédéral et provinciaux, et, bien sûr, des experts de l'industrie nucléaire. On peut d'ordinaire formuler plusieurs sujets de thèse à partir de chacun de ces projets de recherche. La liste des projets ci-dessous représente l'activité de recherche présentement en cours au CMR, et de nouveaux sujets s'y ajoutent fréquemment.

En génie nucléaire, M. William S. Andrews, le tout premier diplômé au doctorat du CMR, a les sujets de recherche suivants: l'application de l'intelligence artificielle et des réseaux neuronaux aux systèmes nucléaires (avec M. Brent J. Lewis), et la modélisation de la dispersion des aérosols dans l'atmosphère à partir de sources ponctuelles transitoires, ce qui inclut la dispersion de la contamination radioactive. Il est de plus impliqué dans un contrat pour déterminer l'étendue de la contamination par l'uranium appauvri des troupes canadiennes lors de missions de maintien de la paix.

Les intérêts de M. Les Bennett résident surtout dans la radiographie neutronique et en instrumentation et mesure des rayonnements. Avec l'aide de plusieurs étudiants au cours des dernières années, il a conçu et mis au point une installation de radiographie neutronique basée sur le réacteur nucléaire SLOWPOKE-2, ce qui constitue une première pour ce type de réacteur. Plus récemment, avec l'aide du capitaine de corvette Lloyd Cosby, il a conçu une nouvelle console de contrôle pour le réacteur SLOWPOKE-2 du CMR, qui est maintenant en service. Il collabore aussi avec M. Brent J. Lewis au projet de détermination des doses de radiation reçues par les équipages des avions de ligne volant à haute altitude.

M. Hugues W, Bonin mène activement plusieurs projets de recherche. Avec M. Van Tam Bui, un collègue spécialiste en génie des polymères, il poursuit une recherche sur plusieurs aspects des interactions des rayonnements avec a first part on the resistance to radiations, with the irradiation in the pool of the SLOWPOKE-2 reactor of various types of samples, which identified the most promising candidates for this application: composites made of graphite fibres and epoxies or polyetheretherketone (PEEK). Since these materials must withstand an aggressive radioactive, chemical and thermal environment for centuries, much research remains to confirm the applicability of these promising advanced materials. Another venue is the radiation processing of polymers. An on-going project consists of destroying spent plastic explosives by using radiation. Already a Master's degree thesis and three undergraduate design projects have proven the feasibility of the concept, enhancing the modest radiation doses sufficient to neutralize the nitrocellulose on which the plastic explosives are based.

Dr. Bonin is also actively involved in nuclear fuel management research, having investigated with the help of LCdr Chris Tingle the optimization problem of the fuel management of a 600-MWe CANDU reactor fuelled with advanced fuel cycle fuel bundles, at the approach to refuelling equilibrium. The computer code developed in this research, called CATER, is also suitable for the refuelling equilibrium period, and also for the transition case of an existing CANDU reactor in which the present 37-rod fuel bundles are gradually replaced with advanced fuel bundles like the CANFLEX™.

Another project, just beginning, is the design of a small inherently safe nuclear reactor intended for the supply of electrical energy on-board the new Canadian Victoria-class submarines. This is the Ph.D. thesis topic of Lt(N) Chris Cole, but the research can be extended to make some aspects into thesis topics of future graduate students. Yet another on-going project is the investigation of the economical and environmental implications of the various parts of the fuel cycles for the CANDU reactor. This project is the Master's degree thesis topic of Capt. Charlene Fawcett and is co-supervised by Dr. Kathy Creber, Professor of Chemistry at RMC. Finally, some recent research projects can be pushed further, such as the computer simulation of the SLOWPOKE-2 reactor with the code MCNP 4A (or successor), which was the thesis project for Lt(N) Martin Pierre. There is also the project aimed at determining accurately the radiation doses at various points in the SLOWPOKE-2 reactor and pool, which was the Master's degree project of Lt(N) Greg Lamarre.

Dr. Brent J. Lewis is also very active in nuclear research, his main interest being the study of the behaviour of fission products and the determination of radiation doses to high altitude aircrews. In the former field, Dr. Lewis collaborates with several Canadian and foreign scientists in experimentation and modelling of nuclear fuel behaviour during normal reactor operation and accident conditions. Of particular emphasis is the computer modelling of the source term and the release mechanisms of the fission products from defective fuel elements. This research, with the collaboration with Dr. William T. Thompson, a metallurgy

les polymères. Le principal projet consiste en le désign de containers faits de matériaux composites à base de polymères pour l'entreposage à long terme de matières radioactives telles que les déchets nucléaires à haute activité et le combustible nucléaire usé, et les déchets radioactifs de faible et moyenne activité. Dans un premier temps, cette recherche s'est concentrée sur la résistance aux rayonnements de plusieurs types d'échantillons de polymères irradiés dans la piscine du réacteur SLOWPOKE-2 du CMR. Ces études ont permis d'identifier les matériaux les plus prometteurs, comme les époxies et le polyétheréthercétone (PEEK). Puisque ces matériaux doivent résister à l'agressivité d'environnements radioactifs chimiques et thermiques durant plusieurs siècles, il reste encore beaucoup de recherches à mener pour confirmer que ces matériaux avancés peuvent bel et bien être appliqués à la construction de ces containers. Une autre facette de cette recherche est le traitement de polymères par radiation. Un projet présentement en cours consiste à détruire par irradiation des explosifs plastiques épuisés. Déjà, une thèse de maîtrise et trois projets de fin d'études au niveau du baccalauréat ont démontré que cette approche est très faisable, révélant même que les doses requises pour cette application demeurent très modestes.

M. Bonin est aussi activement impliqué en recherche en gestion du combustible nucléaire, ayant étudié avec l'aide du capc Chris Tingle le problème de l'optimisation de la gestion du combustible d'un réacteur CANDU-600 alimenté avec des combustibles avancés durant la période de l'approche à l'équilibre de rechargement. Le logiciel développé au cours de cette recherche, appelé CATER, peut aussi servir à l'optimisation de la gestion du combustible à l'équilibre de rechargement, et même pour la période de transition d'un réacteur CANDU actuel pour lequel les grappes de 37 crayons seraient graduellement remplacées par des grappes de combustible avancées comme, par exemple, les grappes CANFLEX™.

Un autre projet récemment démarré est celui de la conception d'un petit réacteur nucléaire à sûreté inhérente conçu pour fournir de l'électricité à bord des sous-marins canadiens de la classe Victoria. Ceci est le projet de recherche de doctorat du ltv Chris Cole, mais cette recherche peut très bien être étendue de façon à concevoir des sujets de thèse sur certains aspects pour de futurs étudiants de maîtrise et de doctorat. Un autre projet de recherche en cours est l'étude des implications économiques et environnementales des diverses composantes des cycles de combustible des réacteurs CANDU. Ce projet est le sujet de thèse de maîtrise du Capt. Charlene Fawcett qui est co-dirigée par Mme Kathy Creber, Professeure de chimie au CMR. Enfin, d'autres projets de recherche effectués récemment peuvent être poursuivis, comme celui de la simulation sur ordinateur du réacteur SLOWPOKE-2 avec le code MCNP 4A, qui a servi de projet de maîtrise au ltv Martin Pierre, et le projet de la détermination des doses de radiation à différents points du réacteur SLOWPOKE-2 et de sa piscine, qui était le sujet de expert member of the Department's teaching staff, uses the FACT computer system to predict the chemical forms taken by these fission products thus permitting more accurate prediction of their behaviour. The research is also extended to the application of artificial intelligence in this domain, with the collaboration of Dr. Bill Andrews.

With the help of Dr. Les Bennett and a team of research assistants and students, Dr. Lewis is intensely involved in a major project aimed at the accurate measurement of the dose rates received by the crews aboard high altitude airplanes from direct and indirect effects of cosmic radiation. This project has become an international collaboration among experts, from institutions such as NASA, Transport Canada, the Canadian Space Agency, the Canadian Forces and various commercial airlines. The RMC group was successful in designing a computer software, PC-AIRE, able to accurately predicting radiation doses to air crews from input data such as the times and locations of flight departure and arrival, altitude flight patterns, time of the year and time within the solar cycle. Dose measurement capabilities have recently been expanded with the acquisition of an expensive Tissue Equivalent Proportional Counter (TPEC) which is often taken on-board commercial flights for gathering experimental data. The computer simulation aspect is also part of this research, with LT(N) Martin Pierre working on this Ph.D. thesis consisting in using Monte-Carlo techniques to simulate and characterize radiation fields and dosimetric implications of the radiation doses received by the air crews.

thèse du ltv Greg Lamarre.

M. Brent J. Lewis est aussi très occupé en recherche nucléaire, ses principaux domaines d'intérêt étant l'étude du comportement des produits de fission et la détermination des doses de rayonnement reçues par les équipages des avions de ligne en haute altitude. Dans le premier domaine de recherche, M. Lewis collabore avec plusieurs scientifiques canadiens et étrangers pour l'expérimentation et la modélisation informatique du comportement du combustible de réacteurs nucléaires en exploitation normale et dans des conditions d'accidents. Plus particulièrement, on essaie de réaliser des modèles informatiques du terme de source et des mécanismes de relâchement des produits de fission d'éléments de combustible défectueux. Cette recherche se fait en collaboration avec M. William T. Thompson, un ingénieur métallurgiste du Département qui utilise le logiciel FACT pour prédire les formes chimiques prises par ces produits de fission, ce qui permet une modélisation plus exacte du comportement de ceux-ci. La recherche implique aussi l'utilisation de l'intelligence artificielle avec la collaboration de M. William Andrews.

Avec le concours de M. Les Bennett et d'une équipe de chercheurs et d'étudiants, M.Lewis est impliqué intensément dans un projet majeur visant à déterminer avec précision les taux de dose de radiation reçues par les équipages des avions de ligne volant à haute altitude, dues aux effets directs et indirects des rayons cosmiques. Ce projet est devenu une collaboration internationale entre experts, incluant des institutions telles que la NASA, Transport Canada, l'Agence canadienne de l'espace, les Forces canadiennes et diverses compagnies aériennes. Le groupe du CMR a réussi à concevoir un logiciel appelé PC-AIRE capable de prédire avec fiablilité les doses de rayonnement reçues par les équipages des avions à partir de données telles que les temps et lieux de départ et d'arrivée des vols, les plans de vol et les altitudes atteintes, le moment de l'année du vol, ainsi que le temps du cycle solaire. On a augmenté les capacités de mesure des doses récemment avec l'acquisition d'un compteur proportionnel équivalent au tissu vivant qui est souvent amené à bord d'avions de lignes pour prendre des mesures expérimentales. L'aspect modélisation sur ordinateur fait aussi partie de ce projet, constituant le sujet de thèse de doctorat du ltv Martin

Campus of the Royal Military College of Canada, Kingston, Ontario.
Campus du College militaire royal du Canada de Kingston, Ontario.

Dr. Sadok Guellouz joined the Department of Mechanical Engineering at RMC in the Summer of 2001, after being a member of AECL`s team for more than two years. His research interests cover the broad area of thermalhydraulics with applications to nuclear engineering. His main endeavours are centred on experimental research in fluid turbulence, with applications to channel flow, heat transfer in the subchannels of CANDU fuel bundles, and the development of new and improved measurement techniques.

The nuclear team at RMC is completed by the analytical group which is the main user of the SLOWPOKE-2 nuclear reactor, and made of Dr. Ronald G.V. Hancock and Mrs Kathy Nielsen, SLOWPOKE-2 Facility Director. Besides the many contracts for neutron activation analysis, these persons carry out research in nuclear analytical chemistry in many domains of interest such as: ancient pottery studies, metallic artifacts from Antiquity, investigation of dietary information of ancient tribes from the determination of trace elements in bones, environmental monitoring, archaeological site chronology from the content of glass beads, geophagy, soil and sediment formation, and lithics.

This coverage of the activities within the nuclear science and engineering programmes at RMC reveals the dynamism of the College which is still growing at a fast rate. Being the only completely bilingual university in Canada and a true national institution gathering students and staff from all parts of our country, RMC continues in its mission to support the Canadian Forces, the Department of National Defence, the people of Canada and Canadian industry that includes the nuclear sector. It is in this spirit that the staff has been actively involved with organizations such as the Canadian Nuclear Society and the Canadian Nuclear Association, having hosted four of the Student conferences and three major topical conferences of the CNS. The future can hardly be brighter now that civilian students may be admitted for graduate studies. As you just saw, the research subjects are not missing for good students! For more information, I can be reached on the internet site of RMC at www.rmc.ca or by phone at 613-541-6000 ext. 6613.

Pierre qui se sert de méthodes de Monte-Carlo pour simuler et caractériser les champs de radiation et les implications en dosimétrie des rayonnements auxquels sont sujets les membres d"équipage des avions de ligne.

M. Sadok Guellouz s'est joint au personnel enseignant du Département de génie mécanique du CMR à l'été de 2001, après avoir fait partie de l'équipe de l'ÉACL pour plus de deux ans. Ses intérêts de recherche couvrent les vastes domaines de la thermohydraulique avec applications au génie nucléaire. Ses sujets d'intérêt particuliers incluent la recherche expérimentale sur la turbulence des fluides avec applications à l'écoulement dans des canalisations, le transfert de chaleur dans les sous-canaux des grappes de combustible CANDU, et le développement de techniques de mesure nouvelles et améliorées.

L'équipe nucléaire du CMR se complète par le groupe analytique qui est le principal utilisateur du réacteur SLOWPOKE-2, et qui est constitué de M. Ronald G.V. Hancock et de Mme Kathy Nielsen, Directrice du Laboratoire SLOWPOKE-2. Outre les nombreux contrats d'analyse par activation neutronique, on effectue de la recherche en chimie analytique couvrant de nombreux domaines d'intérêt: étude de poteries anciennes, études d'artifacts métalliques datant de l'Antiquité, détermination des coutumes alimentaines de peuplades anciennes à partir deséléments concentrés à l'état de traces dans les os, surveillance de l'environnement, chronologie de sites archéologiques à partir de la composition de billes de verre, géophagie, formation des sols et des sédiments, et études d'outils préhistoriques.

Ce survol des activités au sein des programmes de science et de génie nucléaires est révélateur du dynamisme de l'institution qui continue de croître à un rythme rapide. En tant que seule université entièrement bilingue du Canada et institution vraiment nationale rassemblant des étudiants et du personnel des quatre coins de notre pays, le CMR continue dans sa mission de soutien des Forces canadiennes, du Ministère de la défense nationale, du peuple canadien et de l'industrie canadienne qui comprend le secteur du nucléaire. C'est dans cet esprit que le personnel enseignant a été très impliqué dans des organisations telles que la Société Nucléaire Canadienne et l'Association Nucléaire Canadienne, ayant servi d'hôte à quatre conférences étudiantes et à trois conférences thématiques majeures de la Société Nucléaire Canadienne. L'avenir peut difficilement être plus brillant maintenant qu'il est possible accueillir des étudiants et étudiantes civils aux programmes de cycles supérieurs. Comme le lecteur vient de le constater, ce ne sont pas les bons sujets de recherche qui manquent pour de bons étudiants! Pour de plus amples renseignements, on pourra communiquer avec l'auteur via le site internet du CMR à l'adresse www.rmc.ca ou au téléphone au 613-541-6000 poste 6613.

Early Development of Full Scale Nuclear Power in Ontario

by W. G. Morison

Ed. Note: Following is the full paper which Bill Morison summarized in the "history" session at the 23rd CNS Annual Conference held in Toronto June 4, 2002. Although this paper is much longer than typical ones published in the CNS Bulletin we felt that it is a significant contribution to the history of the Canadian nuclear program. It has been edited slightly, primarily in the deletion of some figures.

In this personal, but well researched, paper Bill provides an insight into the many aspects of the early and rapidly expanding nuclear power program of Ontario Hydro. He was very much involved, initially as the safety analysis for the Douglas Point project, and subsequently in increasingly senior positions with Ontario Hydro where he became vice-president. Semi-retired, he now has his own consulting company, Morwil Inc.

Bill Morison

Introduction

A review of the electric power system in Ontario in the early 1950's indicated that nearly all available hydraulic resources would be developed within the decade; and that thermal stations would also soon be required to meet the rapidly rising demand (7% per year), for electric power in the province. In fact, two multi-unit coal fired stations, (J. C. Keith GS in Windsor and R.L. Hearn GS in Toronto), using coal imported from the United States, were subsequently brought into service in the mid-nineteen-fifties; and the first units of the Lakeview G.S. were approved for construction in 1957.

Initial Consideration of Heavy Water Moderated Power Reactors

In parallel with the planning and construction of these conventional power facilities in the early 1950's, there was considerable interest within Ontario Hydro about the possibility of nuclear power.

