CANADIAN NUCLEAR SOCIETY · SOCIÉTÉ NUCLÉAIRE CANADIENNE

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CANADA 150

CNSC CCSN


- 37th Annual CNS Conference
- New Executive Council for CNS
- Update on Breathing Radon

Editorial

Staffing Requirements for Small Modular Reactors

There are many advantages to designing an autonomous reactor, that is, one that can be operated safely while unattended by staff. Some SMR vendors are actively considering this concept, since it is both unnecessary and inconvenient to maintain a qualified and licensed pool of operators in some northern remote regions where SMRs might be located. Instead, remote control and monitoring would ensure the safe operation of a SMR, and if a problem arises the SMR would be automatically shut down, safely, until an off-site team could be dispatched. However, the concept of an unattended nuclear control room raises concerns for both the public and the regulator.

All nuclear power plants operate automatically, although presently the control room is attended 24/7 by licensed operators. There is also a technical team of maintainers as well as administrative support, due to the complexity of interconnected mechanical and electrical components. Power reactors are simply too big to be controlled manually, so the reactor regulation system (RRS) is computer controlled (actually, two computers with one as a backup). Small changes in local reactivity (say within one cell of the entire reactor core) are readily detected by flux monitors and the RRS will adjust the reactivity by the local addition or removal of flux absorbing materials. The RRS, in essence, keeps the reactor "trim" at any set power. The power output can be set manually in the reactor control room or remotely by dispatch from grid control.

Of course on-site staffing of a large power reactor is necessary due to the hundreds of thousands of moving components, but by limiting the number of moving parts, only the control room needs to be considered. In theory, a CANDU nuclear power plant could operate with the control room unattended; there are sufficient alarms and signals to alert attention if human intervention is needed. But that does not happen. Conventional wisdom (and regulatory requirements) dictates the "comfort" of having a human operator on guard to intervene when needed, which is rare.

Consider, for example, the so-called self-driving car. Indeed, the Uber experiment of autonomous operation of its fleet still maintains a human behind the wheel "just in case". It makes the passengers "feel more comfortable".

However, staffing a SMR in a remote (and harsh) location is not convenient. Commuting to work could also be impeded during winter months, and it might be difficult to recruit qualified physicists and engineers to the small communities that don't see the sun for months at a time. But is on-site staffing needed for a SMR?

SMR designs have very few moving parts; maintenance is a "once in a few years" activity. Thus, the SMRs are fit for unattended operation. But still, the regulator needs to be "comfortable" with an SMR operating without onsite attendance. Such regulatory comfort may be attained with some concession with the adoption of Defence-in-Depth, a globally accepted principle. Although it would be a comfort to have staff in the control room, humans can also create a problem: what if the operator accidently pushes the wrong button? (Yes, it really did happen! In a real nuclear reactor! In Canada!)

So here is a comforting compromise that may appeal to all concerned. The SMR in the remote village will have a staff of one man and one dog. The purpose of the man is to feed the dog. The purpose of the dog is to keep the man away from the controls!

In This Issue

The Annual General Meeting of the Canadian Nuclear Society took place in conjunction with our 37th Annual Conference and 41st Annual CNA/CNS Student Conference, held this year in Niagara Falls, ON at the scenic Sheraton on the Falls Hotel. Congratulations to Daniel Gammage as out 2017/2018 CNS President. A full report of the AGM, Conference Events and some selected papers from the conference, are provided in this edition.

Also in this edition is a proposed Canadian Dream of "Synergistic Fuel Cycles in CAMDU and Fast Neutron Reactors", as an all inclusive energy centre providing clean energy (electricity, Hydrogen, synthetic methane and other fossil fuel replacements. UOIT Adjunct Professor and retired Nuclear Engineer Dan Meneley makes a convincing case.

Remember Don Wiles (presently Professor Emeritus of Chemistry at Carleton University) who worked with radium in 1948? He remains in good health despite his bone burden of radium ()chemically similar to calcium) and breaths radon gas at 25 times the legal limit. He has provided a follow-up article and questions the validity of the Linear No Threshold (LNT) and questions if there is a threshold for radiation harm.

Neil Alexander continues to provide interesting speculations and wonders if our industry is making it harder to communicate on technical issues. By example, he explains his fear of standing on the glass floor at the top of the CN Tower, where the strength of the glass is really a technical issue.

I trust you are enjoying a safe summer, driving carefully, and wearing floatation devises while boating!

From The Publisher

Attending a Canadian Nuclear Society annual conference is a wonderful event for anyone. It's an exposition of new advanced technology, of new techniques, of new applied science. We saw it this year at the 2017 Annual Conference, lots of it. It came in the form of technical papers and new products being showcased. It came in the form of new business opportunities and clear, unmistakable signs of growth.

It also comes in new participants in the industry. With more than 80 students attending the conference, the largest number to date at any CNS conference, it's becoming evident that Canada's nuclear industry is attracting the best and brightest from our academic institutions. This was so amply demonstrated at the Student Poster Contest. While still earning their degrees, they are doing new and interesting things in science and engineering, and they are solving difficult and complex problems in these fields.

It's showing that our industry is not simply alive but growing strongly. As demonstrated at the Conference, Canada's nuclear industry now has Canada's largest clean energy projects in the nation, the refurbishment of the Darlington reactors, to be followed in 2020 by the Bruce reactors. Our industry has new, immediate export prospects, notably in China and Argentina, and Canadian industries are finding non-CANDU business opportunities overseas.

In short, after more than a half-century of research and development, Canada's nuclear industry is a true, home-grown, high tech industry capable of competing with any other nuclear industry just about anywhere in the world. It is now central to Canada's industrial economy. For more than 40 years, nuclear power has been the dominant form of electricity production in Canada's industrial heartland, Ontario. Given the expected outcomes of the refurbishments of the Bruce and Darlington nuclear power stations, it will remain so for at least another half-century. It's moving forward with developments to manage all of its waste products, the only energy industry which can justly claim to do such. And it does so with no gaseous emissions.

And our industry is not just Canadian. With the spread of Canadian nuclear technology, it's now remarkable how many come to our conferences from overseas to exchange knowledge and share their experiences. With respect to new technology, there are no less than seven applications before the Canadian Nuclear Safety Commission (CNSC) for new small modular reactor design approvals. Some of these come from companies outside Canada.

One would think that a modern nuclear industry such as ours would be an achievement to be celebrated. It is attracting some attention from government. The recent report of the Parliamentary Standing Committee on Natural Resources (RNNR) was highly complimentary about the role that the industry has played and what it believes should be the future strong role of the industry in Canada.

But like any good thing, the nuclear industry has its critics. One particular piece of academic fantasy comes to mind, the 2015 study by an inmate of Stanford University. In 2015, he produced a study claiming that various forms of renewable energy, wind and solar predominantly, could provide all the electricity required by the United States. And do so by reducing atmospheric emissions to near-zero.

His analysis was rebuked by a large paper this month from the US National Academy of Sciences. It included items like fantastic misrepresentations of what hydraulic energy could produce.

But the most egregious of all of the 2015 paper's assumptions concerned nuclear. The Stanford author chose to inflate the atmospheric emissions of nuclear by assuming a nuclear weapons exchange among unnamed nations every 30 years and adding the carbon cost of burning buildings and vegetation to the tab of nuclear power.

Readers of the Bulletin can work out for themselves all the things that are absurd about this presumption. The point here is not however to tally up all the things wrong with it. The point is to illustrate the depth of intellectual dishonesty to which opponents of nuclear power need to stoop to voice their opposition. In this case, the allegation about nuclear is buried within footnotes and references. But it's still there and central to the argument made against nuclear power.

Sheltered by the sanctity of academic tenure, it's a cheap and easy fiction for an antinuclear activist to fabricate. We should feel some comfort from this. If these are the depths to which our opponents have to descend, that they have no better argument to make, then the future does indeed belong to nuclear power and not to charlatans.

And that's why so many of the young best and brightest are coming into our industry and to our conferences.

CGH

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Collage of Achievements in the Canadian Nuclear Industry as Canada Celebrates 150 years.

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2017 Canadian Nuclear Society Annual Conference

Our Nuclear Future: Renewal and Responsibility

by COLIN HUNT

Dan Gammage, CNS President 2017-18, opens the Annual Conference.

There was a strong sense of both achievement and optimism at the 2017 Canadian Nuclear Society (CNS) Annual Conference in Niagara Falls, Ontario this year. In previous years, CNS annual conferences were much about future opportunities for growth. This time, conference speakers could add achievements during the past year.

Such was particularly the case with the remarks of Glenn Jager, President and Chief Nuclear Officer, Ontario Power Generation (OPG). The principal focus for Mr. Jager was on the refurbishment of the Darlington nuclear power station. At the end of spring, the refurbishment of Darlington Unit 2 was 26 days ahead of schedule. He noted that OPG has now completed three of 10 steps in the refurbishment plan, for a total schedule of 40 months.

"Darlington is now 27 years old," Mr. Jager said. "This 10-year, $12.8 billion project is Canada's largest infrastructure project today."

He added that Unit 3 refurbishment will be started only when that of Unit 2 is complete. It will be followed sequentially by Units 1 and 4.