This was based on nuclear studies/activities in the United States and Britain; and in particular on reports issued by Dr. W. B. Lewis of AECL Chalk River about the potential for heavy water moderated-natural uranium fuelled concepts. Discussions between representatives of Ontario Hydro, (Dr. P. Dobson of the Research Division, and Harold Smith of Engineering), and representatives of other Canadian power utilities; and J. L. Gray and Dr. Lewis and others at Chalk River in the period 1951-3; led to a favourable impression within Ontario Hydro of the potential of the heavy water moderated reactor concept. It was decided to pursue study of this concept for possible future application in Ontario, rather than pursuing the ordinary water concepts (PWR and BWR), being developed in the United States, or the graphite moderated reactor concept being pursued in Britain.

First Nuclear Power Study at Chalk River

In early 1954 a study group (see Appendix A) was set up at Chalk River to study the design of nuclear power facilities for the production of electricity by a nuclear plant in which the reactor uses heavy water to moderate the neutrons produced in fission of natural uranium. The group was to:

- Establish the general basis for detailed design of this 20MWe "Demonstration" nuclear plant.
- Establish the physical and operational characteristics of the plant.
- Provide a capital cost estimate (exclusive of property and development costs).
- Complete the study by April 1955.

The group completed their studies and documented their results (NPG-5), by April 1955; and the following arrangements were made to proceed with detailed design, manufacture and construction:

- The Canadian General Electric Company (CGE) was to be responsible for the detailed design and manufacture of the reactor and of the nuclear portion of the plant.
- AECL was to undertake any development work required, apart from that

undertaken by CGE.

- Ontario Hydro would provide the site near the recently completed Des Joachims hydraulic station on the Ottawa River, and undertake the design of the "balance of plant", "co-operate" in the construction and operate the station when it was completed.

Some of the study group listed in Appendix A, moved to CGE in Peterborough to assist in the design of the nuclear plant.

The proposed reactor concept consisted of a vertical cylindrical pressure vessel with vertical zircaloy fuel channels with access through the upper head of the vessel for refuelling. The fuel channels were surrounded by concentric aluminium tube s, and the space between the tubes were to be filled with helium to separate the hot heavy water coolant from the separately cooled heavy water moderator.

Development and design work proceeded immediately on all aspects of this demonstration plant, including placement of orders for long lead time items, (e.g.: reactor vessel and turbine generator).

Second Nuclear Power Study at Chalk River

It was realized, at that time, however, that if nuclear power was to meet at least a portion of the growing electricity demand in Ontario in the following decade(s), that a much larger nuclear power plant would be needed as soon as possible. In September 1955, the Nuclear Power Branch at Chalk River (see Appendix B) began a study to be completed by early 1957, of a larger heavy water moderated nuclear unit. This unit was to have an output comparable to the largest conventional thermal power unit existing, or being installed at that time, in the Ontario Hydro system. The R. L. Hearn GS in Toronto was being extended at that time by the addition of 4 - 200MWe units to be in service by 1957. This study of a 200MWe "full-scale" heavy water moderated nuclear unit was intended to provide:

- A conceptual nuclear plant design.
- Development needs and times for systems and component supply.
- Manufacturing and construction information.
- Safety and reliability assessments.
- Estimated capital and operating costs for comparison of base load nuclear electricity costs with power cost from the 200MWe coal fired units being built at the Hearn GS in Toronto.

The study, involving 11 man years of engineering activities, was completed and documented in a report (NPG-10) dated May 1957. The most "novel" aspect of this study was the proposed reactor concept and orientation. The reactor proposed, consisted of between two and three hundred horizontal zircaloy pressure tubes, about 16 feet long, spaced on a square lattice of about 12 inches, to contain the fuel and hot heavy water coolant, with access for fuelling and coolant at each end of each pressure tube. The cool heavy water moderator was to be contained in a large horizontal cylindrical vessel (subsequently called the calandria), surrounding the pressure tubes. The hot pressure tubes were to be separated from the separately cooled moderator by concentric thin walled tubes extending the full length of the calandria.. The reasons for this horizontal pressure tube concept, as opposed to a vertical pressure vessel, were based on a number of perceived advantages including:

- Ease of access to fuel channels.
- Support of the reactor channels and vessel.
- Access for pressure tube replacement.
- Capability to make the reactor concept as large as required for greater energy output within Canadian manufacturing/construction capability.
- Favourable experience at Chalk River with fuel-in-tube access and cooling arrangements.

This was the origin of the now familiar CANDU reactor concept.

It was concluded that even with neutron absorption by the zircaloy pressure tubes and surrounding calandria tubes, fuelling with natural uranium oxide fuel would be feasible and economic with heavy water moderation; and that there was no apparent reason why the plant described could not be developed to be as safe and reliable as a conventional thermal power plant. However, considerable study and development work would be required on a variety of items (e.g.: fuel channels and closures, fuelling machines, and heavy water containment), before the start of final design and construction of this plant; and in view of the conceptual nature of the reactor design and the ten fold increase in output compared to the 20MWe demonstration plant.

Impact on the Nuclear Power Demonstration Plant Design

In early 1957, it was realized by the Canadian General Electric (CGE) design team in Peterborough that the pressure vessel concept they were working on for the 20MWe Nuclear Demonstration Plant would not be a suitable demonstration for the proposed 200MWe pressure tube concept and for projected future full-scale horizontal pressure tube nuclear plants. In April 1957, the horizontal pressure tube concept was examined by the CGE design team to determine if the 20MWe pressure vessel reactor demonstration plant (NPD), then under design and manufacture, could be converted to this pressure tube reactor concept. This change was accepted by August 1957, renamed NPD-2, and rescheduled to start-up in 1961.

The design features, lifetime performance and the important contributions of NPD-2 to the Canadian nuclear program is described in an accompanying paper by Lorne McConnell et al, at this annual CNS Conference in 2002.

The Purpose and Scope of This Paper

This paper is intended cover the early development of full-sale nuclear power in Ontario from the *Second Nuclear Power Study* at Chalk River in 1955 -57, described above, to the in-service of the first phase of the Pickering NGS in 1971, a period of about 15 years. However, a brief mention is made above of related situations and events which set the stage for this period, such as: the rapidly growing demand for electricity in Ontario in the 1950's, the depletion of indigenous hydraulic resources to produce electric power, the growing dependency on imported coal fired generating stations, and a keen interest in the possibility of nuclear energy to produce electric power. A brief mention is also made later of events and decisions after 1971 to put in context some of the decisions and directions taken during this early 15 year period of development of full-scale nuclear power in Ontario.

Establishment of the Nuclear Power Plant Division of AECL in Toronto

Following discussion and exchange of correspondence between AECL and Ontario Hydro in 1957 it was decided to establish an AECL Nuclear Power Plant Division in Toronto in early 1958, to undertake the needed development and begin the detailed design studies of the proposed 200 MWe nuclear power plant. The management of this new division was to be provided by H. A. Smith , Assistant General Manager Engineering of Ontario Hydro, and J. S. Foster of AECL as on site Deputy Manager, who directly managed this new AECL Division (Fig 1.).

The location selected for the development laboratory and design office was in the west yard of the Ontario Hydro's A. W. Mamby Service Centre, Etobicoke, in existing "warehouse type" buildings. In addition to providing the accommodation for this new AECL Nuclear Power Plant Division, Ontario Hydro assigned engineers to take part in the development work and to participate in the design studies of this 200 MWe concept.

Figure 1: John Foster (seated) and Harold Smith at new offices of NPPD, 1958.

Agreement to Proceed with Design and Construction of 200 MWe Nuclear Plant

By mid 1959 considerable progress in development and design studies had been completed and the Federal Government authorized AECL to proceed with the final design and construction of a nuclear power station to produce 200 MWe, scheduled for operation in early 1965. By agreement, Ontario Hydro was to:

- Provide the site (subsequently selected at Douglas Point on Lake Huron)..
- Provide interconnections to the Ontario power grid.
- Assign 12 to 15 engineers to take part in the continuing development and design work.
- Undertake the construction.
- Operate the station when it was completed.

Figure 2

- And buy the electrical energy produced and delivered to the power system on the same basis as it buys power from other interconnected utilities.

AECL was to pay Ontario Hydro for its services at cost. However, a certain portion of the engineering, construction, and operating costs were paid for by Ontario Hydro, representing the value of the training and experience gained. The design of the Douglas Point Station was optimized on the basis of economic data applying within Ontario Hydro at the time.

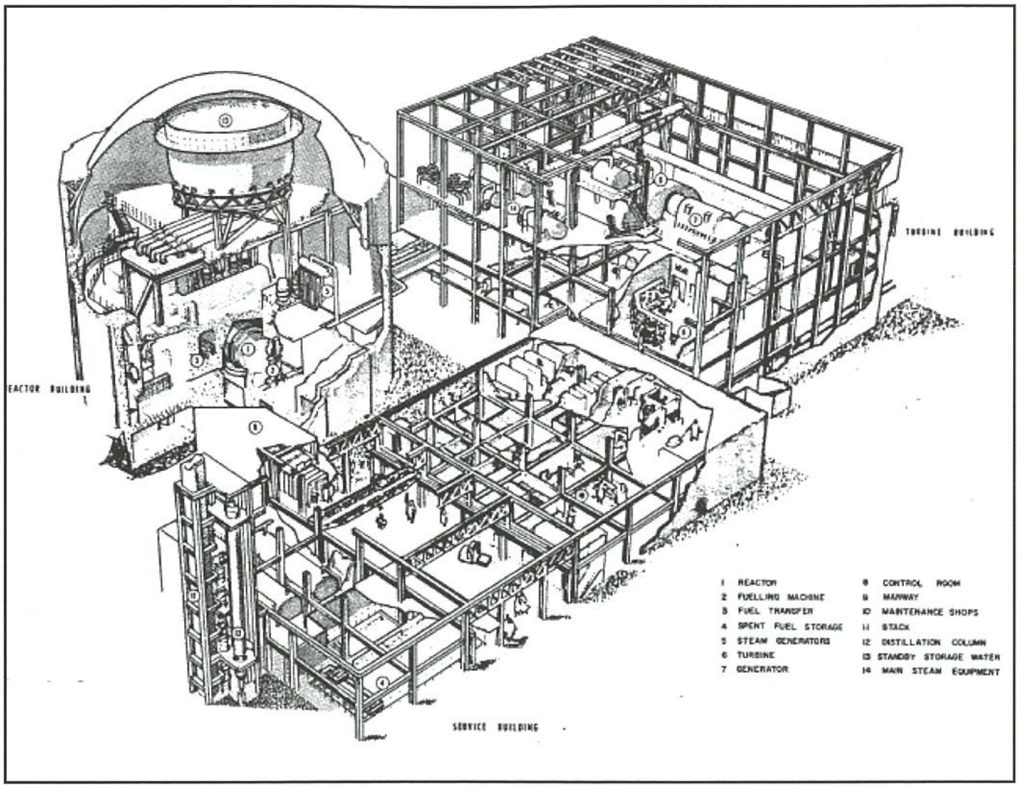


Figure 3

Project Management of Douglas Point

The Nuclear Power Plant Division of AECL (NPPD) provided overall management of the project, the design of the nuclear portion of the plant and related development work, and a small resident engineering staff at the site. An early photograph of most of the AECL and assigned Ontario Hydro personnel at NPPD, who provided the overall management of the project and lead the development and nuclear design work on Douglas Point (and Pickering A), is shown in Fig 2.

General Description of Douglas Point

The general layout of the plant and equipment is shown in Figure 3, which is a cut-away perspective of the Reactor, Turbine and Service buildings. One of the design requirements was that the need to enter the reactor building should be kept to a minimum. As much of the machinery and equipment as possible was located in the Service building.

The Douglas Point reactor vessel/calandria, made of stainless steel, was 19.6 ft in diameter and 16.4 ft long and contained the heavy water moderator and reflector, Figure 6. There were 306 Zircaloy -2 fuel channels, 3.25 inches inside diameter on a 9 inch square pitch, which were located and free to move axially within the 4.24 inch diameter calandria tubes made of nickel free Zircaloy. The overall length of the coolant assemblies, including the end fittings was 30.2 ft, which accommodated bi-directional fuelling by remotely operated fuelling machines through the end fittings; and feeder connections for the flow of high pressure heavy water coolant in and out of each channel. Note that each end shield and the calandria were separately supported by hanger rods from above.

Douglas Point Fuel

The Douglas Point fuel bundles consisted of 19 elements, 0.6 inch OD, and 19.5 inches long, containing pressed and sintered natural uranium-dioxide pellets within the 0.015 inch thick Zircaloy-2 cladding. Fuelling was normally done by removing 2 used bundles per operation from one end of a channel and simultaneously replacing two new bundles in

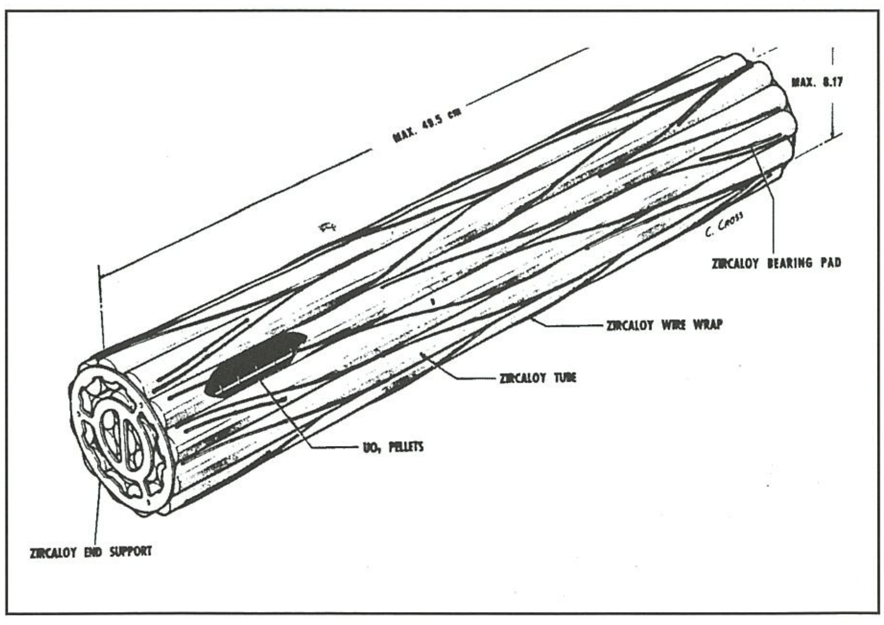


Figure 4: Douglas Point Fuel Bundle

the opposite end of the same channel. The average fuelling rate at full reactor power was about 5 bundles per day, with fuel burnup of about 9000 MWd/tonne U.

Douglas Point Heat Transport and Steam Cycles

Heavy water was used in both the reactor heat transport and moderator systems, each having its own circulating and heat removal system. In the heat transport system, the heavy water coolant raised in temperature from 480°F to 560°F in passing over the fuel in the reactor, and entered the 8 U-shaped tube in shell heat exchangers, raising ordinary water saturated steam at 565 psig, which was fed into the HP turbines. The moderator heavy water was drawn off the calandria at about mid -level, circulated through (lake water cooled) heat exchangers, and returned to the calandria near the bottom.

Initial Accident	Compounding Failure(s)	Activity Releases curies			Nominal Probability (per year)
		Iodine,	Volatiles,	Non-Volatiles	
Uncontrolled insertion of booster rods in operating reactor -	None	0	0.	0	10^{-2}
initial pressure boundary failure in core	Protection System	2×10^{3} (2)	4×10^{3} (4)	1×10^{4} (0.1)	10^{-5}
Loss of cooling	Control and Protection	2×10^{3} (2)	4×10^{3} (4)	1×10^{4} (0.1)	10^{-7}
As above, with initial pressure boundary	None	0	0	0	10^{-3}
failure outside of core	Protection System	1×10^{7}	7×10^{7}	2×10^{7}	10^{-6}
Uncontrolled fast pump-up - reactor initially at	None	0	0	0	10^{-5}
low power with equilibrium fuel	Protection System	4×10^{6} (6×10^{2})	2×10^{7} (4×10^{3})	5×10^{6} (30)	10^{-8}
As above with most reactive fuel	None	0	0	0	10^{-5}
	Protection System	6×10^{6} (5×10^{2})	4×10^{7} (3×10^{3})	8×10^{6} (20)	10^{-8}
Failure of reactor inlet header at full	None	0.3	10^{5} of H^{3}	2	10^{-4}
power, 265 in^2 opening	Emergency Cooling	2×10^{6} (2×10^{3})	5×10^{6} (5×10^{3})	6×10^{6} (60)	10^{-6}
	Protection System	6×10^{7} (6×10^{4})	1×10^{8} (1×10^{5})	5×10^{8} (5×10^{3})	10^{-7}
Failure of pump suction header at full power 60 in^2 opening	None	3×10^{4} (30)	8×10^{4} (80)	5×10^{5} (5)	10^{-4}
	Emergency Cooling	2×10^{6} (2×10^{3})	5×10^{6} (5×10^{3})	6×10^{6} (60).	10^{-6}
	Protection System	6×10^{7} (6×10^{4})	1×10^{8} (1×10^{5})	5×10^{8} (5×10^{3})	10^{-7}
Unrestricted opening of end of fuel channel, reactor at full power	None	6×10^{3}	2×10^{4}	2×10^{4}	10^{-4}

Table I

Calculated Radioactivity Releases and Likelihood of Occurrence of Accidents.