With respect to Pickering, Mr. Jager noted that OPG has invested more than $200 million in continued operation of the station. Originally, its reactors were scheduled to shut down in 2020, but OPG is now looking to extend operation of its six reactors to 2024.

Mr. Jager noted that nuclear power has been more than half of Ontario's electricity supply for more than 40 years. He said that the future of nuclear generation in Canada depends in large part on the success of refurbishment and life extension projects at Darlington, Pickering and Bruce. He emphasized strongly the good co-operation between OPG and Bruce Power in contributing to the success of both companies.

Following Mr. Jager, Gary Newman, Chief Nuclear Officer of Bruce Power, echoed his views about the benefits of strong collaboration between the two companies for the success of their nuclear refurbishments. Mr. Newman stated that Bruce Power has already invested hundreds of millions of dollars in its life extension programs prior to commencing major component replacement in 2020.

2017 Conference Chair Gary Newman, Bruce Power.

"Our Asset Management Program will ensure that Bruce Powr will continue to operate its reactors over the next 50 years," Mr. Newman said.

He also gave credit to CNS Council Member John Roberts for his work in extending the life of its steam generators.

Longer life for nuclear power plants was also the theme of the remarks of Bob Coward, President-Elect of the American Nuclear Society (ANS). He stated that American nuclear utilities are now looking at the operation of existing reactors from 60 to 80 years after first startup.

This view was supported by the final speaker of the opening plenary, Mr. Suhwan Bae, General Manager of Korea Hydro & Nuclear Power Company (KHNP). Mr. Bae noted the success of the refurbishment of its first CANDU reactor, Wolsong 1, and added that KHNP was looking at extended operation of its fleet of newer CANDUs and PWRs.

Plant life extension was also the theme of the second day of the conference. Stephen Burns, Commissioner of the US Nuclear Regulatory Commission (NRC) noted that US nuclear plant operators began looking at extended plant life more than a decade ago. Given the success experienced in subsequent years, Mr. Burns indicated that many operators are now looking at a second operating licence renewal to extend operating years to 60 to 80 years.

Mr. Burns noted that the NRC and the nuclear industry have agreed on the four top technical issues regarding a second licence renewal and are now working to resolve those issues.

On the future operation of CANDU reactors in China, Mr. Qiao Gang, Project Engineering Director of China National Nuclear Operation Company (CNNO), indicated that the two CANDUs at Qinshan Phase III have maintained lifetime operating capacity factors of about 90 per cent.

They started operating in 2003-3 with a pressure tube design life of 189,000 hours. However, based on the experience of other CANDU operators and their own work, they now expect to achieve tube life of

210,000 hours. It is now expected that the two reactors will be retubed in 2028-29.

Mr. Gang indicated that preliminary planning work has begun on the future refurbishment of the Qinshan reactors.

Concluding the Tuesday plenary, Adrian Cojanu of the Cernavoda Nuclear Power Plant in Romania noted that Cernavoda Unit 1 is now just over 20 years old. Mr. Cojanu said the company expects to achieve 30-year operating life for the reactor prior to refurbishment and a second 30-year operating cycle.

Lise Morton, Vice President, Ontario Power Generation.

The back end of the nuclear fuel cycle was the focus of the plenary on Wednesday, June 7. OPG Vice President Lise Morton took the opportunity to clarify the current situation of OPG projects. She noted that all radioactive waste in Ontario from its nuclear power sector is fully funding now. Ms. Morton noted that this included the Deep Geologic Repository (DGR) for low and intermediate level wastes.

Ms. Morton said that a decision was expected by the federal Minister of the Environment on the DGR by the end of 2017. She also indicated that all of the radioactive waste from the Darlington refurbishment will be stored for 25 years by OPG prior to disposal.

Speaking for the Nuclear Waste Management Organization (NWMO), Vice President Derek Wilson said that the NWMO has been making good progress in site selection for high level used nuclear fuel. He indicated that reduction in the number of volunteer sites commenced in 2010. At this time it is expected that final selection of the preferred site will be made in 2023.

Francesca Ottoni, Senior Vice President, SNC-Lavalin.

Keynote speaker for Wednesday, June 7 was Francesca Ottoni, Vice President Marketing for SNC-Lavalin. Ms Ottoni observed how much had changed in the world's nuclear industries over the past decade.

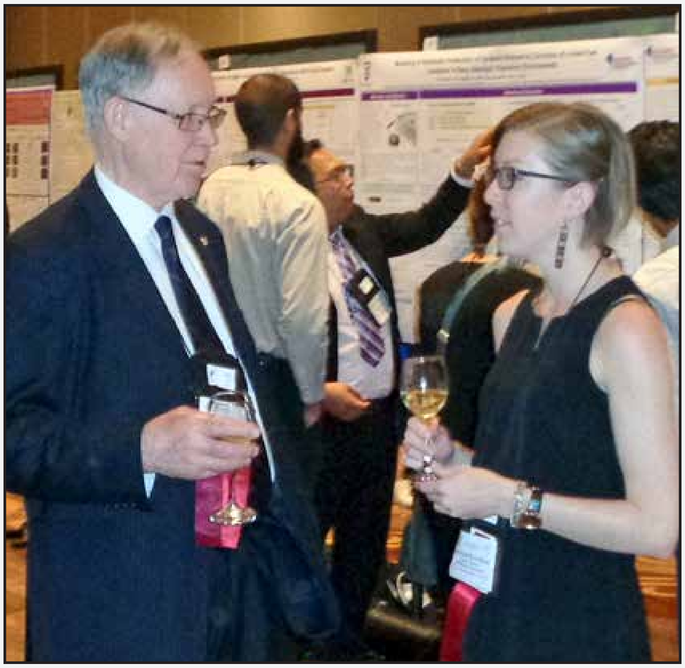
"Who would have guessed 10 years ago, that industry giants Areva and Westinghouse would experience such severe cost overruns resulting from next generation technology plagued with stricter regulatory requirements, and construction complexities. The long break in nuclear construction meant the industry simply wasn't ready for it."

On the other hand, Ms. Ottoni noted, nuclear power generation was thriving in Asia, with strong development in China, South Korea and the United Arab Emirates. And for Canada, there were the strong prospects of new CANDUs in China and in Argentina.

A large difference for Ms. Ottoni over the past decade was the much larger number of women in the industry.

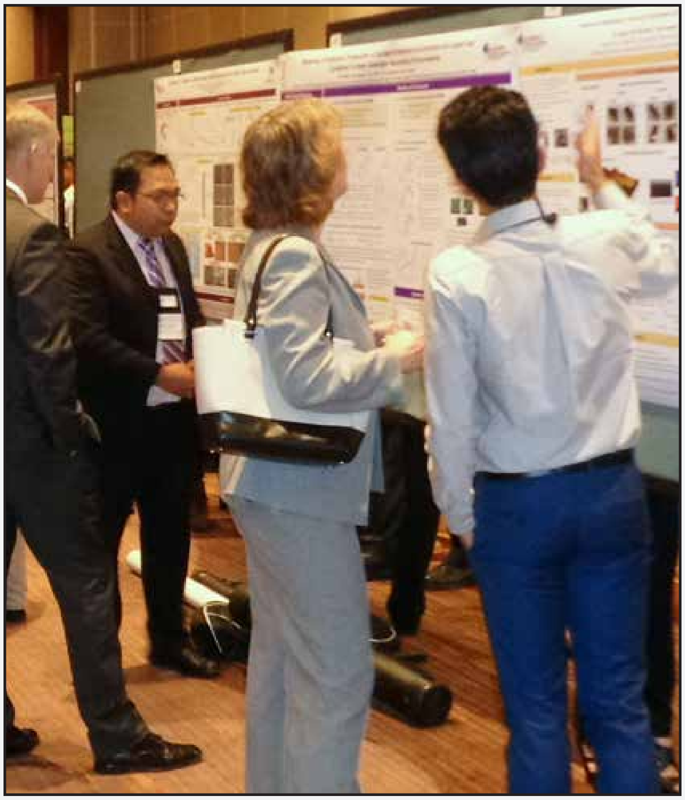
"If I had looked around the room at a CNS conference a decade ago, I'm sure I would have seen fewer women. Today, we know that more women in key decision-making roles boosts productivity, breeds innovation and strengthens recruitment efforts."