The Douglas Point steam cycle was a conventional saturated cycle with external moisture separator and live steam reheat; and six stages of feedwater preheat. The steam exhausted from the final stage of LP turbines was condensed in a single lake water cooled condenser which provided a vacuum of about 29 inches.

Reactor and Station Control

Douglas Point was the first nuclear power station to utilize digital computers for reactor and station control, although provision was made to control the reactor manually. In steady operation the reactor was programmed to provide thermal energy to provide the steam to meet the electrical demand of the operator/power system. In steady operation, control of the reactor reactivity was by day-today refuelling; the loss in reactivity due to fuel burnup being replaced by new fuel. During changes in power level of the reactor, additional controls provided include:

- changes in moderator level
- movement of neutron absorbing rods vertically in the moderator
- insertion or removal of enriched rods (boosters) vertically in the moderator
- addition or removal of neutron absorbing liquid in the moderator

Rapid reactor shutdowns were accomplished by quickly dumping the moderator heavy water into the dump tank. For less severe power changes a power set-back was provided which allowed decreases in reactor power of 1% per second down to 2% of full power.

Containment and Radiation Protection

The reactor and the associated systems and circuits are contained within the reinforced concrete reactor building, which is designed for internal pressures of 6 psig, to prevent the escape of radioactive fission products to the surrounding countryside after any credible accident. At the time Douglas Point was being designed there was no regulatory "Siting Guide"; so a series of assumed single and dual failures of systems and components were assessed as to the likelihood of occurrence and the consequential activity releases to the containment building and from the building as shown in Table 1.

These releases from the building were then assessed to determine the risk to the surrounding population based on a range of weather conditions. The reactor systems and building were designed to provide containment to limit the risk of fatality to the most exposed member of the surrounding public to one in a million years. This corresponds to the normal risk to life of about one in a thousand years for the urban population in Ontario.

To achieve these low risks, very considerable effort was made during the design to provide highly reliable nuclear systems and components; to provide mitigating capability in the event of failure of systems and components; and to provide effective containment in the event of any single or dual failure accident. During the design and development process, extensive tests were done to determine the reliability of components and controls, and on systems, such as the dousing system in the reactor building, to provide actual performance information. For example, the dousing system was designed and tested to ensure that the pressure in the reactor building would not exceed the building design pressure after the maximum possible escape of high pressure coolant from the largest conceivable failure of the heat transport system. The 400,000 imperial gallon dousing system in the top of the reactor building was designed to automatically provide, in the event of need, a cold water spray to condense the steam from the accident, and to provide a head tank to ensure continuous cooling of essential nuclear related systems during pump outages.

Summary of Douglas Point Accident Analysis Results

Table 1 shows the assumed accident(s), the estimated radioactivity releases to the Reactor Building; and in brackets below, the estimated release from the building, and the nominal probability of the accidents. This approach to accident analysis was subsequently adopted by the AECB in their Siting Guide", first issued for licensing of Pickering A.

Initial Operation of Douglas Point

The projection made in 1959 of the first operation of Douglas Point in early in 1965, was made three years before the 20MWe NPD came into operation; and involved design, development and construction of a prototype commercial-size (200MWe) nuclear facility; which was to provide electricity, and design and performance information, that could be confidently used as the basis for future decisions on even larger nuclear power facilities. Development and engineering took longer than anticipated, a few of the suppliers were behind in their deliveries, and some difficulties were experienced with equipment during commissioning. Fuel loading into the Douglas Point reactor was completed in November of 1966, and the station first went critical on November 15, 1966. Within two months, the plant reached half load. However, the station encountered difficulties which kept it out of service for nine months in 1967. Two months of this lost time was due to a hole in a calandria tube, and leakage of moderator into the reactor vault, caused by lateral vibration of the vertical tube surrounding a booster element. The remainder of the lost time in 1967 was due to damage in varying degrees, to all primary coolant pumps. Douglas Point went back into service on December 15, 1967.

It performed well at 75% full load for the winter months to provide electricity to the Ontario Power grid, and demonstrated very low leakage of heavy water from the primary system. Commissioning and testing of systems, were then resumed, including a substantial effort to get the on power fuelling system in service.

Overall Performance of the Douglas Point Station

The load factor of the Douglas Point station varied considerably from year to year with a life time load factor of about 50%. It was utilized for technological development on equipment and systems, such as valves and seals and for demonstration of full-scale chemical decontamination of the heat transport system which reduced radiation fields by a factor of six with no apparent adverse after effects. The Douglas Point station also served a unique dual-purpose, for a period, in providing electricity to the Ontario grid and at the same time providing steam to the Bruce Heavy Water Production Plant A. By the early 1980's, the Douglas Point pressure tubes were in need of replacement, due to the build up of zirconium hydride, if the plant was to continue operating. In May of 1984, AECL, the owners of Douglas Point, announced the closure of the station after 17 years of service, as the first large scale heavy water moderated and cooled nuclear power station. Throughout its life Douglas Point provided needed electricity for the Ontario grid and valuable performance information and lessons for future commercial nuclear plants designs.

Planning and Decisions on the First 500Mwe Nuclear Units

In 1962, the 20 Mwe Nuclear Power Demonstration went into service, and the design and construction of the 200Mwe Douglas Point Plant was proceeding on schedule for operation in 1965. Atomic Energy of Canada and Ontario Hydro had collaborated in the design, construction and operation of these two prototype plants, and late in 1962, the two organizations entered into preliminary discussions concerning a larger successor. These discussions culminated in an exchange of correspondence in the summer of 1963, which among other things provided for cooperation in the design of a heavy water moderated nuclear power plant consisting of 500MWe units, and required production of a fairly comprehensive preliminary design report and cost estimate.

Power Projects was instructed to carry out, in cooperation with the appropriate divisions of Ontario Hydro, the preliminary design for the initial two-unit phase of a 2000MWe station employing 500MWe units and to produce by July 1964, a report presenting a design and estimate for that phase. This study, lead by Power Projects, and involving the assigned Ontario Hydro personnel, and including the Ontario Hydro Engineering Division and the Operations Division, was completed and documented in July 1964, in report TDI-3, which comprised: a Project Outline, with estimated costs for the 2-500Mwe station; and three Appendices on the Plant Description, Preliminary Safety Evaluation and a Proposed Development Program.

Proposed General Arrangement of the Multi - 500MWe unit Plant

Two sites were initially considered for this nuclear plant: one was adjacent to the Douglas Point station on the eastern shore of Lake Huron; and the other on a 115 acre site owned by Ontario Hydro east of Toronto in the Township of Pickering called Fairport. Based on Power System preference and economic estimates, the Fairport site was favoured and was the basis of the report, although estimates were included for both locations.

The ultimate station at that time, consisted of four units, each comprised of a single reactor and single turbo-generator together with their auxiliaries and associated switchyard equipment. The reactors were to be housed in individual buildings in a line along the shore; the turbo-generators were arranged in a line down the turbine hall, which runs parallel to the shore; single-pass condensers were proposed with the condenser cooling water being discharged into a canal between the plant and the switchyard; the switchyard was located on the landward side of the plant, convenient for connection to the power grid; and the common services, station control and administration areas were located centrally.

Proposed 500MWe Nuclear Plant Systems

The proposed nuclear steam supply system was similar to that for Douglas Point but the two and a half fold increase in capacity made some changes necessary, and others desirable. The reactor was to be a horizontal pressure tube, natural uranium oxide fuelled, heavy water moderated and cooled type, designed for on-load fuelling from both ends of the stainless steel calandria, which was to have integral end shields. The nominal rating of the reactor was 1700 Megawatts (thermal).

The comparison of the main dimensions of this proposed 1700 Megawatt (thermal) reactor against the Douglas Point reactor is shown below:

At that time, it was considered prudent to maintain the fuel elements the same as those being designed and tested for Douglas Point, so the proposed fuel bundle had 28 elements identical to the 19 elements in the Douglas Point bundle; however, the power was increased a modest 5% in element thermal rating.

The proposed reactor control and shut down methods were similar to those being designed for Douglas Point, except that, shutoff rods as well as moderator dump were included to provide more rapid shutdown capability; and it was considered necessary to provide reactor zonal control because of the larger reactor core. For neutron power control purposes, the reactor was divided into 14 zones (two axial slices each divided into one central and six peripheral zones), controlled by a neutron absorbing fluid (ordinary water or boric acid) in chambers in nine vertical tubes through the core. Greater emphasis was proposed on the use of digital computers for both reactor and station control.

The reactor fuelling system was based on the Douglas Point concept of two fuelling machines, one located at each end of the reactor; working in conjunction with each other, to remove two (or three) spent fuel bundles from a "channel" at one end of the reactor and inject the same number of new fuel bundles at the other end of the same channel. The fuelling rate was estimated to be 8 bundles per day of 28 element bundles at full reactor power.

The proposed primary heat transport and moderator systems and materials were essentially the same as in Douglas Point, but with more attention to ease of maintenance and even fewer mechanical joints. The primary heat transport system was considered capable of generating steam at 579 psig.

Containment

Based on the accident analysis for Douglas Point, and with nuclear units capable of producing two and a half times the energy within each reactor building of about the same volume as Douglas Point, safety analysis and containment received particular attention for this proposed multi-unit station at Fairport, located just twenty miles east of downtown Toronto. At the outset of the preliminary safety study, it was anticipated that for this multi-unit station it may be desirable/necessary and economic to provide relief for each primary containment building (reactor buildings) into a secondary containment structure. Several proposals, such as a large gasholder were being studied.

	500 MWe	Douglas Point (200Mwe)
Core Length	594 cms	500 cms
Core Diameter	637 cms	450 cms
Calandria OD	7.85 m	6.05 m
No. of Coolant/Pressure Tubes	390	306
Coolant/Pressure Tube ID	10.4 cms (4.07 inch)	8.25 cms (3.25 inch)

One concept, which was described in an October 1964 supplement to the TDI-3 report on the Project Outline, involved a large reinforced concrete "vacuum building", connected to each reactor building by a reinforced concrete duct, but separated by large valves which would open automatically in the event of an accident in a reactor building . The proposal was that within seconds after any loss-of- coolant accident in a reactor building, the pressure in all buildings would automatically reduce to below atmospheric pressure, thereby limiting any release of radioactive products from the station.

While this novel containment was not fully developed at that time, enough work had been done to make this the proposed containment system in discussions with regulatory authorities in seeking site approval for this multi-500MWe unit station in the fall of 1964.

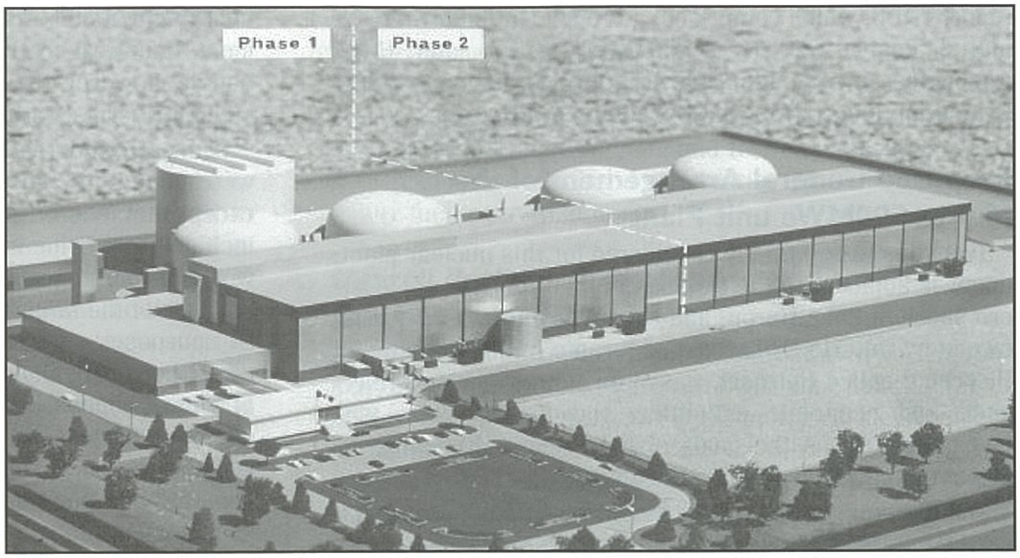


Figure 5

Agreement to Proceed with Design of the First 2-500Mwe Unit Station.

In September of 1964 a three-way agreement was reached between Ontario Hydro, the Government of Canada and the Government of Ontario, to proceed with the Design and Construction of the first two-500Mwe unit station. Ontario Hydro was to pay 40% of the capital cost of the 2 unit station (equivalent to the cost of a two-unit thermal station of the same output); the Government of Canada. was to pay 33% of the capital cost; and the Province of Ontario was to pay 27% of the capital cost.

The cost to the two governments, was to be recovered with interest from the revenue produced by the 2-500MWe station. The two-unit station was to be designed as a base load station for full power operation by the fall of 1971

Ontario Hydro would be the owner of the 2-500MWe Unit station; and would pay the full cost of units3 and 4 when, and if they were approved for design and construction. Ontario Hydro acquired additional land (up to 500 acres) at this site in the Township of Pickering, in anticipation of the construction of this multi-unit station.

Design Summary of the Pickering NGS

Shortly after approval to proceed with design and construction of the first two 500MWe units of this multi-unit station was received, the eventual station concept was increased to 8 -500MWe units; four units on each side of a central entrance, administration and service centre. A model of the first two-unit phase and the second two-unit phase, showing the entrance, Administration Building, Service Centre, four Reactor Buildings, and the Vacuum Building, are illustrated in Figure 5. The eventual station concept was to have four more like units to east of the of the Central Service area.

Figure 6 is an 1965 aerial view of Ontario Hydro's 500 acre site and vicinity in the Township of Pickering, with a superimposed plan view of the approved first phase of the multi-unit station, and a line (exclusion radius) 3000 feet from the centre of all reactor buildings of the projected eight unit station. Note the proximity of the community, and the different arrangement of water intake and discharge than in the pre-approved plan.

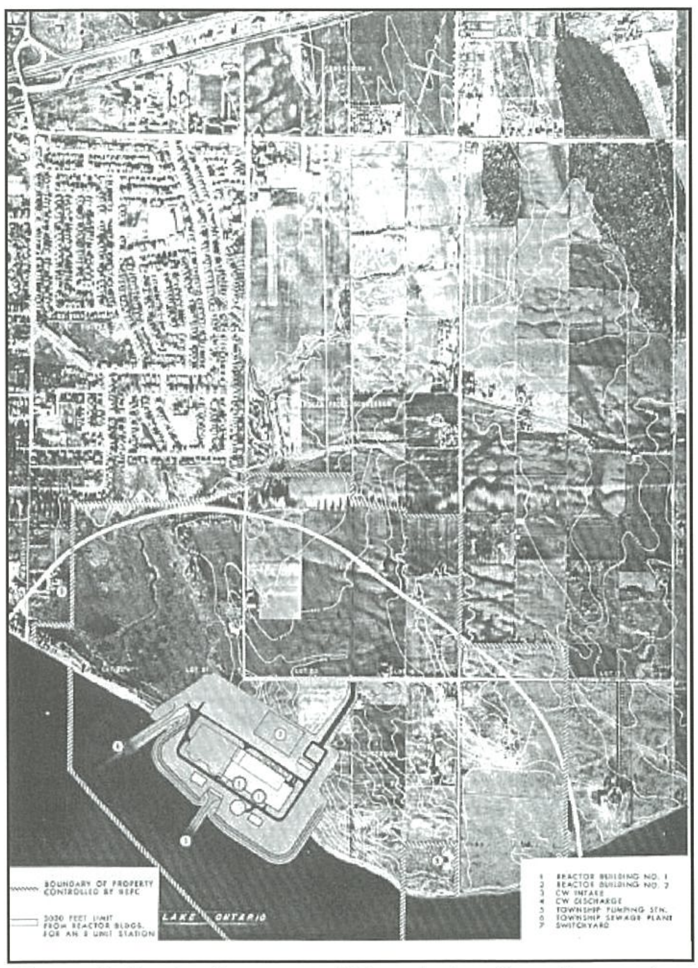


Figure 6: Station Layout and Boundaries Superimposed on Aerial View of Ontario Hydro's Property in Pickering Township.)

Figure 7 is a cut-away view from the lake side of the 2-500MWe unit, first phase, of the Pickering Nuclear Generating Station, which illustrates the station layout and containment system components, Reactor Buildings, Relief Duct and Vacuum Building. Each reactor, together with its associated boilers and closely related auxiliary equipment and systems is located in a 140 foot diameter reinforced concrete Reactor Building, designed for an internal pressure of 6 psig.