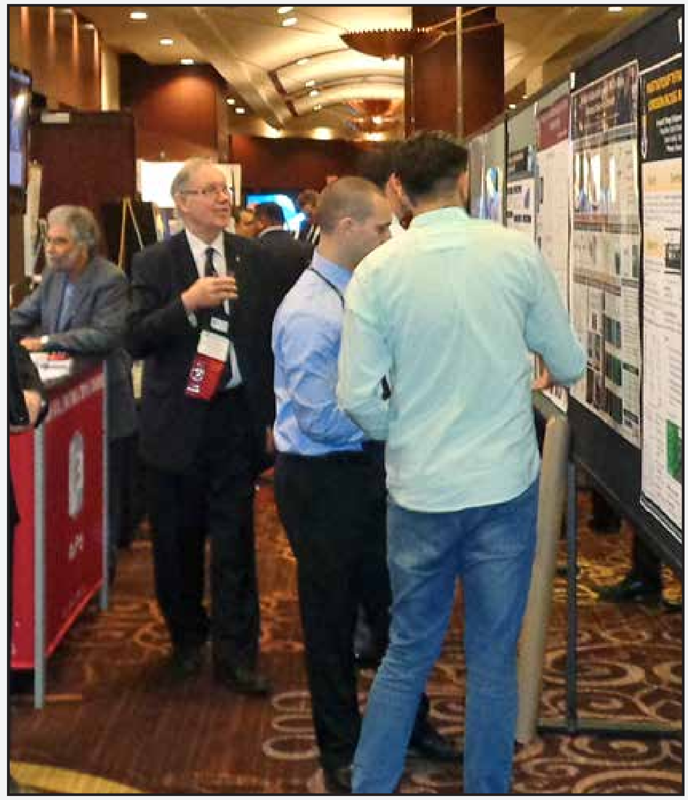
In closing, the 2017 CNS Annual Conference had approximately 400 delegates in attendance. These included about 80 students, the larger than any previous CNS conference. The conference sponsors included Host Sponsor Bruce Power, and sponsors Amec-Foster Wheeler, ANRIC, the Canadian Nuclear Association (CNA), Canadian Nuclear Global Services Inc., Canadian Nuclear Laboratories (CNL), the Canadian Nuclear Safety Commission (CNSC), New Brunswick Power, ES Fox Ltd., J.A Plourde Performance, Kinectrics, L3 MAPPS, the Nuclear Waste Management Organization (NWMO), the Organization of Canadian Nuclear Industries (OCNI), the Power Workers Union (PWU), SNC-Lavalin, Stern Laboratories, Tyne Engineering and Veolia. Thirty exhibitors with display booths were also present at the conference.

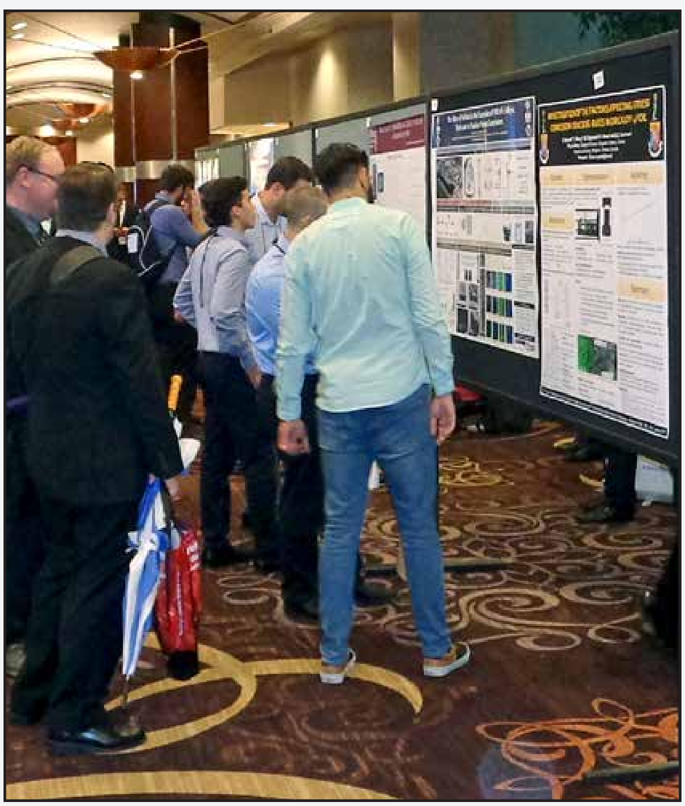


CNS 1st Vice President John Luxat and Student Conference Chair Kendall Boniface.

Scenes from the Student Poster Session







2017 Canadian Nuclear Achievement Awards

by RUXANDRA DRANGA, CNS-CNA Honours and Awards Chair

On June 6, 2017, the CNS and CNA jointly recognized 30 recipients for their outstanding contributions within the Canadian Nuclear industry and the Canadian nuclear research and academic communities, during the 2017 Canadian Nuclear Achievement Awards. The awards ceremony was held in Niagara Falls, Ontario, during the 37th Annual Canadian Nuclear Society Conference and 41st CNS/CNA Student Conference. This year, awards were presented for eight out of the ten available award categories, to recipients who exemplify the expertise, innovation and commitment found across our industry. The awards were presented by Dr. John Barrett, CNA President and Dr. Peter Ozemoyah, CNS President (2016-2017).

The **W.B. Lewis Medal** was presented this year to **Dr. Arthur McDonald**. Dr. McDonald is a Professor at Queen's University and the Director of the Sudbury Neutrino Observatory Institute. He started his career as a Postdoctoral Fellow and Research Officer at Atomic Energy of Canada Limited, Chalk River Laboratories, then moved to academia. In August 2001, under Dr. McDonald's leadership, a collaboration at the SNO Institute, reported a direct observation that neutrinos oscillate, changing flavour from electron neutrinos to muon and tau neutrinos. This observation answered a long-standing question of the Standard Model of elementary particles, with major implications for our understanding of the universe. In addition to receiving numerous awards, designations and recognition for his outstanding work in particle physics, Dr. Arthur McDonald is also the co-winner of the 2015 Nobel Prize in Physics "for the discovery of neutrino oscillations, which shows that neutrinos have mass".

The **Ian McRae Award of Merit** was awarded to **Ms. Joan Miller**. Ms. Miller is an internationally recognized senior executive with over 36 years of leadership at Atomic Energy of Canada Limited and Canadian Nuclear Laboratories. Her many and varied contributions in the areas of decommissioning and waste management, nuclear research and development, product and service development, nuclear facility operations and commercial project delivery have had far reaching and enduring positive impact on Canada's nuclear industry, government and communities. Early in her career, Ms. Miller and her team led the CANDU industry's pioneering work in the development of tritium handling and heavy water management systems. Since 2007, Ms. Miller was Vice President of AECL's Decommissioning and Waste Management organization. Under her leadership, the organization made impressive progress in often-complex DWM projects at Port Hope, Whiteshell Laboratories, the CANDU prototype reactors, and at Chalk River Laboratories. Throughout her career, Ms. Miller has been a role model, mentor and advocate for women in Canada's nuclear industry. Since her retirement in 2015, Ms. Miller continues to be an active participant in the nuclear industry and the Canadian Nuclear Society.

Dr. Igor Pioro received the **Harold A. Smith Outstanding Contribution Award**. Dr. Pioro is currently a Professor in the Faculty of Energy Systems and Nuclear Science at University of Ontario Institute of Technology. Dr. Pioro's career spans more than 35 years, having worked in various positions including engineer, senior scientist, deputy director, professor and associate dean. Throughout his career, Dr. Pioro made outstanding contributions to nuclear engineering research, teaching and professional services, particularly in the fields of nuclear energy systems and thermalhydraulics of nuclear reactors and Generation-IV reactor concepts. Dr. Pioro is also an outstanding educator and promoter of nuclear energy in Canada and internationally. At UOIT, he has held the positions of Graduate Program Director and Associate Dean in the Faculty of Energy Systems and Nuclear Science, developing six nuclear engineering courses. Internationally, he has been invited to give lectures and seminars on nuclear engineering, Generation-IV reactors, and energy generation at various universities, institutes and organizations.

Mr. Barclay Howden was the recipient of the **George C. Laurence Award for Nuclear Safety**. Mr. Howden's career spans more than 3 decades in various positions in the Canadian nuclear industry. His early contributions were in operation of the National Research Universal (NRU) Reactor. He joined the Atomic Energy Control Board, currently the Canadian Nuclear Safety Commission, in 1991. Early projects included the development and implementation of a complete emergency response program at CNSC. In 2003, as Director General of the Directorate of Nuclear Cycle and Facilities Regulation, Mr. Howden played a crucial role in implementing a risk-informed matrix to prioritize compliance verification activities. In 2007,

Back row (left to right): Simon Bérubé, Andrew Grieve, Jason Donev, Christopher Hollingshead.
Front row (left to right): Christopher Alcorn, Robert Liddle, Joan Miller, Barclay Howden, Mojtaba Momeni, Wei Shen, Perryn Bennett, Arthur McDonald.

he demonstrated his excellent leadership and composure in guiding the organization through the challenges of the NRU reactor extended outage, for which he was instrumental in preparing and delivering the CNSC's management response to the House of Commons Committees. Furthermore, he led the establishment of the CNSC's Harmonized Plan, bringing the lessons learned from corporate-wide improvement initiatives under one umbrella. Over his long and impressive career with the CNSC, Mr. Howden has led and implemented initiatives that have significantly enhanced nuclear safety in Canada. His strong management and leadership skills, professionalism and sound technical expertise gained him credibility and respect with both fellow CNSC colleagues and licensees.

The **John S. Hewitt Team Achievement Award** went to the **CWEST team**, which was comprised of engineers, technologists and various subject matter experts from Kinectrics Inc. The team was commissioned to design and build a circumferential wet-scrape tool to reduce outage duration and personnel dose during hydrogen-equivalent sampling at Bruce Power Nuclear Power Plants. The tool, which was successfully used at Bruce Power Unit 7, has shown significant improvements over the previous method of acquiring the samples. For example, the impact on the critical path was reduced by 50% while the doses to personnel have been reduced by a factor of 4 (from 2 rem/channel to 0.5 rem/channel). Significant improvements have also been noted in terms of human performance and ease of operations.

Two **Education and Communication Awards** were presented this year. The first award went to **Dr. Jason M.K.C. Donev** for enthusiasm and commitment to teaching and communicating with the public about nuclear science and nuclear energy. Dr. Donev is an educator, science communicator, and ambassador for nuclear science in Canada and internationally. He works as a Senior Instructor at the University of Calgary, where he has been an innovator in nuclear energy education. In his role at the university, Dr. Donev developed a curriculum that engages undergraduate students, imparts to them his passion for nuclear science, and teaches them to consider nuclear power within a holistic context of energy supply and consumption. In addition, Dr. Donev has been a tireless leader in teaching and communicating to the public about nuclear science and nuclear energy. He was one of the instructors who helped establish the CNS Nuclear 101 course, as well as the Society's nuclear education and outreach online forum.

The second **Education and Communication**

Award was presented to **Mr. Robert Liddle** for his passion and commitment as a tireless educator and advocate for the nuclear industry. Mr. Liddle's career spans almost 40 years in the nuclear industry. Mr. Liddle's background is in journalism, which, along with his innate curiosity and natural storytelling ability, positioned him to be one of the public faces at the Bruce Power site, where he worked in different roles, ranging from public education at the Visitor Centre to Manager of Community Relations. Mr. Liddle's ability to explain things in a way that everyone could understand, his contagious enthusiasm about nuclear technology, and his ability to mentor and teach communications professionals have been noted by colleagues, members of the community and other officials.

Dr. Wei Shen has been designated as **Fellow of the Canadian Nuclear Society** this year. Dr. Shen is working as a Technical Specialist in the Physics and Fuel Division at the Canadian Nuclear Safety Commission. Prior to joining the CNSC in 2013, Dr. Shen worked at AECL/Candu Energy in the area of reactor physics codes and methods. He has been a strong proponent of the Canadian nuclear industry and a strong supporter of the CANDU Research and Development community. His expertise in CANDU and PWR reactor physics, safety analysis, fuel management and software development and qualification, which he has accumulated over 20 years, is recognized by national and international peers. Dr. Shen has been an active member of the CNS since 1999, and part of the Sheridan Park Branch executive for over 12 years. He is currently a member of the CNS Council and a member of the executive committee of the Ottawa Branch. Over the years, Dr. Shen served as Technical Program Chair and Plenary Program Chair for numerous CNS Annual Conferences and Technical Meetings, including this year's Annual Conference, and has participated in or helped organize various CNS courses and symposia.

The final presentation was for the **R.E. Jervis Award**, which was awarded to **Mr. Mojtaba Momeni**, a PhD student in the Department of Chemistry at Western University. He obtained the award for his research in the area of corrosion of Cr-Fe-Ni alloys in nuclear reactor environments, under the supervision of Dr. Clara Wren. His research on enhancing the understanding and modelling of corrosion kinetics and how water chemistry induced by gamma radiation may affect corrosion kinetics has already produced significant amount of information valuable to the Canadian nuclear industry.

What a remarkable slate of recipients! Congratulations once again to all the honourees, who represent so well our nuclear community in Canada and internationally. Stay tuned for the Call for Nominations for the 2018 Canadian Nuclear Achievement Awards, which will come out this fall. On behalf of the CNS and CNA Honours and Awards Committee, I encourage you to continue to nominate your meritorious colleagues and join us next year to celebrate their achievements!

Synergetic Fuel Cycles in CANDU and Fast Neutron Reactors

by D.A. MENELEY*

[Ed. Note: The following paper was submitted to The Bulletin by the author.]

Abstract

Nuclear fission energy is expected take up part of the job of restoring world climate stability – quickly, economically, and safely.

The tasks aimed at restoring climate stability should perhaps be divided into urgent responses and sustained responses. This paper addresses one sound alternative for developing a sustained response. The author recommends establishment of integrated nuclear energy parks offering a diverse range of services in addition to electrical power.

Modern designs of reactor systems fueled by uranium, thorium or plutonium can bring together well-known concepts for diverse energy-intensive products. Creating nuclear energy parks to provide integrated services is well within economic reality, including heat and electricity production, high-pressure water electrolysis, carbon-neutral synthetic oil and gas production, and even vital non-electric products such as transportation fuel and pure water.

Today's energy supply scene is rich with both opportunity and challenge. We face a fast- developing crisis on earth – our only living space − caused by various consequences of our own existence, such as diminishing availability of oil and gas and by the climate instability that fossil fuels help to cause. The trend away from fossil fuels will continue as the world's energy production capacity is expanded and diversified to answer the need, and as fossil fuel supplies slowly diminish. At the same time we have an opportunity to eliminate the primary cause of our climate's instability, (by switching off our favorite fossil fuel sustaining energy sources) by offering a business opportunity for fossil fuel companies to transition away from fossil fuels while still using some of their existing infrastructure. We can do this by introducing large-scale energy production from uranium and thorium supporting a wide range of end products in nuclear energy parks.

A few years ago this author was invited to publish a paper in memory of Dr. W.B. Lewis, the originator and worthy proponent of the PHWR power system, later named CANDU. This near- breeder system is a good match for the newer design concept of an FNR (Fast Neutron Reactor) identified as the IFR (Integral Fast Reactor). The PRISM design variant of IFR offered by the General Electric Company is now market-ready. The CANDU-IFR combination constitutes one viable answer to the steadily increasing future world energy demand.

Introduction

Climate stability? How would it be if we started with fuel cycle stability? And how would it be if we started with fuel cycle stability in one part of the world instead of the whole world? How would it be if we started with Ontario, Canada? This contraction of goals might seem to be unrealistic. Ontario does have an unfair advantage at present, in that we no longer generate electricity with coal, as well as having clean, proven uranium energy for over half of our electricity.

The correct answer to that charge is that the subject of fuel cycle stability tends to grow quickly into a very "wicked problem" indeed. That is, the number of "yes, but" and "yet if" statements soon gets out of hand. While it is true that Ontario has an advantage because of our early start, it is also true that Ontarians worked hard to earn that advantage. Only in later years has the province turned away from this success path, under various pressures.

This presentation is an "academic" exercise in the sense that the author is a semi-retired professional engineer, not a staff member of a vendor company or government agency. However, the accumulated experience that led to this "academic" text was gained through decades of work in both theoretical and applied enterprises associated with the nuclear energy enterprise.

A diverse product delivery chain can be built around this energy center − [1].

It is sufficient to our purposes to say that systems under development today will change nuclear fission energy installations from almost exclusively electricity generating systems into industrial energy centers, capable of supplying essentially all of the energy needs of a society at either the national or international level. Obviously we must anticipate a massive increase in the number of plants in the nuclear fission fleet. This move will demand careful attention to fissile fuel supply. How can we do this?

* Adjunct Professor, University of Ontario Institute of Technology

Figure 1(a) – View of today's nuclear enterprise at the Bruce Nuclear Generating station (BNGS).

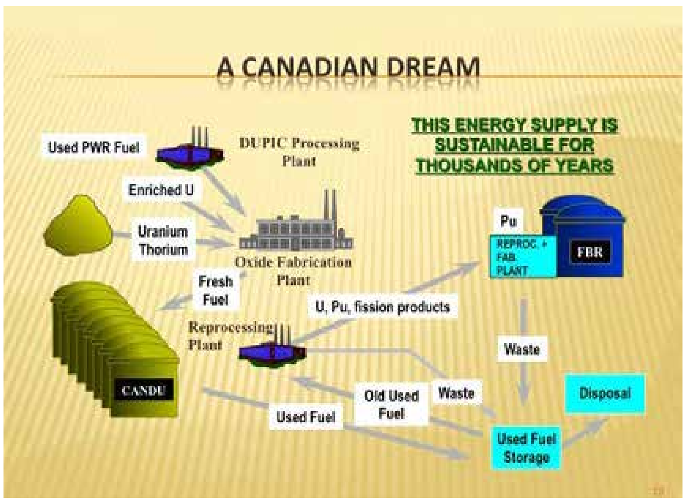


Figure 1(b) – Schematic of possible development of the BNGS site in the future.

A Sketch of the Fuel Supply Task

As noted above, Figure 1(a) shows the preset-day layout of the Bruce Generating Station in the upper left; it consists mainly of 6384 MWe of generation capacity supplied by eight CANDU reactors, interim used fuel storage, plus education and administration buildings. Bruce is not the largest plant site in the world, but certainly is among the largest.

This plant site uses about (6384/0.3) x .9 x 365.25 /7500 = 933 tons of natural uranium each year. All used fuel is stored on-site. The used fuel isotopic composition [2] is U=0.9857, U235=0.0023, TRU=0.0044, Fissile Pu=0.0027, FP=0.0099}.

Figure 1(b) shows one possible configuration of a nuclear energy center in the year 2100. First, assuming neither the installed capacity nor the performance of CANDU plants has changed since the year 2017, there will then be 933 x 83 x .9857 = 76,300 tons of used fuel available on site, along with 933 x 83 x .0027 = 209 tons of fissile plutonium, intimately mixed with the uranium, along with minor actinides and fission products.