The stainless steel calandria has integral steel and ordinary water end shields, and internal circumferential shell shields. The 390 Zircaloy-2 coolant tubes, in which the fuel resides, are located inside calandria tubes, and are supported in sliding bearings at the end shields of the calandria. The calandria tubes are separated from the coolant tubes by "garter springs" in a sealed annulus containing carbon dioxide.

The heavy water, which fills the calandria serves as a moderator, reflector, and coolant for the internal circumferential shell shields. Below the calandria and connected to it by four moderator discharge ports is the cylindrical dump tank. The goose-neck shaped dump ports provide for a gas-liquid interface between the helium in the dump tank and moderator in the calandria. The primary coolant temperature is raised from 48°F to 56°F in passing through the reactor, and produces steam in 6 boilers fed from each end of the reactor, to produce saturated ordinary water steam at 585 psig, which is fed into the High Pressure (HP) turbine.

The containment system for the Pickering Station consists of the Reactor Buildings, the pressure relief duct, in which are located pressure activated relief valves, and the Vacuum Building. The arrangement of these structures is shown in Figure 8. This arrangement constitutes a negative pressure containment system, which is designed to contain all the energy which could be released inside a reactor building following any conceivable single or dual failure accident to the nuclear systems. The Vacuum Building, during normal operation of the Pickering Station, is maintained at a very low pressure (less than 1psia). The Reactor Buildings and relief duct are designed to withstand an internal pressure of 6 psig. In the event of a loss-of-coolant accident inside a Reactor Building, the pressure in that Reactor Building and the connecting duct would begin to rise. This increase in pressure actuates the pressure relief valves and within 15 seconds the pressure everywhere within containment would be reduced to below atmospheric pressure, preventing escape of any radioactive products. Water, contained in the top of the Vacuum Building is automatically forced over a weir in the top of the building by the rise in pressure in the Vacuum Building and sprays cold water within the building to condense the steam from the loss-of-coolant accident. Note that this is a passive containment system, all actions occur automatically in the event of a pressure rise in a reactor building.

Design Feed-Back from Douglas Point to Pickering Stations

The difficulties encountered at Douglas Point, although vexing at the time, provided invaluable experience for the designers of the first Pickering units. For example, the pump troubles led directly to changes in the pump seals, gland cooling system, motor bearings and a more thorough test program for the Pickering pumps. Many minor design or equipment inadequacies were detected in the Pickering design when difficulties arose in Douglas Point, and before construction of these systems/equipment began for the Pickering First Phase Units. The experience with heavy water containment and subsequent changes made at Douglas Point heavy water containment and recovery systems confirmed the precautions taken in the Pickering design to eliminate mechanical joints and to use bellows sealed valves where ever possible .

The First Phase Pickering units were a "second generation" of large heavy water moderated and

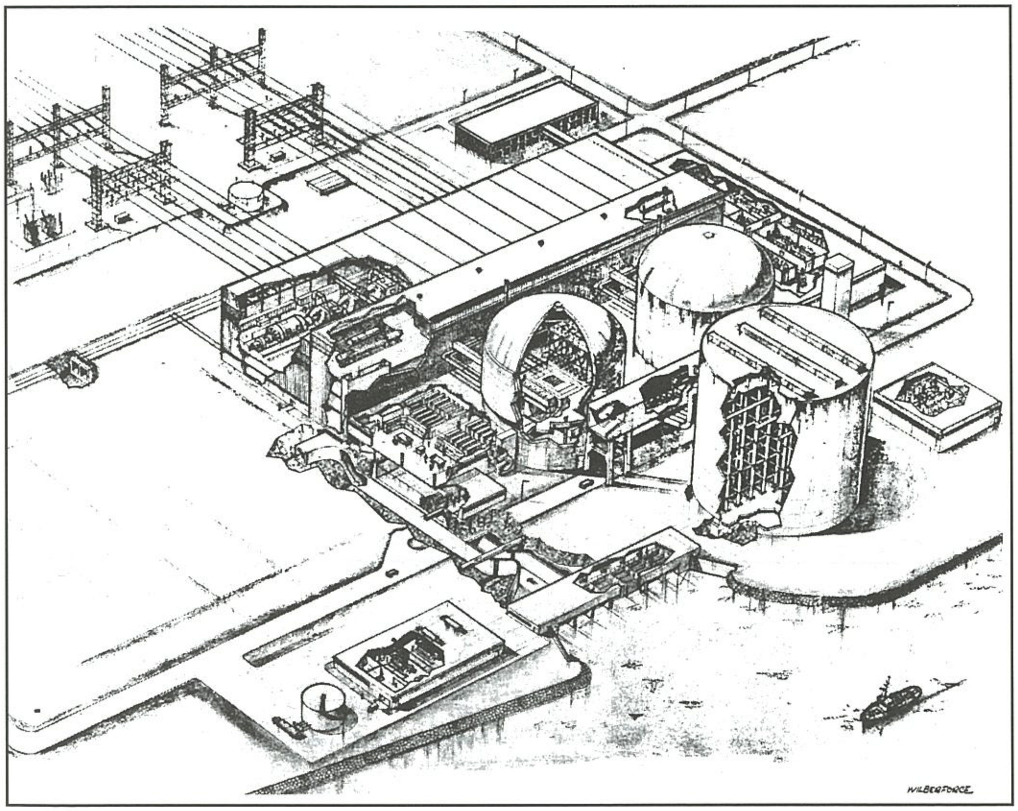


Figure 7: Cut-Away Perspective of the First Phase of the Pickering NGS.)

cooled nuclear units designed by the same group at Power Projects, and many improvements over the Douglas Point design were made to:

- Improve performance and maintainability.
- Reduce heavy water losses.
- Increase the station output.
- And reduce capital and operating cost.

The basic aim in the design of the Pickering Station was to produce a reliable and tolerant power station as free as possible of frills and operating restrictions. Very significant reductions were made in numbers of components such as valves and instruments, and in the simplification of the process systems.

Site and Station Approvals

The Pickering site was approved for a nuclear station by the Atomic Energy Control Board in November 1964.

In the summer of 1965, preparations of the site began and some preliminary construction of the first unit of the Pickering Station was started in the fall of 1965. The Atomic Energy Control Board granted a permit for construction of the first two units of the Pickering Station in February 1966. Delays in construction were experienced by a 10 month labour strike in 1967, and by slow delivery of some equipment such as the reactor end shields for Unit No 1. The combination of labour troubles and late equipment delivery set back the critical date for the first unit by about the length of the labour strike.

Ontario Hydro approved proceeding with the design, procurement and construction of Units 3 and 4 at Pickering in 1967, for in service in 1972 and 1973, providing a continuing supply of equipment from suppliers for four units, and extension of the Pickering site construction activities to four units.

In February 1967, Ontario Hydro also sponsored a study of the "third generation of large nuclear stations", with the aim of reducing power cost and further improving operating performance and flexibility. These studies were directed toward a power station of four 750MWe units , the largest units considered acceptable on the Ontario Hydro system in the mid to late 1970's. In April 1968, a project outline of the proposed 3000MWe station was issued from Power Projects; and in December of the same year Ontario Hydro committed the station (subject to approval of the Atomic Energy Control Board), for the design and construction of a four unit nuclear station of 750MWe units, to be built on the east shore of Lake Huron, adjacent to the 200MWe Douglas Point Station. This station, which became known as the Bruce A Nuclear Generating Station, was scheduled for in service in the period 1976 to 1979, to meet the projected load growth at that time. Site preparation for this Bruce Station began in 1969, two years before the first unit of Pickering A was brought up to power.

Heavy Water Supply

The rapid expansion of the Ontario nuclear power program based on heavy water for moderation and cooling, resulted in a substantial increase in the need for heavy water. Each 500 MWe Pickering unit required about 500 tons of heavy water for moderation and cooling, and the larger (750MWe) units approved for the Bruce site in 1968 required about 600 tons/unit of heavy water.

Two heavy water production plants, both with planned 400 tons/year capacity, were committed for construction in Nova Scotia in the mid 1960s. By 1968 they were still under construction and commissioning and had not produced any significant quantities of heavy water. The only other possible supplies of heavy water, at that time, were from the United States, and from existing inventories in Russia, Sweden and Norway, and these supplies were both limited and expensive. It was felt by AECL, that another heavy water production plant was needed in Canada to ensure adequate supplies of heavy water would be available for the expanding Canadian nuclear power program, and in particular for the committed nuclear power generation units in Ontario. In 1968 it was decided by AECL and agreed to by Ontario Hydro, that an 800 tons/year heavy water production plant be built adjacent to the Douglas Point NGS. The choice of this location allowed the possible use of heat (steam) from the Douglas Point NGS to be used in the production of the heavy water. While AECL took the

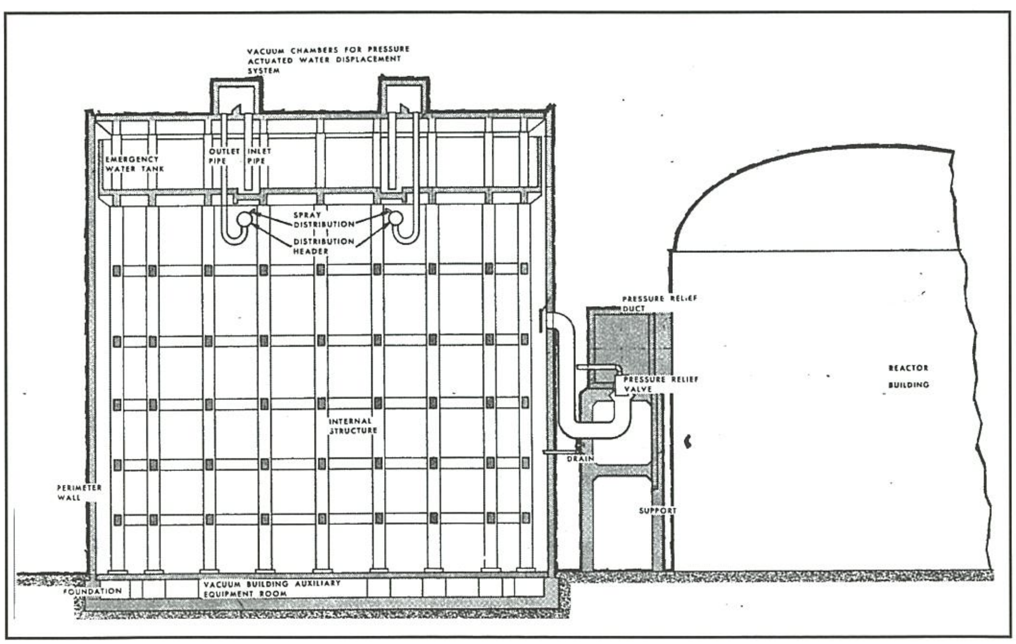


Figure 8: Pickering Negative Pressure Containment Structures and System.

initiative in 1968 to get design and construction started on this HWP A plant, it was subsequently "taken over" (purchased, owned and operated) by Ontario Hydro.

There was a "scramble" to acquire enough heavy water to fill the first Pickering NGS unit(s) from all available Canadian and off-shore supplies; and the supply of heavy water could barely keep up with the demand during the following ten years. This supply came from the 400 tons/year Canadian General Electric Company's heavy water production plant at Port Hawkesbury, Nova Scotia, which came into operation in 1971; the 800 tons/year Bruce HWP A plant which was brought into service in 1973; the 400 tons/year heavy water production plant at Glace Bay, Nova Scotia which began limited heavy water production in 1976; and a second 800 tons/year heavy water production plant, Bruce HWP B, built by Ontario Hydro adjacent to the Bruce HWP A, which came into operation in 1978.

Status of Ontario Hydro's Full-Scale Nuclear Program in 1971

The first 500MWe unit of the Pickering station became critical in early 1971 and was brought into service in the summer of 1971. The second unit became critical in the fall of 1971 and was brought into service at the end of 1971, with in service of the third and fourth units following in 1972 and 1973.

By 1971 the 200MWe Douglas Point Station was in service providing electricity to the Ontario Power System, and was being readied for dual operation as a supplier of steam to the adjacent Bruce Heavy Water Production Plant A that was then under construction. Site Preparation was underway for the construction of the 4 -750MWe Bruce Nuclear Power Station on the north end of the Bruce site .

Initial Operation of the Pickering Units

The Pickering units were brought to criticality and power essentially on schedule as shown in Table 2.

The units performed well right from the start, however, there was a 4 month strike in Ontario Hydro from July 1, 1972 to the end of October 1972, when all the Pickering units were shut down. The winter peak Net Capacity Factor for all three operating units was 96% in the winter of 1972/73, and 95% for all four units in the winter of 1973/74. The annual Net Capacity Factor in 1973 was 83.4%.

This excellent early performance provided confidence in the heavy water moderated concept, and resulted in initiatives by Ontario Hydro to proceed with four additional units at Pickering for in service in the early 1980's. It also raised/increased interest in other provincial utilities (Quebec and New Brunswick), in heavy water moderated nuclear power plants, and in the subsequent commitment of single unit stations in each province. This early performance at Pickering also provided AECL with a demonstration to show potential off-shore customers (Argentina and South Korea), the potential capability of heavy water moderated power systems.

Subsequent Performance of the Pickering Units

It is not intended to go into any detail of the performance of the Pickering units over the past thirty years of service. In general the performance has been good. However, over the years there have been a number of causes of lost production due to:

- Replacement of some leaking pressure tubes in Units 3 and 4, in 1975 and 1976, apparently due to improper rolling-in of the new zirconium-niobium pressure tube material in the end fittings of these two reactors.
- Outages for turbine and generator overhauls.
- Fuel handling outages.
- And a number of minor miscellaneous causes.

However, the greatest causes of lost production from the four units of Pickering A were:

- The failure of a Zircaloy-2 pressure tube in Unit 2 in August 1, 1983 which resulted in an extended shut down of Unit 2, and eventual re-tubing of all four reactors in sequence in the 1980's with Zr-2.5%Nb alloy, the material used subsequently in all CANDU reactors.
- A small loss-of coolant accident (LOCA) in Unit 2 in December of 1994 due to a diaphragm failure in a relief valve, resulting in Unit 2 being out of service for all of 1995 and three of the four Pickering A Units being shut down through the first five months of 1995.
- The complete shutdown of all four units since 1997, due to lack of trained operators and maintenance staff to keep the station operating in an acceptable condition. This extended outage is expected to come to an end in 2002 with the restart of units in sequence, over the next year or so, as they are restored and/or upgraded to comply fully with regulatory requirements.

Concluding Remarks

The early development of full scale nuclear power in Ontario using heavy water as the moderator and coolant

Table 2 Key Start Up Dates for Pickering Units

ACTIVITY	UNIT NO 1	UNIT NO 2	UNIT NO 3	UNIT NO 4
Load fuel	06 - 20 Jan 71	11 - 27 Aug 71	01 - 13 Mar 72	19 - 31 Mar 73
Critical	25 Feb 71	5 Sept 71	24 Apr 72	16 May 73
First Steam	16 Mar 71	29 Sept 71	29 Apr 72	19 May 73
First Power	04 Apr 71	06 Oct 71	02 May 72	22 May 73
Full Power	30 May 71	07 Nov 71	12 May 72	28 May 73
In Service	29 July 71	30 Dec 71	01 June 72	17 June 73

FUNDAMENTAL DEVELOPMENT	APPLIED DEVELOPMENT		
CRNL & WRNE	Power Projects	W.P. Dobson Research Laboratory	Manufacturers
- Physics parameters - Fuel Technology Burnup Canlub - Metallurgical - - Zircalloy and Zirconium -Niobium - Creep	- Prototype design and component testing - Material fretting - Fuel channel flow characteristics - Pump seal development - Computer program development and testing - Specialized tooling development - Tube welding - Swagelock joints - Channel installation and removal tools - Miniature television techniques with associated remote manipulators.	- Elect. & Inst. penetrations of reactor building wall - Special paint finishes - Hydraulic studies C.W. inlet and outfall - Vacuum building model tests - Tube plugging - Pump vibration recording	- Development jointing techniques - Stress relieving techniques - Deep hole boring - Flux monitoring - Overlay techniques - Metallurgical processes - Tube rolling techniques - NDT techniques.

Table 3
Fundamental and Applied Development

was a bold and exciting venture, with major commitments following rapidly one after another.

The resulting distinctive and successful CANDU nuclear power system is the product of close cooperation between Atomic Energy of Canada Limited (AECL), Ontario Hydro, and Canadian industry over more than two decades. The system was planned and designed from the outset to meet the needs of Ontario Hydro and other power utilities for reliable, safe, environmentally benign; and economic electrical energy, using Canadian expertise and resources and skills. It represents an outstanding Canadian technological development toward energy self-sufficiency and competitiveness; and the capability to meet the future needs for electrical energy in Canada with no release to the environment of combustion products and greenhouse gases.