Now, hypothesize a method of extracting uranium from used thermal reactor fuel, sufficient to produce a first charge for one IFR reactor of 1 GWe capacity (or a number of smaller units of 1 GWe total output) with average plutonium percentage of 15 %. Obviously, there will be adequate fissile material available for the first fuel load of a couple of large FNRs.

Once the fast reactors and their integral pyro-processing units are operating, they will be capable of drawing on the used fuel inventory for their own refueling requirements (only 2-3 tons of used CANDU fuel per year). In addition, excess plutonium then can be utilized (again, inside the IFR processing unit) to manufacture recycle fuel for CANDU units operating either on a recycled- uranium-plus-Pu cycle or on a Thorium-U233-Pu cycle. The CANDU units, therefore, are sustainable indefinitely, until they are retired at their ultimate life limit.

Electricity Demand Scenario

This paper is founded on the results of a recent study published in the open-access journal "Sustainability" [3]. For present purposes this reference paper will be deemed correct within its chosen assumptions. Quoting from the closing paragraph of that paper,

"This study should be considered as a preliminary attempt to associate quantified impacts to a foreseeable nuclear energy development. It gives some guidelines to perform future studies that could consider different hypotheses for the energy demand growth, different hypotheses on the uranium (and thorium, which was not considered in the present study) resource availability, and different type of reactors to be deployed, as well as the technological readiness of innovative fuel cycle facilities."

Information from this landmark paper [3] is used here to serve as the basis for exploring further options, while leaving the basic assumptions regarding energy demand unchanged.

Figure 2 as copied from Reference 3 shows the assumed annual world demand for electrical energy until 2200. Admittedly, this is a gross extrapolation, but one that is quite credible given population and other factors. What this figure does not include, however, is any allowance for nuclear generating capacity being installed specifically to eliminate fossil fuel burning, or to extract carbon dioxide from the atmosphere.

The dashed red line in Figure 2 indicates the effect on total energy demand of adding 10 GWe of nuclear capacity per year from 2025 to the year 2200. The first task of these units will be to achieve faster reduction in consumption of fossil fuel for electricity production. The second priority will be a broadening the product base to include carbon-neutral synthetic fuel production, so as to reduce

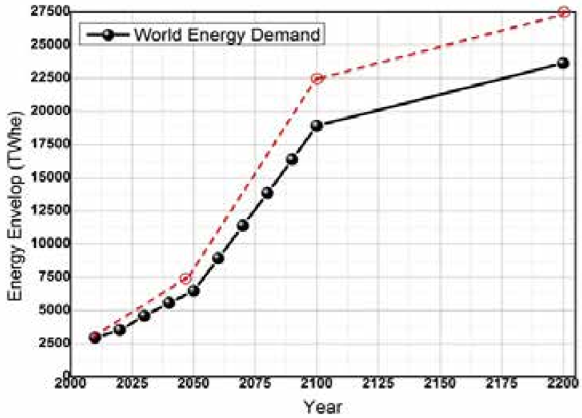


Figure 2 of [3]: World Energy projections (Twhe).

fossil fuel consumption in the transportation sector. By the year 2100, some 750 additional 1 GWe units will be operational in the world, in addition to the roughly 2200 new units already dedicated to the rising world electrical energy demand as identified in Reference 3. (NB: Agneta Rising, WNA Director General, at the Nuclear Africa 2017 conference {Mar 29, 2017}, estimated that the world must built one thousand 1 GWe nuclear units by 2050, for the purpose of reducing carbon combustion.)

A third goal of these new units will be a reduction in the existing level of carbon dioxide in the atmosphere. This can be achieved by extracting of CO2 from the seawater used for condenser cooling, through manipulation of the CCW water temperature during normal operation, and by other proposed methods [4].

Reactor Models

The models used in the Reference [3] report are listed in Table 1, without change. Table 1 includes three new reactor models that were not included in the original study; namely the CANDU heavy water reactor [7] the newest PHWR – the Advanced Fuel CANDU Reactor (AFCR) [8] and the high-gain Integral Fast Reactor, the IFR [5].

It is apparent that the choice of metal fuel for IFR-type Fast Neutron Reactors is superior in every way to the older selection of oxide fuel. These substantive advantages are described in detail in Reference 5. For applications considered in this paper, the foremost advantages of metal fuel are its higher breeding ratio, on-site integrated reprocessing capability, and lower cost.

The heavy water reactors listed in Table 1 have distinct advantages over the LWR in terms of higher internal conversion ratio and on-power fuelling capability. In addition, the AFCR variant can utilize thorium fuel "spiked" with a small number of fissile driver bundles in a heterogeneous configuration, to easily enter into sustainable utilization of thorium in a synergetic fuel cycle along with the IFR design.

In Figure 5 we see that uranium reserves are barely able (even after assuming perfect alignment between fuel availability and customers' fuel requirements) to last until the end of the current century. Acceleration of the "off fossil fuels" strategy but still retaining the LWR-only policy would move this unavailability date up to about 2070, only 53 years away. In the impossible event that all LWR-powered plants were converted to thorium fired CANDU-powered plants, the unavailability date would move back some 20 years to 2090. Better, but surely not good enough.

As is well known, [6] it would be an overwhelming challenge to extract enough uranium from seawater to supply fuel to a thermal reactor fleet of a few thousand 1-GWe thermal reactor plants. The scale of the extraction equipment (dissolved uranium is present

Table 1 of [3] (Modified) Summary of Reactor Characteristics

	PWR	CANDU	ISOGEN	AFCR	FNR	IFR
Burnup (GWd/tHM)	50	7.5	136	35	78	200
Cooling time (years)	5 --	2	--	2/5	2	
U235 enrich. or Pu content (%)	4.5	0.71	21.19	0.71eq	15.8/21.2	
Nominal electrical power (GWe)	1	1	1	1	1	1
Thermal efficiency (%)	34	30	40	30	40	40
Load factor (%)	85	90	85	90	85	85
Breeding or conversion ratio	0.38	0.80	1.02	.95-0.99	1.45	1.60
Cycle length (EFPD)	410	n.a.	340	n.a.	300	--
Fuel irradiation time (EFPD)	1640	360	1700	n.a.	2100	
Fuel type	UO2	UO2	(U.TRU)O2 /UO2	(U.Th)O2 /UO2	(U.TRU)O2 /UO2	(U- Zr) TRU)/U
Radial blanket irrad. time (EFPD)	--	--	2720	--	2400	--
MA/Pu mass ratio			0.1		0.1	

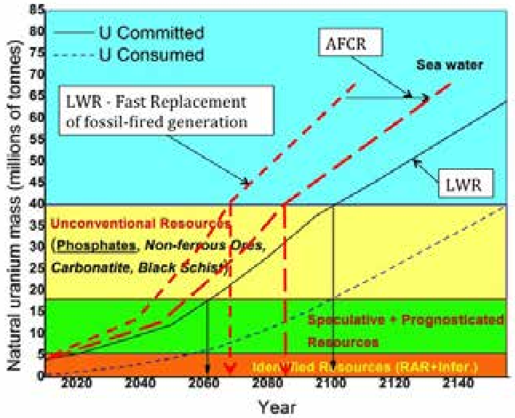


Figure 5: Natural uranium consumed and engaged for PWRs once-through case.

in seawater at about 4 parts per billion) would itself prove to be a major undertaking.

Fortunately, the IFR design exists as a real option. This design can achieve a compound system doubling time of 8.5 years, corresponding to a fleet growth rate of over 8 percent per year. This advantage is made firm by the use of pyro-processing, so that the ex-core cooling time is greatly reduced. Furthermore, the introduction of pyro-processing achieves yet another objective; that is, a reduction of the weaponry proliferation concern.

Figure 8a from Reference 3 shows the effects of having an improved doubling time and shorter out-reactor cooling time The IFR design can be introduced more quickly into the fleet, and therefore can respond to a higher world energy demand that might well occur because of a desire for nuclear energy to accomplish a faster elimination of fossil fuels in electrical power production. This rapid phase-out of thermal reactors will greatly reduce the amount of uranium that must be mined, processed and finally put into long-term storage.

Contrary to the conclusion stated in Reference 3, the support of a thermal reactor fleet in the mix will not be needed beyond the end of the 21st century, in the current scenario. There is a second way in which our descendants might wish to take advantage of the increased availability of fissile plutonium. We know that the AFCR design has a high internal conversion ratio. With the addition of only a small amount of plutonium to its fuel cycle this reactor can, even when operating in a once-through cycle with mostly thorium dioxide fuel, produce a substantial amount of uranium 233 mixed in its used fuel inventory.

Given the fact that thorium dioxide used fuel is more difficult to reprocess than its cousin uranium dioxide, it might prove possible to create yet another useful fissile element that could find its way into the market via the near-breeder molten salt reactor designs that are now popular among designers but which suffer from a shortage of fissile material to start up and sustain their operation.

While the effect of using some recycled plutonium from IFR to sustain the AFCR on a once- through cycle would slow the rate of buildup of installed capacity of the FNR reactor type, the benefit of creating an inventory of uranium 233 could prove to be important in fostering the installation of a fleet of a new and promising design – the molten salt reactor, or MSR.