To Canada and Ontario it represented an extensive investment in development and organization of expertise, knowledge and skills and in a number of facilities necessary to undertake such a major energy initiative. It was necessary to integrate Canadian capability in Research and Development, Design, Manufacturing, Construction and Operations to provide the integrated competence to undertake this extensive nuclear development program in Ontario. A brief summary of some of the fundamental and applied development activities is shown in Table 3.

There are a number of important lasting benefits from the early full-power program, including:

- A valuable energy technology for AECL to market in Canada and abroad.
- Proven Canadian capability to manage large, complex technological developments.
- An immediate indigenous competitive electrical energy source for Ontario, and the technology and know-how to meet future electrical energy needs in the province.
- New Canadian manufacturing technology and upgraded quality assurance capability.
- Advanced design and construction expertise and quality assurance methodology.
- Nuclear plant commissioning and operating expertise, training facilities and programs.
- Nuclear safety technology and licensing criteria and procedures to ensure public safety.

The early development of full-scale nuclear power in Ontario was a bold Canadian venture. It is an outstanding example of what can be achieved by dedication and cooperation of governments; and their agencies, boards and crown corporations; private companies and talented Canadians.

Acknowledgement

Input and helpful comments to this document were made by: Fred Kee, Larry Woodhead, Elgin Horton and Gerry O'Sullivan.

References

1. W. B. Lewis, 1951, An Atomic Power Proposal, AECL DR-1.
2. W. B. Lewis, 1955, The Heavy Water Reactor For Power, AECL DL-25
3. Nuclear Power Group, Preliminary Design of Small Scale Nuclear Plant, Apr 1955, AECL NPG-5
4. H. A. Smith, Report No 2, Small Scale Nuclear Plant, Apr 1955, AECL NPG-8
5. Nuclear Power Branch, A Study of Full-Scale Uranium - Heavy Water Nuclear Plant, May 1957, AECL NPG - 10
6. The Canadian Study for a Full Scale Nuclear Power Plant, 1958, AECL No 557
7. Ontario Hydro Annual Report 1958
8. The Eighth AECL Symposium on Atomic Power, Sept 24, 1962, AECL 1599
9. The Ninth AECL Symposium on Atomic Power, Sept 23, 1963, AECL 1807
10. Assessment of Pressure Tube Diameter, TDI-2
11. Project Outline for First Two 500Mwe Units of Proposed Multi-Unit Nuclear Power Station for Ontario, July 1964, TDI-3
12. Supplement to TDI-3, Containment Scheme for First Two 500MWe Units Of Proposed Multi-Unit Nuclear Power Station for Ontario, Oct 1964
13. I. L. Wilson, C. E. Beynon, W. G. Morison, N. L. Williams, Studies of Candu-type Reactors in the 500Mwe Range, Aug-Sept 1964 Geneva Conference, AECL 2006
14. W. G. Morison, Progress Report on the Pickering Generating Station, C.N.A. Meeting , June 1966
15. The Eleventh AECL Symposium on Atomic Power, Oct 13, 1966, AECL 2486
16. The Twelfth AECL Symposium on Atomic Power, April 19, 1968, AECL 3067
17. Pickering Generating Safety Report, Phase 2, 1967
18. Pickering Generating Station, Design Description, AECL-Ontario Hydro, 1969
19. W. G. Morison, Heavy Water Power Reactors, IAEA, 1968
20. W. G. Morison, Heavy Water Nuclear Power Stations, the next 10 years, New Zealand Electric Journal, 1969
21. L. W. Woodhead, Performance Review of CANDU-PHW Nuclear-Electric Units and the Bruce Heavy Water Plant, C.N.A. , June 1976
22. Douglas Point Nuclear Generating Station, AECL 1596
23. W. G. Morison, Pickering Generating Station, J.Br. Nucl. Energy Soc. Oct 1975
24. F. J. Kee and L. W. Woodhead, Progress Review of Ontario Hydro's Nuclear Generation and Heavy Water Production Programs, C.N.A., June 5-8 1977
25. W. G. Morison and H. S. Irvine, Large Scale Fuel Channel Replacement Program, Int. Decommissioning Symposium, Oct 1987
26. Douglas Point Safety Reports
27. Pickering NGS-A Safety Reports.31 of 32

Appendix A

Members of the "Nuclear Power Group" set up at Chalk River in early 1954 to undertake the preparation of the preliminary design and cost estimate of a small (20Mwe) nuclear plant:

H. A. Smith Ontario Hydro
W. E. Cooper " "
M. D. Berry " "
J. S. Foster Montreal Engineering Company Ltd
D. O. Gregory Canadian Brazilian Services
H. B. Merlin " " "
G. E. Haddeland Shawinigan Water and
Power Company Ltd
W. M. Walker British Columbia Electric Company Ltd
R. A. Green Babcock-Wilcox &
Goldie-McCulloch Company Ltd
E. Critoph Atomic Energy of Canada Ltd
E. Siddall " " " "
P. Tunnicliffe " " " "
A. C. Whittier " " " "
S. J. Whittaker " " " ".

Appendix B

Members of the Nuclear Power Branch at Chalk River in September 1955 set up to undertake the preliminary design, development and cost estimate of a 200Mwe heavy water moderated nuclear power unit.

H. A. Smith Ontario Hydro
M. D. Berry " "
D. O. Gregory Canadian Brazilian Services Ltd
H. B. Merlin " " " "
D. S. Simons Manitoba Hydro-Electric Board
D. J. Stelliga Babcock-Wilcox & Goldie-McCulloch Ltd
W. M. Walker British Columbia Electric Co. Ltd
N. L. Williams " " " " "
E. Critoph et al Atomic Energy of Canada

GENERAL news

AECL Appointments

Paul Fehrenbach has been named Chief Operating Officer, Nuclear Laboratories, for Atomic Energy of Canada Limited at the beginning of July 2002.

Shortly thereafter he made the following announcements.

With the Whiteshell site entering a transition from an operating license to a decommissioning license, it is now appropriate for the GM Decommissioning and Waste Management to assume responsibility for the Whiteshell Laboratory site nuclear license. Accordingly, effective 2002 July 15, **Dr. C.J. Allan** will assume responsibility for the WL site nuclear license in addition to this other duties.

Dr. W. C. H. (Bill) Kuperschmidt will take over from Colin Allan as General Manager of Decommissioning and Waste Management on Colin's retirement, effective 2002 September 30. Before assuming his new position, Bill will be transferring to WM&D as a special advisor to Colin on July 15. Bill will report directly to Paul Fehrenbach effective September 30. During the transition period, Bill will retain the AECL lead for completing the agreement between AECL and Health Canada for support of the Radiation Biology and Health Physics R&D programs.

Bill joined AECL at Whiteshell Laboratories in 1982, after obtaining his B.Sc. degree in chemistry from the University of Guelph and a Ph.D. from the University of Alberta. In 1993, he was appointed manager of the Research Chemistry Branch, and in 1997 moved to Chalk River Laboratories, to become Director of the Reactor Safety Division.

Mr. P. (Paul) Lafrenière, GM Facilities & Nuclear Operations, retains his current responsibilities, including the responsibility as the site license holder for CRL, for site regulatory and compliance programs, and the landlord responsibility for Canadian AECL sites.

Study shows no increase in cancer mortality in Port Hope

In June 2002 the Canadian Nuclear Safety Commission (CNSC) released the results of a study entitled "Cancer and General Mortality in Port Hope, 1956 - 1997". The study, carried out by Health Canada and subjected to a scientific peer review by independent scientists, found that the overall cancer mortality rates in the town of Port Hope, Ontario are comparable to rates throughout the Province of Ontario.

The study was commissioned by the CNSC and conducted by scientists at Health Canada.

Using data from the Canadian Mortality Database (CMDB), the study compared rates of cancer and other causes of death in Port Hope with provincial death rates, comparing death rates back to as early as 1956. It also compared cancer mortality results with a previous cancer incidence study conducted for the Port Hope area, results of which were released in August 2000.

The findings of this recent study are consistent with the earlier cancer incidence report. On the whole, the study findings demonstrate that the patterns of cancer mortality and incidence in Port Hope are no different from those throughout Ontario.

A consistently increased mortality from circulatory disease was observed. This relative excess of mortality from circulatory diseases is not likely to be due to environmental factors particular to Port Hope, in part because elevated rates were also observed in the much larger Northumberland Census Division which includes Port Hope.

Copies of the health study may be requested from the CNSC by calling 613-996-6860 or e-mail to: media@cnsc-ccsn.gc.ca.

New president for COG

The Board of Directors of CANDU Owners Group Inc. (COG) has appointed Brian MacTavish as president. After a long career with Ontario Hydro and Ontario Power Generation, Brian retired in June 2001. At that time he was Site Vice-President of Pickering. His appointment at COG began July 2, 2002.

Bruce A restart ahead of schedule

On July 29, 2002, Bruce Power announced that it will accelerate plans to restart two units at its Bruce A generating station after the Canadian Nuclear Safety Commission (CNSC) said a December date for the first day of hearing to consider an amendment of the station's licence can be achieved.

The second day of hearing would likely to be held next February.

On that basis Duncan Hawthorne, Bruce Power's CEO, said Bruce A Unit 4 could be generating electricity as early as April of 2003, well ahead of the current objective of summer of 2003. He also commented that Unit 3 could be returned to service before next summer (which would help Ontario meet its power needs during the peak summer months).

By restarting two of its Bruce A units, Hawthorne said Bruce Power will be able to provide Ontario with another 1,500 MW of clean and reliable electricity. He noted that since the province's electricity market opened to competition (May 1, 2002), Bruce Power's operating reactors at the Bruce B generating station have safely worked at a capacity factor of nearly 100 per cent.

Hawthorne said the restart has been a challenging and complex project. The company has reviewed its original project cost estimates. In light of security enhancements following the events of September 11, 2001 - as well as additional work to improve the reliability of the units once they restart -project costs are likely to be in the $400 million range, compared to earlier estimates of $340 million. Approximately $195 million has been spent on the restart to date.

New LLW facility at Chalk river

In May an above ground waste storage facility, called the Modular Above Ground Storage (MAGS), was officially opened for business at Chalk River Laboratories (CRL). The $2.5 M facility comprises a waste sorting and handling building, a supercompactor and storage buildings in a new Waste Management Area.

MAGS is the first new waste storage facility to be commissioned at CRL in 20 years. It is an innovative process that involves substantial volume reduction of some low-level radioactive wastes that would have been stored in sand trenches. The materials to be stored in MAGS are wastes such as clothing, cleaning supplies, equipment and building materials that have become radioactive. Wastes are sorted, compacted into steel storage containers, and tagged for identification. The supercompactor, (equipped with air pollution control devices), is expected to reduce overall volume by 50 per cent per year.

The MAGS storage buildings are prefabricated metal buildings with reinforced concrete floors containing drainage and ventilation systems. Each building has a capacity for two years' worth of low-level radioactive waste at CRL. Wastes will be packaged either in steel containers or in 45-gallon drums for storage. A bulk storage area will hold materials such as contaminated soil, or pieces of concrete, on an asphalt pad with a liquid collection system, or in large metal luggers.

OPG purchases CO_2 emission credits

In early July 2002 Ontario Power Generation (OPG) announced purchase of nine million tonnes of carbon dioxide emission credits to be used towards reducing its greenhouse gas (GHG) emissions.

OPG's stated strategy for managing GHG is based on avoiding and reducing emissions from its facilities and removing CO_2 from the atmosphere.

OPG officials state that the company will continue to stabilize net emissions of greenhouse gases at levels equivalent to the 1990 level into the foreseeable future.

Emission reduction options being employed by OPG include returning nuclear units to service, improving energy efficiency, increasing green energy sources, carbon sequestration and emission trading. In 2000 OPG purchased over 10 million tonnes of emission reduction credits to offset its CO_2 emissions.

CO2e.com, a subsidiary of Cantor Fitzgerald, helped facilitate the CO_2 emission credits trade, in two transactions between OPG and BlueSource LLC, a US-based firm that identifies, secures and markets greenhouse gas emission reductions. The purchased emission reduction credits stem from geological sequestration projects in Texas, Wyoming and Mississippi. In 2000 and 2001, Blue Source's clients expanded the construction of a CO_2 pipeline which gathers locally produced CO_2 and transports it to crude oil producers for injection into mature oil fields to enhance oil recovery. The CO_2 used for this process would otherwise be vented into the atmosphere by natural gas processing plants. The CO_2 is sequestered in underlying bedrock that formerly held the oil.

AECL pitches ACR in the USA

In late June 2002, AECL Technologies Inc. held a media conference to announce plans to introduce the ACR-700 nuclear reactor to the US market. "We believe that the ACR-700 is the first reactor on the market that has the right combination of cost, safety, security, size, reliability and environmental advantages to meet the needs of generators selling into competitive markets," said AECL President and CEO Bob Van Adel. "Until now, potential buyers have had to choose between upgrades of older expensive light water technology and exotic designs that won't be commercialized for many years. The ACR-700 provides proven technology with familiar light water reactor features, sized and priced optimally for today's energy markets. US utilities finally have a viable option."

The ACR-700 is an evolution of AECL's current 700 MWe class CANDU 6 design, now under construction in China and Romania. Applying innovative construction techniques developed there, AECL has been able to significantly reduce construction time, and lower costs for the ACR-700. And by moving from heavy water to light water cooling and using slightly enriched uranium fuel, the ACR-700 is much less expensive to operate than today's reactors. The overnight capital cost for twin units is $1,000/kWe and the levelized cost is $30/MWh.

AECL has formally requested a pre-application review from the Nuclear Regulatory Commission (NRC), and public meetings and a two-day technical workshop on the ACR-700 are planned for July and September 2002, respectively. Discussions are also underway with a number of US generators. As well, the international licensing process has been initiated for the ACR-700, which will meet Canadian, US, UK and International Atomic Energy Agency standards as well as customer needs and requirements. The ACR-700 has already been identified as a lead technology for the replacement of the aging nuclear fleet in the United Kingdom.

Based in Washington, DC, AECL Technologies Inc. is a subsidiary of Atomic Energy of Canada Limited (AECL) headquartered in Mississauga, Ontario.

22nd CNS Nuclear Simulation Symposium

Nuclear Power in Canada: Step Into the Future

November 03-05, 2002
Westin Ottawa Hotel, Ottawa, Ontario, Canada

The scope of the Symposium covers all aspects of nuclear modelling and simulation, and includes sessions in thermal hydraulics, reactor physics and safety analysis. The main objective of the Symposium is to provide a forum for discussion and exchange of views amongst scientist, engineers and academics working in various fields of nuclear engineering.

For general conference information contact:

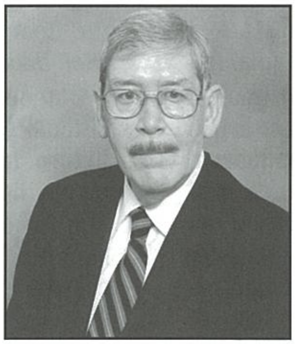
Ms. D. Rouben, Canadian Nuclear Society Office
480 University Ave, Suite 200
Toronto, Ontario, CANADA, M5G 1V2
Telephone: (416) 977- 7620
Fax: (416) 977- 8131
E-mail: cns-snc@on.aibn.com

or

Dr Dumitru Serghiuta
Chair of the 22 nd Nuclear Simulation Symposium
Canadian Nuclear Safety Commission
280 Slater, P.O.Box 1046, Station B
Ottawa, ON K1P 5S9, CANADA
Telephone: 613-947-2201
Fax: 613- 943-1292
E-mail: serghiutad@cnsc-ccsn.gc.ca

CNS news

Meet the President



On June 3, 2002, **Ian Wilson** became President of the Canadian Nuclear Society for the year 2002 - 2003.

As is still evident in his speech Ian hails from Scotland. He was born and raised in the Clydeside town of Dumbarton, Scotland. In 1959 he obtained an honours degree in mechanical engineering from the University of Strathclyde (then known as The Royal College of Science and Technology) and began his professional engineering career in the gas industry as a specialist in industrial uses of gas.

Following a stint with Guinness's Brewery in Dublin, Ireland, he decided to come to Canada in 1966, with his wife Anne, daughter Lesley and son Stuart, working initially for Canadian International Paper.

In 1969 he joined Ontario Hydro, as a specialist in thermodynamic studies and a year later became Supervising Thermal Studies Engineer in the Generation Concept Department. In 1972 he was appointed Ontario Hydro's representative on AECL's year-long study of a 1250MW CANDU BLW (PB) design. Returning to Hydro he became supervisor of a small team conducting state-of-the-art studies into wind power, solar energy, magneto-hydrodynamics, hydrogen, advanced gas turbine concepts, energy storage, etc. He chaired a NATO Science Council study group on Thermal Energy Storage in early 1976.

In mid 1976 Ian joined Ontario Hydro's Public Hearings Department as the Public Hearings Officer responsible for coordinating input, including submissions on the nuclear power program, to public hearings such as the Royal Commission on Electric Power Planning. He became Manager of the Public Hearings Department in 1982.

In 1985, Ian accepted a one-year secondment as Vice-President (Technology) of the Canadian Nuclear Association. He ended up staying with CNA until his retirement from Hydro in 1993. He then worked for the CNA for a further two years, retiring in 1995 as both Vice-President (Technology) and General Manager.

During his years of service at CNA, Ian authored dozens of nuclear industry submissions to provincial and federal parliamentary committees and commissions of inquiry. In addition he wrote a number of special submissions including the successful citation of CANDU as one of Canada's top ten engineering achievements.

He played a pivotal role in the development and delivery of the CNA's Public Information Program of the late 1980s and early 1990s. Throughout the Program he was responsible for ensuring the accuracy of industry advertisements and publications on a wide variety of nuclear topics.

In his role at the CNA Ian appeared frequently on TV and radio and wrote hundreds of newspaper articles and letters. His prominence as a nuclear industry spokesman was recognized publicly when his biography was solicited by and first published in *Canadian Who's Who* in 1994.

Despite being nominally retired Ian continues to take an active role in industry affairs. He was a CNA representative at every session of the final hearings of the Environmental Assessment Panel reviewing the High-Level Waste Disposal Concept, participated on CNA's Climate Change Task Force and recently updated the text of the CNA's fact sheets.

For the past four years Ian has been an active Member of Council and of the Executive Committee of the Canadian Nuclear Society. For the past three years Ian has been a member of the Annual Conference Organizing Committee of the CNS and has twice served as Executive Chair of the Committee.

The Canadian Nuclear Society is fortunate to have someone with Ian's background and capability as its president.

McLean Moving

Adam McLean, the very energetic chairman of the Toronto Branch of the Canadian Nuclear Society, is moving to pursue his doctoral studies in San Diego, California.

Adam was awarded the CNS Education and Communication Award at the 2002 Annual Conference held in Toronto in June. (See page 6)

He assured everyone that he will be returning to Canada when he completes his studies. He will also continue as coordinator of the International Youth Nuclear Congress to be held in Toronto in 2004.

Over the past few years Adam's youthful enthusiasm, energy and enterprise has helped re-vitalize the Society. He will be missed.

Annual General Meeting

Close to 60 members gathered at the Holiday Inn on King in Toronto late afternoon June 2, 2002, for the 5th Annual General Meeting of the Canadian Nuclear Society Inc. (the 23rd meeting of the Society) at the end of the first day of the 2002 Annual Conference.

While complying with the formal requirements for a meeting of an incorporated organization the overall atmosphere was relaxed (possibly aided by the free drink offered to those attending).

David Jackson, president for 2001- 2002, opened the meeting about a quarter hour after the scheduled time of 5:00 p.m. The first order of business was for the secretary to declare that the number attending exceeded the quorum requirement of 30.

Following acceptance of the minutes of the 2001 AGM the president introduced the executive and thanked them for their contributions and cooperation. He then presented his report on his year in office. *(See separate item.)*

Andrew Lee presented his treasurer's report, noting that the Society ended the year 2001 with a significant surplus despite the forecast of a deficit. This, he pointed out, was due to the efforts of a relatively small group of dedicated members who had volunteered to organize the various courses, symposia and conferences offered by the Society. *(Note that although the term of office for the Council is from AGM to AGM the fiscal year of the Society is the calendar year.)*

Then followed brief reports from the various Divisions and Committees. On international matters some members suggested exploring relationships with the nuclear societies in India and Pakistan. Domestically it was noted that the CNS has joined the Engineering Institute of Canada, which is now an organization of organizations. Ben Rouben reported that membership in 2001 was the largest in the history of the Society.

In the report on the Student Conference, which had been held on the Sunday immediately prior to the Annual Conference, it was noted that few full members or representatives of industry were present. Following some discussion it was moved that next year's conference organizers should look into ways of better integrating the Student Conference with the Annual Conference.

Then came the presentation of the Nominating Committee by Ken Smith who submitted a list of nominees to just fill the Council. With no nominations coming from the floor this slate was declared elected by acclamation. *(See accompanying box.)*

Outgoing president David Jackson then presented the traditional gavel to Ian Wilson, CNS president for 2002 - 2003. In turn, Ian Wilson presented David Jackson with a plaque in recognition of his leadership over the past year.

Just before closing the meting Ian Wilson expressed his hope that he could maintain the high standard of his predecessors. Since the Society now had a sizable surplus he invited members to suggest new programs or initiatives that would further the objectives of the Society.

The meeting adjourned about 6:45 p.m.

Canadian Nuclear Society / Société Nucléaire Canadienne, Inc.
2002/2003 Council

Executive	**Affiliation**	
President	J.E. (Ian) Wilson	Retired (formerly CNA)
1st Vice-President (President Elect)	J.J. (Jeremy) Whitlock	AECL
2nd Vice-President	W.G. (Bill) Schneider	Babcock & Wilcox
Treasurer	J.W. (Walter) Thompson	OPG
Secretary	B. (Ben) Rouben	AECL
Past President	D.P. (Dave) Jackson	McMaster U

Members at Large	
J.M. (Jerry) Cuttler	Cuttler & Associates Inc.
K.W. (Ken) Dormuth	AECL
R.S. (Ralph) Hart	R.S. Hart & Associates
E.M. (Ed) Hinchley	Retired (formerly AECL)
V.S. (Krish) Krishnan	AECL
S.Y. (Andrew) Lee	Retired (formerly OPG)
M. (Marc) Leger	AECL
J.C. (John) Luxat	OPG
A.G. (Adam) McLean	University of Toronto
K. (Kris) Mohan	AECL
E.M. (Dorin) Nichita	AECL
J. (Jad) Popovic	AECL
P.J. (Patrick) Reid	Candesco Research
M.R. (Michel) RhÈaume	Hydro-QuÈbec
R. (Roman) Sejnoha	Retired (formerly AECL)
K.L. (Ken) Smith	UNECAN
M.R. (Martyn) Wash	OCI
B.F. (Bryan) White	AECL
E.L. (Eric) Williams	Bruce Power

Annual General Meeting

President's Report

Since our last annual general meeting we have seen some great changes in the world and in the outlook for nuclear energy. The year 2001 started on high note for the nuclear industry with a nuclear renaissance gaining momentum. Reactor performance figures were up all over the world and more nuclear electricity was produced in 2000 than ever before. The California power shortage added growing urgency to secure additional nuclear capacity, a trend already driven by the threat of climate change, increased air pollution from fossil fuels, and continuing political instability in the Middle East.

Then came September 11th and everything changed for the worst. The horrifying images of the aircraft smashing into the World Trade Centre Towers were soon transposed to aircraft smashing into all types of installations critical to the functioning of our society including nuclear power stations. A new and mounting criticism was levelled at nuclear power, namely that power reactors were particularly vulnerable to terrorist attack because, according to the critics, the consequences of an aircraft hit on a reactor would be catastrophic. At the moment, India and Pakistan, both early beneficiaries of Canadian nuclear technology and now nuclear weapons states, arc involved in nuclear brinkmanship over Kashmir.

The CNS plays a positive role in mitigating this turmoil by providing reliable and authoritative information to our members, the public and governments. Our objective is not so much to influence public policy, which is more the role of the CNA, but rather to ensure that decisions are based on sound technical information. Therefore, a primary objective of the CNS continues have good programs in education and communications;

- Teachers Courses on Nuclear Energy
- AECL's Science for Educators Seminar
- Journalism Workshops on Scientific Reporting
- Deep River Science Academy
- Science Fairs and other special events

Our 2001 Officer's Seminar was on the theme of Communications with media relations professionals from OPG, AECL and the CNA attending. New ideas coming out of the Seminar included an interactive web site, a business card with web site locations (`Ask an Expert") and our new CNS Newsletter.

Throughout the past year the CNS has continued to provide courses and stage conferences that enhance the dissemination of information on nuclear topics. All the our conferences were successful this year including:

- the 2001 Annual Conference
- the International Conference on CANDU Fuel
- Climate Change 2: Canadian Technology Development
- International Steam Generator Conference

Our conference program continues to thrive with planning for several conferences in full swing, including the international Youth Nuclear Congress in 2004. Our professional education program is also flourishing with popular courses in CANDU Chemistry, CANDU Reactor Safety and CANDU Fuel Technology and in other topics given in the past year and planned.

Generally, the CNS Branches continue to offer active seminar programs and to participate in their communities in various ways. However, some Branches are relatively inactive for a variety of reasons with, in some cases, the possibility of revival.

There have been many other positive accomplishments in the past year and I can mention only a few. Our membership numbers have steadily increased, we have successfully integrated the Honours and Awards functions of the CNA and the CNS and we have continued to cultivate our ties with organizations such as the ANS, PBNC, EIC and other national and international organizations.

These few highlights of the CNS program over the past year show that our Society is in good shape and playing an active and vital role in the nuclear enterprise. However, there are also areas in which we must continue our efforts to improve. We are fundamentally a volunteer organization that depends on the efforts of its individual members. I would like to personally thank all those members who have worked so hard over the past year to make it so successful. Finally, on behalf of the CNS Council, I would also like to thank our sister organization the CNA, the companies in the nuclear industry, and all of the other organizations and individuals that have supported CNS activities in 2001-2002. I have enjoyed my year as your President and I thank you for your support and encouragement.

David Jackson

Treasurer's Report

Ed. Note: *At the Annual General Meeting, June 3, 2002, CNS Treasurer Andrew Lee tabled the audited statement for the Canadian Nuclear Society Inc for fiscal (calendar) year 2001. Only his report is presented here. Copies of the Financial Statermnt are being enclosed with this issue of the CNS Bulletin for members in good standing. The report below has been edited slightly to reflect this arrangement.*

The Auditor's Report for the Canadian Nuclear Society for the year ending at December 31, 2001 is tabled with this report. This audit was carried out by David Rogers, Chartered Accountant, in accordance with generally accepted auditing standards. The audit has shown that the financial statements present fairly the position of the Society as at December 31, 2001.

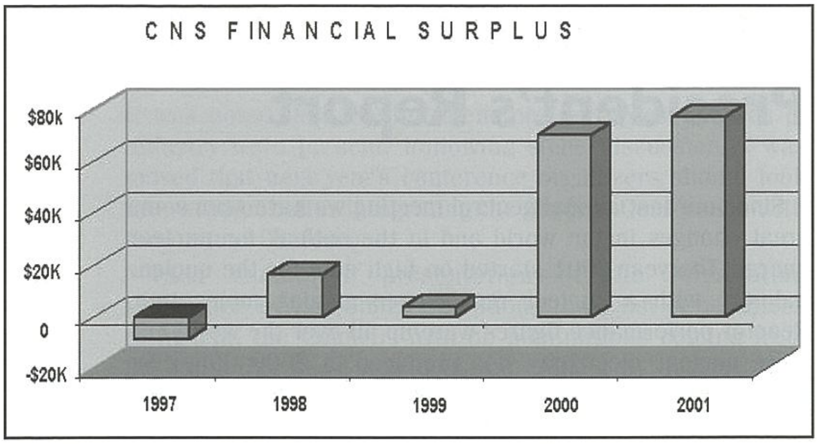
The year of 2001 was a financial success with a surplus of $76,670. The main reason for the operating surplus is that the Annual Conference, the Climate Change Conference and the Candu Fuel Conference exceeded revenue expectations. The Chemistry course and Reactor Safety courses also contributed to this financial success. In addition, there are also excess revenues from the Candu Maintenance Conference and the Simulation Symposium from the year of 2000. An overview of the end-of-year surplus for the past five years is shown graphically on the back of this page.

After the significant increase in net income in 1996, we have consistently budgeted for an annual deficit. However, each year, we have been surprised at year-end by unexpected revenue from conferences which were scheduled for the last couple of months of the year. Your Council has recognized the existence of this increasing surplus, and has already committed the expenditure of more than $45,000 from the Special Projects Fund - on various education and communication activities. One of the various activities was the establishment of a highway plaque to commemorate the startup of NPD. We expect that about $30,000 of the $45,000 will be spent during 2002, and we expect to commit to other future expenditures of this type.

The Society's current assets include cash, receivables, sales taxes recoverable and prepaid expenses, as well as investments and education fund and equipment. The liabilities include payables; membership fees received in advance, dues and a portion of the Education Fund due to the Canadian Nuclear Association.

This concludes the 2001 Treasurer's Report.

Andrew Lee, Ph.D., P.Eng.
Treasurer



CNS Surplus/Deficit in dollars:

1997	**1998**	**1999**	**2000**	**2001**
-$9,004	$16,195	$3,665	$69,881	$76,670

CNS Special project Fund for Education & Communication related Expenditures:

2002 Expenditures:

NPD commemorative mugs - Motion 34.2	3,157
Historical Plaque on the highway at NPD - Motion 25.7, 33.5	7,500
NPD information sign - Motion 35.2	2,000
Unlocking the Atom book purchase - Motion 26.8	5,000
Unlocking the Atom book purchase - Motion 34.13	7,000
Unlocking the Atom book purchase - Motion 35.5	1,000
Total	**25,657**

Future Expenditures:

CANDU display at Ontario Science Centre - Motion 5.11	5,000
Canteach @ 5,000/yr for 3 years - Motion 31.5	5,000
Total	**20,500**

Unallocated Value of Special Project Fund **1,460**

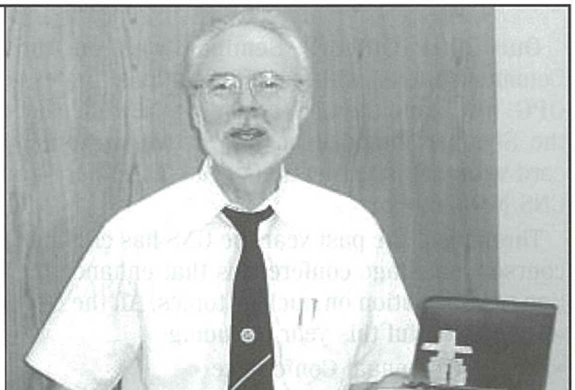
Inukshuit winners

To encourage delegates at the 23rd CNS Annual Conference to return their badges (as an economy move) the conference organizers offered two Inukshuit statues as prizes in a draw.

A random draw was conducted after t0he conference supervised by CNs secretary Ben rouben and treasurer Andrew Lee. The winners were:

- Dave shier of the Power workers Union
- Stefan Doerffer of AECL.

The accompanying photo shows Stefan Doerffer with his prize.



NPD Commemmorative Plaque

On Saturday, June 1, 2002, a special ceremony was held on the disused parking lot of the Nuclear Power Demonstration (NPD) plant near Rolphton, Ontario, to commemorate the 40th anniversary of the first electricity from a nuclear plant in Canada.

The ceremony marked the culmination of a three year effort led by Jeremy Whitlock, vice-president of the Canadian Nuclear Society in conjunction with the Ontario Heritage Foundation, who served as chairman for the event.

Close to 100 people crowded into and around a tent set up for the ceremony that began with a welcome by Whitlock who conveyed greetings from former NPD staff now at the Bruce station. Cheryl Gallant, MP for Renfrew-Nipissing-Pembroke, brought brief greetings from the federal government. David Torgerson, senior vice-president at Atomic Energy of Canada Limited followed with short remarks on behalf of the three organizations involved with the NPD project, AECL, Canadian General Electric and Ontario Hydro. He applauded the CNS effort to recognize the importance of NPD which was the first of some 22 CANDU plants around the world.

Jeremy Whitlock then introduced Norman Ball, director of the Centre for Society, Technology and Values, at University of Waterloo, who had written the background paper for the Ontario Heritage Foundation to support the decision to erect a plaque. He commented that NPD was a reflection of Canada's commitment to peaceful use of nuclear energy. Making reference to papers by J.A.L. (Archie) Robertson (who was in the crowd) he added that NPD was very "appropriate" technology, "making the best use of what you have". NPD, he said, is a "mirror of who we are'" and is "one of Canada's technical historical highlights". *(Dr. Ball's talk is reprinted in this issue of the* CNS Bulletin.)

Georges Quirion, a member of the Board of the Ontario Heritage Foundation, provided a few remarks about his organization, noting that there are now about 1100 historic plaques around the province (including one for ZEEP at the Chalk River Laboratories of AECL, the first reactor outside the USA).

Then came the unveiling of the plaque with all of the above participants plus Lorne McConnell, the first superintendent of NPD, taking part. *(See text of plaque on page 60.)*

In closing Jeremy Whitlock commented that the plaque would be mounted on Highway 17 at the look-out for the Des Joachims hydro dam along with an interpretative sign being prepared by the CNS.

The previous evening a special gathering was held in Mackenzie High School in Deep River where Lorne McConnell talked about the beginnings, development and achievements of NPD. (He gave essentially the same presentation in a special session at the 23rd CNS Annual Conference in Toronto the following week.)