Shown in Figure 8b from Reference 3, the Molten Salt Reactor (MSR) has a high conversion ratio, as does the AFCR. The AFCR can serve as a source of U233 for "topping up" the MSR and so would eliminate the need for any addition of U235 or plutonium; thereby simplifying that reactor fuel cycle. The MSR then could replace the "Isogenerator" version of the fast reactor that is discussed in Reference 3. The big difference, of course, is that some excess plutonium is used to sustain the AFCR fleet, while that fleet is fueled mostly with thorium dioxide fuel, "spiked" as needed with a small amount of plutonium from the high-gain FNRs. Note that reprocessing and fabrication of MOX-CANDU and AFCR fuel would be carried out in an integral containment boundary including those FNRs that participate in the coupled fast-thermal fuel cycle. This would be done to satisfy needs for

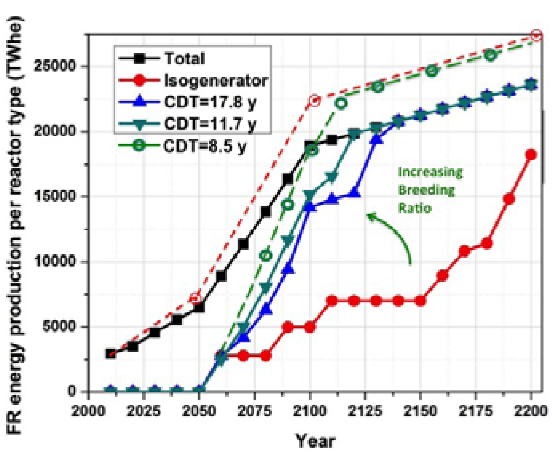


Figure 8a of [3]: Nuclear energy production of fast reactor fleet.

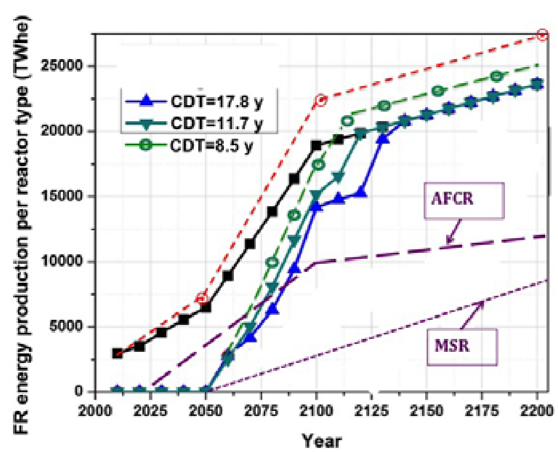


Figure 8b from [3]: Nuclear energy production of fast/thermal reactor fleet.

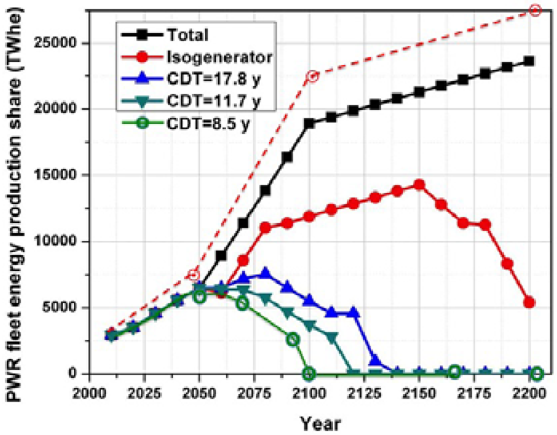


Figure 9 from [3]: Nuclear energy production of LWR fleet.

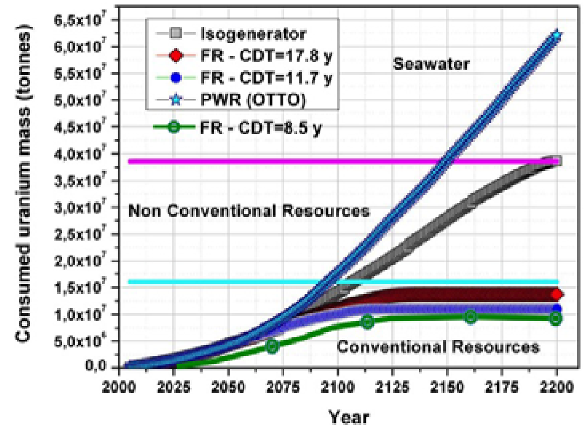


Fig. 10 from [3]: Mass of uranium consumed vs time for different fast reactor classes.

avoiding any appearance of proliferation vulnerability.

Note also that there is no advantage to be gained by using thorium fuel in a fast reactor – such a fuel system would suffer a substantially lower FNR breeding gain due to the unfavorable trend in thorium cross sections at high energy.

An additional advantage of the AFCR option is its ability to get started sooner with the enormous task of building up the world's sustainable energy production capacity. Similar to the LWR option, large-scale installation of CANDU or AFCR can begin immediately. The world has delayed all of these new fuel cycles unnecessarily for a variety of reasons. Now, the builders of these new reactor fleets must run, just to catch up with changing events.

Fig. 9 from Reference 3 shows the distinct advantages of a high breeding gain of the metal-fueled version of the FNR. With a compound doubling time of 8.5 years, all LWRs could be phased out by the end of the current century, thereby greatly reducing the amount of uranium that must be mined, eliminating the need for uranium enrichment (a prime proliferation concern), and drastically reducing the quantity of used fuel waste.

Finally, Fig. 10 from Reference [3] shows the ultimate advantages of fast neutron reactors (FNR). First, the land-based uranium inventory is never consumed. Considering human energy needs, this means that humans need not mine much uranium to sustain our well being indefinitely into the long-term future. Less uranium means fewer old mines to secure, less refining for fuel preparation, less fuel handling, less short-term storage of used fuel and fewer long-term disposal headaches. All this is achieved, and more cheaply, too.

One further distinct advantage of the FNR is not as obvious. If we choose to use some of the excess fissile material produced by early-start FNRs in existing and future "High-C" thermal reactors, then we can ease the strain of transitioning to the FNR by making full use of the output from existing fleet of thermal reactors for as long as we wish, without causing strain on uranium or thorium reserves.

Referring once again to Ref. [3], this very general conclusion holds for the homogeneous model. It has even greater relevance for the heterogeneous model, in which each political region follows the fleet growth that lies within the range of their best interests. The so-called advance regions can commit to the FNR early and heavily to begin the process of reducing atmospheric carbon dioxide, while the still-developing regions can delay for some time – until their own needs justify making this transition away from fossil fuels.

Governments can assist this trend effectively by introducing an appropriate form of disincentive toward atmospheric carbon emission. Worldwide reduction of financial subsidies for fossil fuels could go a long way toward creating a pool of debt financing to be applied to an extensive expansion of nuclear capacity.

As published in Reference [9], Figure 11 illustrates a novel architecture concept for management of the impending rapid expansion of world nuclear energy application. The "Regional Center" of this concept corresponds to the grouping of FNR, CANDU, fuel reprocessing and fabrication facilities shown in Figure 1(b).

The smaller sites served by each regional center might be located in the same country, or in foreign countries choosing to avail themselves of the available energy from nuclear fission, but which are unable or unwilling to undertake the extensive tasks involved in supporting long-term plant operation. The main interchanges between a given site and the energy center are fresh and used reactor fuel. The smaller sites do not conduct any out-reactor fuel management tasks; thereby ensuring that no concentrated fissile material exists outside defined security boundaries.

If the reactors operating at the smaller sites are of

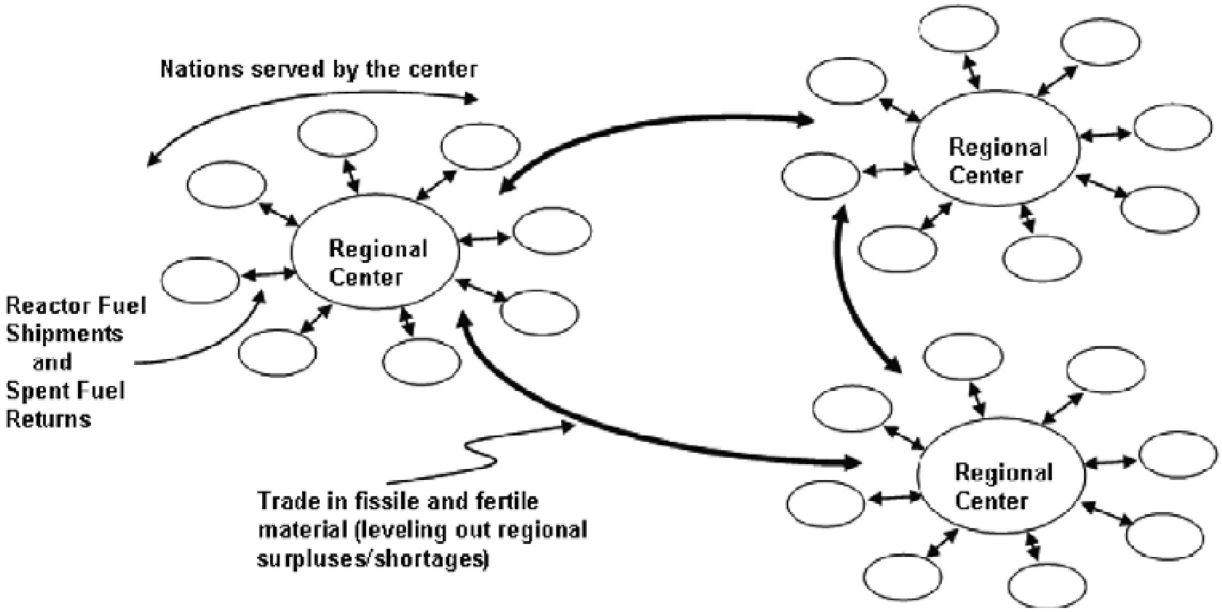


Fig. 11: The "STAR" concept of the nuclear power expansion and management [9].

the ARC-100 type, a new fuel load is required only once in 20 years. At the same time, reload fuel can be exchange on any convenient interval; for example, if reactors at a given site are of the CANDU type (with daily refueling) then used fuel accumulated in the used fuel bay can be shipped at any time. New fuel bundles can refill the fresh fuel storage inventory as and when required. In this way the inventory of radioactive material at the small site can be minimized.