More information and photographs, including the text of Lorne McConnell's talk at Deep River can be found on the CNS Web site < www.cns-snc.ca >

NPD - a historical achievement

Ed. Note: *Following is the text of the talk by Dr. Norman R. Ball of the University of Waterloo at the unveiling ceremony, June 1, 2002 of a historic plaque to commemorate the 40th anniversary of the first nuclear generated electricity in Canada from the NPD station. Dr. Ball prepared the background paper for the Ontario Heritage Foundation to support their decision to erect the plaque in cooperation with the Canadian Nuclear Society.*

I am honoured and delighted to be asked to speak to you and to share this important occasion as we celebrate both the Nuclear Power Demonstration reactor and the first nuclear power generated electric power being fed into the Ontario Hydro electric grid for the people of Ontario.

For the invitation to speak here today, I would like to thank the Canadian Nuclear Society, especially Dr. Jeremy Whitlock for his assistance. I am also grateful to the Ontario Heritage Foundation: first, for asking me to research what turned out to be a fascinating topic, and second, for seeing fit to honour this great achievement with a commemorative historic plaque.

My thanks also to Atomic Energy of Canada Limited (AECL), Ontario Hydro, and Canadian General Electric. Without their work in the 1950s and 1960s, there would be no Nuclear Power Demonstration reactor and no celebration today.

But most of all, my sincerest thanks to the many men and women who contributed to this great pioneering effort. The Ottawa Valley is a valley of pioneering and that pioneering has gone from exploration, fur and timber trade all the way to nuclear reactors.

The NPD reactor is revolutionary. Some say that Canadians do not have a revolutionary history but they are wrong, because their view of history doesn't extend beyond politics. We find the most revolutionary of Canadian history when we turn to engineering, science, and technology. I was delighted when the previous speaker, Ms. Cheryl Gallant, MP for Renfrew-Nipissing-Pembroke, referred to the NPD reactor as "revolutionary." Now there is someone who understands the breadth of Canadian history.

The NPD reactor revolutionized reactor design and on June 4, 1962, revolutionized electric power in Ontario, when it supplied the Ontario Hydro power grid with the first nuclear-generated electricity in Canada.

Our history tells us who we are, particularly when we look at how we respond to crises, new information, and new situations. The NPD was to serve both as prototype and as a research and training centre for much larger-scale nuclear electric generating facilities. The discovery that the NPD reactor design could not be scaled up successfully meant that the NPD reactor risked becoming a research and development dead end, relegated to a lesser role rather than helping to lead the way to larger-scale reactors. This was a grave surprise and a test of who we were.

Canadians reacted admirably. Some might have decided to leave the design unchanged and simply redefine the role of the NPD reactor so as not to face the need for major design rethinking.

But that didn't happen. Last night, Lorne McConnell told us about the "agonizing decision" which stopped design and construction on the NPD-1 and led to a new design, then called the NPD-2, the reactor we are honouring today. That decision was an act of bureaucratic courage and a model for how to deal with surprising new information and insights, a model of the relationship between research and development, a model of how we should be guided by research. The entire NPD project team reacted courageously and with the best interests of the people of Ontario, and the rest of Canada, in mind. That decision is truly one of the proud moments in our history. It allowed the NPD reactor, known temporarily as NPD-2, to serve as proof-of-concept for the CANDU reactor design and, over its 25 years lifespan, make many contributions to the field of nuclear power in Canada and abroad.

The NPD reactor and Canada's pursuit of nuclear-generated electric power also tells us about our sense of community and our ideals.

Last night, Lorne McConnell mentioned his sense of community, and today we should also speak of community. We are all members of various communities. Last night we saw something of the Deep River Community, which is a focal part of Canada's and the world's nuclear power community. We are members of the communities of our various professions and trades, each of which contributed to the success of NPD and the story of CANDU and nuclear-generated electricity in Canada. We are also members of the Canadian community, and as Canadians, we took our own approach to nuclear knowledge.

During the Second World War, Canada contributed to the development of the atomic bomb. It was a wartime necessity; sometimes we have to do terrible things in the hopes of avoiding even more terrible events. However, even before the war was over, Canada had decided that after the war it would use nuclear knowledge to advance peaceful purposes. While many countries talked about "Atoms for Peace," for Canada the slogan meant atoms for peaceful purposes only. The Canadian-made bomb would be the cobalt bomb for treating cancer. For some other nations such as the United States and the United Kingdom "Atoms for Peace" meant atoms for peaceful purposes, but not to the exclusion of developing atomic weapons.

Canada's interpretation of the catchphrase "Atoms for Peace" was part of our continuing search for what is appropriate for us. The search for the appropriate is an important recurring theme in the history of Canadian engineering history, as well as other aspects of our history. And to me there is such a thing as appropriate nuclear technology.

In 1978 the prestigious journal Science published a retrospective article by Canadian nuclear scientist J.A.L. Robertson, under the title "The CANDU Reactor System: An Appropriate Technology."[1] [2]. Robertson explained that "The selection of reactor types for national power systems is not determined by physics alone" Naval propulsion was the first application of nuclear power in the United States. Minimum physical size was the dominant criterion and light-water reactors were a reasonable choice. Enriched fuel was available from diffusion plants built during the war, and construction of large pressure vessels was within U.S. industrial capability." In Britain, early emphasis on nuclear weapons also influenced the approach to nuclear design. This meant that when these countries turned to "civilian nuclear power" they already had larger-scale reactors, experience with their financial implications, and "demonstrated engineering viability and established industrial infrastructure."[3]

But what was the situation in Ontario? First, the hydro-electric generating mindset accepted high construction and initial capital costs, but expected low operating costs along with near continuous operation. Canada also had a good source of natural uranium in the Elliot Lake mines in Northern Ontario. On the basis of price, natural uranium was the logical choice of fuel - even though it had one disadvantage. For reasons we do not have time to explore here, natural uranium (as distinct from enriched uranium) required a heavy water moderator rather than a light water moderator. But Canada already had considerable experience with heavy water moderated reactors.

And so scientific principles and knowledge, combined with what we as Canadians thought was an appropriate way for us to behave, led to the basic characteristics of the CANDU reactor, which was Canadian, used heavy water as both moderator and coolant (which were kept separate), and relied on natural or unenriched uranium fuel.

Turning these basic design decisions into an efficient, safe reactor led to some very elegant and practical science and engineering. Again, there were far too many achievements to list them here. For example, "the separation of coolant and moderator meant that their chemistries could be independently optimized. Specifically, neutron poisons could be added to the moderator to control or shut down the reactor without jeopardizing the corrosion control of the primary coolant circuit."[4]

The basic design philosophy also led to bold engineering solutions, particularly in the CANDU reactor's most important feature, namely "the concept of on-power fueling, which had not previously been attempted for a water-cooled reactor."[5] This was no small feat. Just as the overall reactor design had had to be changed completely, so too did the design of the fueling machinery, but that was the kind of

Following the official unveiling ceremony the main participants pose with the historical NPD plaque. In the background is the remaining NPD building.: Left to Right: Cheryl Gallant (MP), Jeremy Whitlock (CNS), Lorne McConnell (OPG, NPD, ret'd), Georges Quirion (OHF), Norman Ball (University of Waterloo)

change one could make in a demonstration project where research, new knowledge, techniques, and understanding are valued above all else, for they are the key to the ultimate goal: viable commercial nuclear electric plants.

Again, we see a design philosophy that sets the research and engineering challenges we face in producing a technology that reflects who we are and who we wish to be. That is to say, it is appropriate technology.

But we should now turn to another question, the answer to which tells us more about who we are.

Why nuclear power? Why design and build the NPD reactor? The answer to both is a sincere desire to make a better world. That answer is about idealism.

Idealism is not a fashionable word; today "idealistic" is often regarded as a synonym for impractical or unrealistic. The word is associated with the kind of people who tend to go on and on about what is wrong with the world rather than what might be done realistically to improve it. But people who merely criticize are not idealists, they are merely whiners, desiccated philosophers who have long since lost touch with day-to-day life. In my experience and research, scientists and engineers are the true Canadian idealists. Many of the people present today are scientists and engineers. You people are idealists. You want things to work better and you're not afraid to take chances in pursuit of your goal.

The NPD reactor is a monument to idealism and how to create a better world. Ontario needed more electric power, but it didn't need more air pollution, so you set about finding a better way for Ontario, and ultimately Canada and the world, to secure more electric power. You took what we already have and coupled it to sound design and ideas. You were willing to explore uncharted territory - a Canadian tradition even older than our country. You undertook the challenge of working in a harsh environment, another hallmark of Canadian technology and engineering.

Those who explore uncharted territory need the courage to follow new possibilities. And those who advance the leading edge of technology must have the courage to face up to the implications of new knowledge, even when it means radical changes in plan. We saw all of this happening as new knowledge led to redesign and new solutions.

The story of NPD and its successors also demonstrates the need for sound, knowledgeable management and corporate governance. Sound management and corporate governance should complement sound science and engineering. We know that any project or industry is only as strong as its weakest link, and if management or administration is weak, then strong engineering or innovation will not save the project or the industry. We have a great deal to learn from the NPD management, which had the courage to scrap one design and adopt an entirely new and eminently successful NPD reactor design. Now that more Canadians are seeing what happens without sound management and corporate governance, we need to look at both types of situation and decide what we want to be known for in the future. Right now, we are known for both approaches to management and governance: the sound and the unsound.

The NPD story also reminds of our need to make and stick to long-term plans for training the best possible people to the best standards. Training is about a commitment to the future and a shared sense of community. Without that commitment to the future and a shared sense of community, we achieve far less than we should. Perhaps it was the commitment to the future and a shared sense of community that made NPD far more than many suspected it might have

Norman Ball (R) speaks with Archie Robertson and Cheryl Gallant following the NPD historic plaque unveiling June 1, 2002.

become when it started.

Is it all over?

But now NPD is closed, decommissioned. Is it dead? If we had been able to hook NPD up to a heart monitor, we once would have seen the healthy beat of a vibrant site. Would we now just see the flat line of death? I don't think so.

History and life are continuums punctuated by special events that help us see things more clearly. Last night, NPD was alive and well. As we listened to Lorne McConnell and met in the high school cafeteria to share experiences, look at a now-archival film, and pore over historic photos and reports, NPD came back to life. We were sharing a sense of membership in four communities: Deep River, NPD, the Canadian nuclear community, and the community of Canadians who want to use what we have to make things better. Above all, NPD was alive when people talked about what it meant then, means now, and could mean in the future if we let it. Last night NPD was a focal point of shared communities.

Perhaps the last two days have suggested what we need to do next. I would like to suggest that we need to take what we glimpsed last night in the high school, what we glimpsed today, what we shared both days, and that we then add even more and bring them together to a new useful life for NPD. Now is the time to give NPD continuing life in a new form. Today, much of the evidence suggests that we tend to forget that as Canadians we were once known for the courage to face the unexplored and to make and stick to long-term plans and commitments in the face of uncertainty.

We need to capture the NPD story, because it holds valuable lessons and reminders for us all. It is a story of commitment; of sustained research and engineering development; of being ourselves and drawing on others as needed; of faith in nuclear power as an essential part of a better world; of appropriate technology and Canada's search for the truly appropriate as distinct from the trendy fashion of the day.

Researching the tip of the NPD story has both humbled and excited me. I've written books and articles on Canadian engineering and technology, and I thought I knew something. This brief research project taught me how much I, and many others, had underestimated the importance of NPD. Let's capture the story and tell it properly, over and over again. It is one of the great adventures of the twentieth century and one of the high points of Canadian history.

Thank you for sharing it with me and I hope I will be able to learn more.

In closing let me say that I admire and appreciate all that you have done. Now, how do we capture and get the story out?

Nuclear Power Demonstration Reactor

On June 4, 1962 the Nuclear Power Demonstration (NPD) Reactor 3 km east of Rolphton supplied the Ontario power grid with the first nuclear-generated electricity in Canada. A joint project of Atomic Energy of Canada Limited, Ontario Hydro and Canadian General Electric, NPD was the prototype and proving ground for research and development that led to commercial application of the CANDU system for generating electric power from a nuclear plant using natural uranium fuel, heavy water moderator and coolant in a pressure tube configuration with on-power refuelling. As a science and engineering research centre, NPD produced internationally significant knowledge and techniques. It was also a training centre for nuclear plant operators. NPD closed in 1987 after exceeding its operational goals.

Le Réacteur Nucléaire Expérimental NPD

Le 4 juin 1962, le réacteur nucléaire expérimental NPD (Nuclear Power Demonstration) situé à trois kilomètres à l'est de Rolphton, produit, pour la première fois au Canada, de l'électricité nucléaire. Construit par …nergie atomique du Canada Limitée, Ontario Hydro et Générale électrique du Canada, il est le prototype qui inspire la conception de son application commerciale, le système CANDU, réacteur à tubes de force qui utilise l'uranium naturel comme combustible, est ralenti et refroidi à l'eau lourde, et qui est ravitaillé en cours de fonctionnement. Le réacteur NPD concentre la recherche dans ce domaine et suscite des connaissances et des techniques capitales reconnues dans le monde entier. Après avoir été un centre de formation pour les techniciens de centrales nucléaires, il ferme en 1987, ayant dépassé ses objectifs opérationnels.

References:

1. J.A.L. Robertson, "The CANDU Reactor System: An Appropriate Technology," Science, 10 February, 1978, volume 199, number 4329, pp. 657-664.
2. In referring to this article during the speech, I mentioned that it "was written by someone I only know, and admire, as J.A.L. Robertson, but some of you here might know him personally." Near the middle of the standing-room audience, a number of people pointed to a man with them and replied "He's right here." As a speaker, I was honoured to have him in the audience and to speak with him later in the day.
3. Robertson, "An Appropriate Technology," p. 658.
4. Robertson, "An Appropriate Technology," p. 658.
5. Robertson, "An Appropriate Technology," p. 658.

Ed. Note: *We have two book reviews this issue, both from Keith Weaver.*

BOOK REVIEW

"Memoirs: A Twentieth Century Journey in Science and Politics"

Edward Teller (with Judith Shoolery)

Perseus Publishing, Cambridge Mass., 2001.

The thought of nuclear weapons is something of a universal turn-off. Perhaps this is as it should be. The apologist's argument that the mere existence of nuclear weapons has allowed a 50-year span during which no global conflict has erupted (the reason being, so the argument goes, that the risk of someone being driven to the first use of nuclear weapons and the high probability of near total annihilation that would result, has driven us all safely back from the brink) is very suspect. As an argument justifying the existence of these weapons, this one doesn't even make it out of the starting gate. At best, it is an ex post facto description of what has been observed to occur during the last half of the 20th century.

In the few decades just prior to this presumed "pax atomica", the appearance of two characters, whose access to powerful technologies made them the worst examples in all of human history (Hitler and Stalin), is indication enough of what might happen if far more potent technologies were available to the wrong people. The demonstrated continuing weakness of humans to live up to their potential (e.g. the failure of systems whose underlying philosophy is good - communism and institutionalised socialism - not to forget the recently unmasked weaknesses of a capitalism that purports to have a human face), provides evidence enough to indicate that responsibility for and control over powerful military technologies must be distributed as much as possible and not concentrated in a few hands.

Edward Teller's involvement in the Manhattan Project, his advocacy for the development of the hydrogen bomb, and his (probably misunderstood) role in the defence initiatives during the Reagan years have undoubtedly coloured his public image. His accomplishments as a scientist (which were perhaps more limited than they would have been otherwise on account of his involvement in defence work) are, by comparison, not well known. But it is the existence of Edward Teller as a person that appears to have been almost completely eclipsed. While an autobiographical account can provide an unreliable view of an individual, this one is easily worth reading.

The prominence of Teller's work on weapons comes through in this book and this is likely of considerable interest to anyone who works in the nuclear business and has followed its short but dramatic history. Fortunately, Teller provides more than just a lab notebook account of what happened. The larger-than-life characters are all here: Oppenheimer, Fermi, Bethe, Szilard, Strauss, Lilienthal, etc. Teller attempts to describe his interactions with these people over a period of years, how views changed and diverged, and why he did what he did. Some may see this as an attempt to write history through a particular lens, and there is no point in denying that this might be occurring, whether deliberate or not doesn't matter. As one participant's account of a period that was (and in large part remains) closed to anyone who was not there, it is valuable material. (Other reviewers, not having some involvement in the industry, have complained that this part of the book is overdone, and that the whole work is thereby made droning and tedious. Different strokes for different folks.) While this material is interesting, for me the best of Teller's book is his account of his life in other spheres.

The story of a Hungarian Jew who was raised during the golden age of physics and in the richness of German culture, who avoided the Jews' bloodbath in Germany and elsewhere in Europe following 1933, who was a member of the notable collection of "Martians" (the ÈmigrÈ Hungarian mafia that included Szilard, von Neumann, and others) is much more interesting. More important still is the reminder that it is all too easy to fall into the trap of thinking of someone in terms of their "demonised" persona, the view of a person in terms of an extended tissue of "factoids" driven in this case perhaps by a universal fear and loathing of something as horrendous as nuclear weapons. There is a real person called Edward Teller, and an engaging account of that person is presented in this book.