This type of system architecture is especially convenient when the fleet capacity is growing rapidly. The regional center can be established and equipped first and can earn revenue from its on-site power plants. The fleet of distributed reactors can then be built up steadily, with an assured supply chain as well as assured support facilities.

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The Economics of Novel vSMRs in the North

by M.A. MOORE*

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Abstract

Very small modular reactors (vSMRs) designed for off-grid communities and other niche applications employ novel design features such as an integral pressure vessel, a sealed reactor core and increased fuel residence times. This paper examines the economics of vSMRs at off-grid locations with an emphasis on remote northern communities. A life cycle cost analysis was performed for three vSMR concepts: a lead-cooled vSMR, a molten salt-fueled vSMR and high temperature gas-cooled vSMR. The economic impacts of the vSMRs novel design attributes have been examined and are compared to diesel generators.

The analysis presented suggests, a vSMR would decrease carbon emissions while protecting the community from the potentially volatile price of diesel fuel. One vSMR was found to be within 7% of the cost of diesel electricity when a carbon tax of $50/ MT CO2is introduced. Therefore, some vSMRs could be a viable alternative to diesel generators for several remote communities.

Keywords: Nuclear Economics, Small Modular Reactors, Lead-Cooled, Molten Salt, Gas-Cooled.

Introduction

More than 50 remote communities in Canada's northern territories rely exclusively on diesel generating stations for electricity. As a result, electricity rates are very high and extremely volatile based on the fluctuating price of diesel fuel. Many of these diesel generators are nearing their end of life, creating an opportunity for these communities to consider alternative sources of electricity.

This paper considers three very small modular reactor (vSMRs) technologies that are touted as alternatives to diesel generated electricity in the North[1]: a lead-cooled fast reactor (LCFR), a molten salt reactor (MSR) and a high temperature gas-cooled reactor (HTGR). The key reactor parameters used in this analysis are listed in Table 1 along with the diesel plant used for comparison.

The levelised unit energy cost (LUEC) was estimated for the diesel plant and each vSMRto enable comparison of the options. The potential economic competitiveness of each technology was assessed relative to the diesel plant.

Table 1 Key Parameters

	Diesel	LCFR	MSR	HTGR
Thermal Capacity (MWth)	30	30	30	30
Electrical Capacity (MWe)	10	11	12	12
Operating Life (years)	40	10	60[a]	60[a]
Refueling Frequency (years)	Continuous	N/A	7	5
Discount Rate (%)	3	5	5	5
Years to Construct	2	4	5	5
Fuel Type	Diesel	19.9% enriched U with no refueling	Uranium mixed in molten salt, enrichment unknown	9% enriched U

a: operating life estimates are for the entire nuclear energy system. For the MSR and HTGR, the reactor vessel(including all internal systems) is expected to be replaced at each refueling.

Note: Although vendor specific design information was reviewed as part of this analysis, the reactor technologies evaluated in this analysis do not represent any specific vendor reactor design.

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1 The North refers to remote communities located in the Yukon, Northwest Territories and Nunavut.

2. Methodology & Analysis

To enable a fair comparison, each reactor was assumed to have a thermal capacity of 30 MWth[2], which was compared to a 10 MWe diesel generator. It was assumed that all power produced would be consumed and therefore no considerations were made for storage or load following. In some communities, residual heat from the diesel generators supply a local district heating network. It was assumed that any of the nuclear technologies would be able to fully meet this need.

Unless otherwise indicated, all costs were escalated to 2015 US dollars using the United States Bureau of Labor Statistics Annual Consumer Price Index [1] and an exchange rate of 1.255 Canadian dollars for every American dollar.

2.1 The Cost of Diesel Electricity

The cost of diesel electricity can be broken down into three categories: capital costs, operating costs and decommissioning costs.

Capital costs were based on a recent project to replace the diesel generating station in Taloyoak, Nunavut that estimated a 2 MWe plant would cost $10.8 M in 2011 Canadian dollars[2]. Using the same economies of scale curve that is recommended for SMR (see Section 2.2.1), a 10 MWe diesel facility was estimated to cost $22 M in 2015 US dollars. Assuming the generating station could be constructed in 2 years and an interest rate of 3% is secured, the interest paid during construction was estimated at $1 M. The levelised capital cost, based on a 40 year operating life, for a 10 MWe diesel generating station in the North was calculated to be $0.0124/kWh.

Operating costs were estimated based on a breakdown of annual operating and maintenance (O&M) costs provided by the Qulliq Energy Corporation (QEC)[3], the crown corporation responsible for electricity production in Nunavut, shown in Table 2.

According to the QEC, the average fuel efficiency for the diesel generators in Nunavut is 3.71 kWh/L[3]. Therefore, a 10 MWe generator with 90% availability[3] would use approximately 21 M litres of diesel fuel annually. The average unit cost for diesel fuel in the North was estimated at $0.75/L, thus the total annual fuel cost for the 10 MWe generating station are $16M.

All other operating costs were calculated in proportion to the fuel costs (Table 2) for a total operating cost of $36 M; or $0.2022/kWh for fuel and $0.2511/kWh for non-fuel operating costs.

The final cost for consideration is the cost of decommissioning the generating station once the generators have reached their end of life. There is limited publicly available information on the cost of decommissioning a diesel generator, therefore the cost of decommissioning a coal plant was used as a proxy. The cost of decommissioning the Kosovo A coal plant was estimated to cost between €30M [4] and €65M [5]. Based on an exchange rate of 1.3946 USD/Euro, the unit cost of decommissioning is between $55,000/MWe and $125,000/MWe in 2015 USD. Since a 10 MWe diesel generator will not obtain the same economies of scale as a decommissioning project the size of Kosovo A (800 MWe), the higher end of the estimate is used to calculate a decommissioning cost of $1 M for a 10

Table 2 Annual Diesel Generation O&M Expenses Breakdown

Expense Type	Breakdown (%)	10 MWe Diesel Costs ($ M)
Fuel and Lubricants	44.6	15.9
Salaries, Wages and Benefits	23.6	8.4
Supplies and Services	15.7	5.6
Amortization and Disposal of Tangible Capital Assets	8.8	3.1
Travel and Accommodations	3.8	1.4
Interest Expense	3.6	1.3
Bad Debt Expense (Recoveries)	-0.1	0
Total	**100**	**35.7**
Note: The true cost varies by facility based on a number of factors such as capacity, age and location.		

2 In this paper MWt and MWe are used to differentiate MW thermal power and MW electric power. A typical nuclear power plant heat-to-electricity conversion efficiency is 30% to 35%, depending on the steam temperature. So, it is expected that a 30MWt vSMR can produce about 10MWe electricity.

3 90% availability was selected to simplify the comparison between the diesel generators and the SMRs by assuming the diesel generator is supplying base load power.

MWe diesel generator. The levelised cost, based on a 3% real discount rate and a 40 year operating life, was estimated at $0.0002/kWh.

2.2 Cost of Electricity from a vSMR

The costs to produce electricity using a vSMR can be divided into four categories: capital costs, fuel costs, non-fuel operating costs and decontamination and decommissioning (D&D) costs. Since none of the vSMRs considered in this report have been built, costs are estimated by benchmarking against light water reactor (LWR) costs.

2.2.1 Capital Costs

The overnight cost of a vSMR can be estimated by making five adjustments to the benchmark LWR overnight costs to account for the following differences between traditional nuclear power plants (NPPs) and vSMRs:

1. economies of scale;
2. significant design changes;
3. co-siting of multiple units;
4. learning curve and economies of replication; and
5. modular construction.

Since all three of the vSMRs considered have a thermal capacity of 30 MWth, the adjustment for economies of scale was the same for each technology. The overnight cost of a 3,030 MWth LWR plant was estimated at $4,436 M [6]. This cost was scaled to 30 MWth using the economies of scale formula recommended by the IAEA [7].

$$Cost(SMR,\$M) = Cost(LWR,\$M) * \left(\frac{SMR\ MWth}{LWR\ MWth}\right)^{n} = \$4{,}436M * \left(\frac{30}{3030}\right)^{0.55} = \$350\ M \quad (1)$$

where n is the scaling factor; estimated between 0.4 and 0.7 by the IAEA [7].