BOOK REVIEW

"Sakharov: A Biography"

Richard Lourie, Brandeis

University Press, Hanover, New Hampshire, 2002.

To many people in the West, there is something fascinating about Russian scientists. They are part of a generalised European tradition, yet they are also embedded within the strong Russian cultural fabric, and throughout most of this century, they have been constrained by a vast ideological tragedy. During that same period, they have lived in a state which evolved first rate military technologies, but whose peoples suffered relative poverty and deprivation. As examples of these scientists, the names Lev Landau, Peter Kapitsa, and Andrei Kolmogorov come immediately to mind.

Andrei Sakharov seems to be unfairly excluded from this company. As a scientist, he could be viewed as something of a combination of Robert Oppenheimer and Richard Feynman. But he is far more than this.

Perhaps like Edward Teller, his potential in science was limited by his involvement in work on atomic weapons, the difference being that in Sakharov's case his participation was dictated by the state. As with the US programme, the detailed technical contributions made to the Soviet programme by Sakharov remain veiled. In addition, for reasons of state paranoia, Sakharov's full involvement in Soviet politics, during the 20 years leading up to the collapse in 1989 of that unlamented empire, was kept out of sight. Richard Lourie's book goes a long way toward rectifying that lacuna, and it should be mandatory reading for everyone who lives in a democracy.

Sakharov is often characterised as the father of the Soviet hydrogen bomb, a description that he always disliked. He never was apologetic for or regretted his work on nuclear weapons. What he did he understood had to be done because his country needed it. Working under the brilliant, forceful and astute Igor Kurchatov in the Ministry of Medium Machine Building (the equivalent of Britain's "Tube Alloys" and the American "Manhattan Project") at Arzamas-16 (the equivalent of Los Alamos), Sakharov devised three independent designs for a hydrogen bomb. All were tested and they all worked. This included a gigantic 50 megaton weapon whose design and testing was technical posturing solely to demonstrate Russian pre-eminence and as a political statement to support some of Krushchev's fantasies. (Such a weapon is impractical. Calculations done by Teller and others have shown that going above about three megatons delivers little or no incremental military advantage. One moves a lot more air around, but that's all.)

Having helped develop these weapons, Sakharov carried out calculations to estimate what would be the effects on populations as a result of extended atmospheric testing or if they were used in anger. Needless to say, he didn't like the answers he got. But the turning point for much of Sakharov's future occurred during the celebration following the testing of the first Soviet hydrogen bomb in 1954. The military big wigs, flushed with their success, were all assembled and Sakharov had pride of position. He was also allowed the honour of proposing the first toast. His toast was this. "May all our devices explode as successfully as today's, but always over test sites and never over cities." The brass grimaced as though Sakharov had audibly broken wind at an elegant garden party. Succeeding toasts were lewd parodies which isolated and humiliated Sakharov. From this point on, his life began to change.

Sakharov began questioning the purposes and objectives of the Soviet weapons programme, and in particular the need for testing. Even though Stalin was dead by then, and the unspeakably repulsive Lavrenty Beria had been liquidated in an underground military bunker, Sakharov's actions were definitely not conducive to his continued well-being. But he was a figure of technical and political prominence and he gambled that this would allow him a freedom of expression which would not be tolerated in anyone else.

Sakharov began agitating. He goaded his fellow academicians to reject membership proposed for a disciple of Lysenko, the inventor of a statement of "genetics" of which the state approved, but which was generally panned as pernicious rubbish. Sakharov prevailed. He agitated against the treatment of dissident scientists banished to the Gulag. He agitated against the rising anti-semitism that was directed at his scientific colleagues. He engaged in a campaign of letters to senior Soviet officials on the need for democratisation. His salary was cut almost in half. His privileges were restricted. A campaign of harassment against him was instituted. He was characterised as a traitor. He agitated, eventually with success, for a visa so that his second wife, Elena Bonner, could receive treatment in the West for advancing glaucoma. He was exiled internally to the city of Gorky, closed to outsiders because of the concentration of military installations there. He and Bonner were personally harassed by the KGB, especially during the dark ruling days of Yuri Andropov, the man who masterminded the crushing of the Hungarian uprising.

In 1975, Sakharov was awarded the Nobel Prize for Peace. There was no question of him being allowed out to accept it, but Bonner made the trip to Stockholm to deliver his acceptance speech. The official Soviet press erupted in a chorus of objections, of how the Nobel committee was making trouble, of interference by the West in internal Soviet affairs. While his stature in the West was rising, within Russia he was isolated. He played the role during this period of a solitary moral force who would not give up, and who would not give in. His heart condition grew worse. There were hunger strikes. His written material had to be guarded all the time. He would carry all his handwritten text, particularly his memoirs growing to many hundreds of pages, in a briefcase. This he had to take with him whenever there was nobody in their Gorky flat, even when he went out on his modest shopping trips. This strategy was not always successful. His manuscripts were stolen by the KGB on more than one occasion when either he or Bonner relaxed their vigilance inadvertently. These thefts had to be followed by a painful reconstruction of the material. He intervened in trials of dissident scientists, the best known ones being perhaps those of Shcharansky and Orlov. Through it all, he and Bonner had only each other to cling to.

Then came Gorbachov. The whole system rapidly began to unravel. Glasnost and perestroika began their shaky evolution. But Sakharov's agenda was too revolutionary for Gorbachov. The first semi-free elections were to be held in the Soviet Union, but Article 6 of the Soviet constitution, guaranteeing the communist party an absolute majority, was to be retained in any future "democracy". Sakharov worked at having this travesty reversed. He successfully stood as the representative to the Duma for the Academy of Sciences. He was now working almost day and night on the affairs of his country and on behalf of individuals and groups. He made presentations before the Duma, and was heaped with abuse by the communist party. He undertook to rewrite the constitution. He completed the last pages of his memoirs. Things were coming to a head and Gorbachov began retreating from his position on Article 6, which was becoming untenable. On December 14, 1989 Sakharov lay down for a rest after his dinner. On going to awaken him at nine o'clock, as he had requested, Bonner found him dead. He was 69 years old.

In an epilogue, Lourie tries to assess Sakharov and his achievements, and what he might have achieved had he lived a few more years and reached his expectation of equalling his father's 72 year longevity. What comes through is Sakharov's technical brilliance, but even more so his human face, his humanitarian accomplishments and his tenacity. He was the man who said "The future can be wonderful, but it might not be at all. That depends on us." He was also the man who lived by Goethe's dictum:

> He alone is worthy of life and freedom
> Who each day does battle for them anew.

In the Times Literary Supplement of June 28, 2002, a review of this book begins with the sentence:

"The life of Andrei Sakharov makes one proud to be a human being."

That says it all.

Much Ado About Neutrons

by Jeremy Whitlock

In this bumper year for nuclear anniversaries in Canada, one might be forgiven for overlooking the fact that AECL isn't the only treasured national institution currently observing its 50th anniversary.

The gentle reader's mind, thus prodded, no doubt turns to the Deep River Symphony Orchestra, the Ottawa Tulip Festival, the DeHavilland DHC-3 Single Otter, CBC Television, the first all-Canadian Governor-Generalship, or indeed, the reign of the monarch so represented - all worthy co-bathers in AECL's pentagenarian limelight.

But for pure pioneering spirit, national identity, ingenuity, perseverance, and world-class accomplishment, one need seek AECL's peer no further than Canada's renown Stratford Festival, now in its 50th season.

Contrary to what most people would think, however, there is actually very little in common between Canada's premiere classical theatre company and Canada's premiere nuclear R&D company. As this no doubt comes as some surprise, the following notes are offered, by way of explanation:

Top Ten Reasons, Fully QA'd, Why AECL Is Not Like The Stratford Festival:

12. As far as is known, Christopher Plummer has never operated a CANDU reactor.
11. Also as far as is known, no AECL luminary has gone on to lead a band of singing kids in short pants over a mountain. There may possibly be an exception involving Mt. Martin.
10. It is almost certain that William Shatner never plied his craft in a reactor control room. Then again, the Stratford Festival would probably like to forget that he ever plied his craft there as well.
9. AECL has never created a bomb.
8. There are no swans on the Ottawa or Winnipeg Rivers. Many a swan song has been heard, however, in these environs.
7. The Stratford Festival tried hard to avoid coincidence between its birthday, July 13 (one day AFTER the Glorious Twelfth), and well-known existing celebrations. AECL, meanwhile, was incorporated on Valentine's Day and inaugurated on April Fool's Day.
6. Stratford's set crew can switch effortlessly from Scottish battlefield to the street where Eliza Doolittle lives, but they probably couldn't change out a calandria and get the reactor going again in under two years.
5. Only one of AECL's "star-cross'd lovers", Research and Development, received a mortal wound.
4. Had Macbeth a federal directive to create a firebreak around Dunsinane Castle, his contractor's backhoes could have taken care of Burnham Wood in no time at all.
3. Stratford recently upgraded its theatres to provide more leg-room, breathing space, and general ease of movement. Cubicle space-management has a somewhat different philosophy.
2. Nuclear scientists have probably performed more Gilbert & Sullivan over the years.
1. The Stratford Festival was conceived by a small band of visionaries, implemented in a railway community on the edge of a picturesque river, presented in a large circus tent for the first few years, and in short order attained international acclaim through brilliant management and production. AECL had a solid roof over its head from the start.

CALENDAR

2002

Sept. 4 - 6
World Nuclear Association 2002 Symposium
London, UK
website: www.world-nuclear.org
e-mail: wna@world-nuclear.org

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

Oct. 7 - 9
ENC 2002
International Nuclear Congress and Exhibition
Lille, France
See Website:
www.enc2002.org
e-mail: enc2002@to.aey.ch

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. 16 - 18
Americas Nuclear Energy Symposium
Miami, Florida
website: www.anes2002.org

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

Nov. 3 - 5
22nd CNS Nuclear Simulation Symposium
Ottawa, Ontario
Contact: Dr. Dumitru Serghiuta
CNSC
Tel: 613-947-2201
e-mail: serghiutad@cnsc-ccsn.gc.ca

Nov. 9 - 13
ANS / ENS International Meeting
New Orleans, LA
Contact: ANS
LaGrange Park,
Illinois, USA
Tel: 708-352-6611
e-mail: meetings@ans.org

Nov. 17 - 21
ANS Winter Meeting
Washington, D.C.
website: www.ans.org

2003

Feb. ??
CNS CANDU Chemistry Course
Cambridge, Ontario
Contact: Bill Schneider
B&W Canada
Tel: 519-621-2130 ext. 2269
e-mail: wgschneider@babcock.com

Feb. ??
CNA Winter Nuclear Seminar
Ottawa, Ontario
Contact: Colin Hunt
CNA
Tel: 613-237-3010
e-mail: huntc@cna.ca

April 6 - 10
ANS Mathematics & Computation Topical Meeting
Gatlinburg, Tennessee
Contact: Bernadette Kirk
ORNL
Tel: 865-574-6174
e-mail: kirkbl@ornl.gov

June 1 - 5
ANS Annual Meeting
San Diego, California
e-mail: meetings@ans.org
web: www.ans.org

June 8 - 11
24th CNS Annual Conference and 28th CNS / CNA Student Conference
Toronto, Ontario
Contact: CNS Office
Tel: 416-977-7620
e-mail: cns-snc@on.aibn.com

Nov. 16 - 18
6th International CANDU Maintenance Conference
Toronto, Ontario
Contact: Martin Reid
OPG - Pickering
Tel: 905-839-1151 ext. 3645
e-mail: martin.reid@opg.com

2001-2002 CNS Council • *Conseil de la SNC*

Executive / *Exécutif*

President / *Président*	Ian Wilson 905-469-1179	e-mail Ian.wilson@ilap.com
1st Vice-President / *1ier Vice-Président*	Jeremy Whitlock 613-584-3311	e-mail whitlock@aecl.ca
2nd Vice-President / *2ième Vice-Président*	Bill Schneider 519-621-2130	e-mail wgschneider@babcock.com
Secretary / *Secrétaire*	Ben Rouben 905-823-9040	e-mail roubenb@aecl.ca
Treasurer / *Tréssorier*	Walter Thompson 416-592-4349	e-mail walter.thompson@opg.com
Past President / *Président sortant*	Dave Jackson 905-525-9140	e-mail jacksond@mcmaster.ca

Members-at-Large / *Membres sans portefeuille*

Jerry Cuttler .905-837-8865
Ken Dormuth 905-823-9040
Ralph Hart .905-689-3197
Ed Hinchley .905-849-8987
Krish Krishnan 905-823-9040
Marc Leger 613-584-3311
Andrew Lee .905-270-8239
John Luxat .416-592-4067
Adam McLean 416-535-0616
Kris Mohan 905-823-9040
Dorin Nichita 905-823-9040
Jad Popovic .905-823-9040
Michel Rhéaume 819-298-2943
Roman Sejnoha 905-822-7033
Ken Smith .905-828-8216
Walter Thompson 506-458-9552
Martyn Walsh 905-373-0852
Bryan White 613-584-3311
Eric Williams 519-396-2249

Committees /*Comités*

Branch Affairs / *Affaires des sections locales*
Jeremy Whitlock . . . . 613-584-3311 whitlock@aecl.ca

Education & Communication / *Éducation et communication*
Jeremy Whitlock . . . . 613-584-3311 whitlock@aecl.ca

Finance / *Finance*
Walter Thompson . . . . . . 416-592-4349 walter.thompson@opg.com

Fusion / *Fusion*
Murray Stewart . . . . 416-590-9917 stewartm@idirect.com

Honours and Awards / *Honneurs et prix*
Paul Thompson . . . . 406-638-5334 pthompson@nbpower.com

International Liaison / *Relations internationales*
Kris Mohan . . . . 905-823-9040 mohank@aecl.ca

Internet /

Inter-Society / *Inter-sociétés*
Parviz Gulshani . . . . 905-823-9040 gulshanip@aecl.ca

Membership / *Adhésion*
Ben Rouben . . . . 905-823-9040 roubenb@aecl.ca

Past Presidents / *Présidents sortant*
Ken Smith . . . . 905-828-8216 unecan@echo-on.net

Program / *Programme*
Bill Schneider . . . . 519-621-2130 wgschneider@babcock.com

Universities / *Universités*
Bill Garland . . . . 905-525-9140 garlandw@mcmaster.ca

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

- Design & Materials / Conception et matériaux
  Bill Schneider 519-621-2130 schneidw@pgg.mcdermott.com
  Marc Leger 613-584-3311 legerm@aecl.ca
- Fuel Technologies / Technologies du combustibles
  Joseph Lau (905) 823-9040 lauj@aecl.ca
  Erk Kohn (416) 592-4603 erl.kohn@ontariopowergeneration.com
- Nuclear Operations / Exploitation nucléaire
  Martin Reid (905) 839-1151 reidmartin@hptmail.com
- Nuclear Science & Engineering / Science et génie nucléaire
  Sadok Guellouz (905) 823-9040 guellouzs@aecl.ca
- Environment & Waste Management / Environnement et Gestion des déchets radioactifs
  Duane Pendergast (416) 568-5437 duane.pendergast@comutare.org
  Judy Tamm (905) 823-9040 tammj@aecl.ca

CNA Liaison / *Agent de liaison d'ANC*

Bill Clarke . . . . (613) 237-4262
e-mail: clarkew@cna.ca

CNS Office / *Bureau d'ANC*

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

CNS Bulletin Editor / *Rédacteur du Bulletin SNC*

Fred Boyd . . . . (613) 592-2256
e-mail: fboyd96@aol.com

CNS Branch Chairs • Responsables des sections locales de la SNC

2002

Bruce	Eric Williams	519-361-2673	canoe.about@bmts.com
Chalk River	Michael Stephens	613-584-3311	stephensm@aecl.ca
Darlington	Jacques Plourde	905-623-6670	plourde@home.com
Golden Horseshoe	David Jackson	905-525-9140	jacksond@mcmaster.ca
Manitoba	Jason Martino	204-345-8625	martinoj@aecl.ca
New Brunswick	Mark McIntyre	506-659-2220	mmcintyre@nbpower.com
Ottawa	Bob Dixon	613-834-1149	dixonrs@ftn.net
Pickering	Marc Paiment	905-839-1151	marc.paiment@opg.com
Quebec	Guy Marleau	514-340-4711	marleau@meca.polymtl.ca
Saskatchewan	Walter Keyes	306-536-6733	walter.keyes@sk.sympatico.ca
Sheridan Park	Parviz Gulshani	905-823-9040	gulshanip@aecl.ca
Toronto	Adam McLean	416-534-3695	mclean@ecf.otoronto.ca

CNS WEB Page

For information on CNS activities and other links

http://www.cns-snc.ca