However, the scaled cost of $350 M does not account for the differences between the benchmark LWR design and the vSMR designs. Therefore, this cost was adjusted to reflect each design.

First, the total cost was divided into direct costs (70%), indirect costs (15%) and owners' costs (15%) [6]. The direct costs were further sub-divided based on the code of accounts for a nuclear reactor [8] [9] to generate the unadjusted costs in Table 3.

The unadjusted costs were then altered to represent each reactor based on key design changes. Design changes common to all three of the vSMR technologies are:

- Reactor vessel will be buried below ground for improved security and physical protection. This will present new challenges during site preparation.
- An integral reactor vessel will be used; simplifying the design and reducing pumping and containment requirements.
- Cores are compact, reducing the vessel size such that it can be prefabricated and transported to the reactor site.
- All designs operate at a lower pressure than the benchmark LWR. Some requiring very minimal pressurization of the reactor containment building.
- All reactor vessels are sealed, therefore the used nuclear fuel (UNF) will not be removed during operation. This will reduce on-site fuel handling requirements.
- Miscellaneous buildings will not be required for these simplified/sealed designs.
- Each reactor will use passive safety systems that will simplify the reactor control system such that minimal operator intervention is required. Therefore, the reactor monitoring and reactor instrumentation and control systems will need to be more robust.
- Larger hoists and cranes, as well as additional supports, will be required to position full modules during construction.
- Prefabricated turbine systems will be available for the vSMRs due to their reduced electrical capacity.

The LCFR is unique because it will not be refueled, operating more like a nuclear battery. The initial core will support operation for 10 years, after that time the reactor will be shut down and the D&D process will begin. As a result, no fuel handling, radioactive waste storage or radioactive waste processing systems are required. However, the lead coolant will be more expensive than the traditional water coolant.

The MSR is the only vSMR considered that uses liquid fuel. This allows the coolant to work more efficiently, thus reducing the requirements for heat exchangers and pumps. The liquid fuel also allows the MSR to be "topped-up" with additional enriched uranium fuel, and gaseous fission products are removed during operation. However, UNF is not removed from the core, nor is the coolant or moderator adjusted during operation of the vSMR. Therefore, some fresh fuel handling facilities are required, but coolant make-up and treatment facilities are not required.

Finally, since the coolant and moderator are not adjusted during operation, every seven years the MSR is shut down and the reactor vessel is swapped out, replacing the graphite moderator and salt coolant. To ensure constant supply of electricity, a second MSR will be linked to the same turbine system and the two reactors will follow alternating operating schedules. The overnight costs in Table 3, were adjusted to include the cost of both reactors for comparison purposes.

Similar to the MSR, the HGTR will also alternate

Table 3 vSMR Overnight Costs Adjusted for Design Changes

	Unadjusted Cost ($M)	LCFR Cost ($M)	MSR Cost ($M)	HTGR Cost ($M)
Direct Cost	**245**	**208**	**321**	**316**
Structures and Improvements	**88**	**54**	**80**	80
Site Preparation	6	13	9	13
Reactor Building	42	14	28	42
Turbine Generator Building	8	8	8	8
Reactor Auxiliary Building	8	2	8	4
Rad waste Building	4	0	0	0
Control Building	4	4	7	0
Administration Building	2	2	2	0
Emergency Power Generation Building	8	8	13	8
Miscellaneous Buildings	2	0	0	0
Ultimate Heat Sink	2	2	4	4
Reactor Equipment	92	84	152	150
Reactor Equipment	**42**	**50**	**84**	**84**
Main Heat Transport System	3	6	3	6
Safety Systems	7	4	7	7
Radioactive Waste Processing System	4	0	0	0
Fuel Handling System	3	0	7	0
Other Reactor Plant Equipment	11	3	9	6
Reactor Instrumentation and Control	19	19	38	42
Reactor Plant Miscellaneous	3	3	5	5
Turbine Generation Equipment	**50**	**50**	**63**	**63**
Turbine Generator	31	31	39	39
Condensing System	5	5	6	6
Feed water Heating System	6	6	7	7
Other Turbine Plant Equipment	4	4	5	5
Instrumentation and Control	3	3	3	3
Turbine Plant Miscellaneous Items	1	1	2	2
Miscellaneous Equipment	**15**	**20**	**25**	**23**
Transportation and Lift Equipment	3	6	7	7
Service Systems	8	8	9	8
Communication Equipment	2	4	8	8
Furnishing and Fixtures	2	2	1	1
Indirect Cost	**53**	**53**	**66**	**66**
Owners Cost	**53**	**53**	**66**	**66**
Total	**350**	**313**	**452**	**447**

operations between two reactors. The initial HGTR is designed to operate at full power for five years and then the reactor will be shut down so the full vessel can be replaced. Therefore the overnight costs in Table 3, were adjusted to account for the two reactors needed to provide constant power. Unlike the MSR, the HTGR is not refueled during operation, therefore fuel handling, radioactive waste storage and radioactive waste processing systems are not required.

Finally, the HGTR uses helium as a coolant and the TRISO fuel form. These both simplify the safety system, thus reducing costs. However, the price of helium is extremely volatile, therefore a larger contingency is required for the reactor coolant.

To determine if there are savings from the third difference, co-siting of multiple units, demand must be considered. Since the electricity demand in most communities in the North is less than 10 MWe, a single 30 MWth would meet the entire demand, therefore co-siting is not an option[4]. No co-siting savings were attributed to the vSMRs considered in this analysis.

Learnings and economies of replication can be divided into three types of savings: savings related to design learnings, savings related to on-site learnings and savings related to economies of replications.

- The benchmark LWR is a mature design that has reached nth-of-a-kind (NOAK) status. Therefore, savings related to design learnings are already included in each of the vSMR estimates.
- The MSR and HGTR are intended to be built in pairs, alternating operations between the units. Therefore, a savings of 4% is estimated for on-site learnings from the construction of the first unit can be applied to the second unit [9]. There were no on-site learnings calculated for the LCFR because only one reactor, with continual operation, is required at each site.
- For all three vSMRs, it was assumed that the vSMR prefabrication facility is mature and therefore has achieved the full 34% reduction in prefabrication costs [9].

The total estimated savings from learnings were \$45M, \$76M and \$76M, for the LCFR, MSR, and HTGR respectively.

The final adjustment to overnight costs accounts for the difference in construction costs. Since the vSMRs are prefabricated in a centralized manufacturing facility materials could be purchased in bulk for several vSMRs that will be fabricated, in addition to the advantage of lower labour rates[5]. Material and labour costs were estimated based on a report from Argonne National Laboratory that published the cost breakdown of an integrated pressure vessel produced at a vSMR factory at 51% labour and 49% materials and equipment [10]. Therefore, the reduction in constructions costs for each vSMR was estimated to be between \$36 M and \$66 M, depending on amount of modularization incorporated into the design.

Based on the five adjustments,(economies of scale, significant design changes, co-siting multiple units, learning curve/economies of replication and modular construction), the overnight costs were estimated and are detailed in (Table 4).

To estimate the total capital cost for each vSMR, the cost of the first core as well as the interest during construction (IDC) must also be considered.

- The first core costs for the LCFR and the HTGR were estimated based on the fuel cycle unit costs found in the Advanced Fuel Cycle Cost Basis report published by Idaho National Laboratory [11].
- There is limited experience fabricating the liquid fuel used by the MSR, therefore unit costs were not available. Instead the first core cost was estimated based on a levelised fuel cost estimate for a conceptual MSR design studied at Lawrence Livermore National Laboratory [12].
- The IDC for each reactor was estimated based on the s-curve spending patterned using the formula (2)[9].

$$IDC\ (\$M) = \left(\frac{\pi^2(1+(1+r)^T)}{(2*(T^2*(\ln(1+r))^2+\pi^2))} - 1\right) * C \qquad (2)$$

Where: r = interest rate (5%[6])
T = time to construct in years
C = overnight + first core costs

Table 4 Capital Cost Summary

	LCFR	MSR	HGTR
Overnight Cost (\$M)	233	318	312
First Core Cost (\$M)	24	10	15
Interest During Construction (\$M)	27	43	43
Total Capital Cost (\$M)	**283**	**371**	**369**

2.2.2 Annual Operating Costs

All of the vSMR technologies analyzed include several passive safety features and extended fuel cycles, which decrease the need for on-site staff. However, some minimum on-site staffing complement would still be required [13].

In addition, both the MSR and the HGTR require the full vessel to be replaced every 5 to 7 years. This would incur additional materials and equipment costs to fabricate the replacement vessels, as well as represent a significant on-site project that would require

4 The dual reactor systems for the MSR and the HGTR were treated as a single unit when design savings were calculated. Therefore co-siting does not apply.

5 Factory labour rates are between 30% and 60% less than on-site labour rates. A conservative estimate of 45% was used in this analysis.

6 An interest rate of 5% was used for nuclear technologies, 2% higher than the interest rate for diesel generation (3%) to reflect the increased risk investors' associate with nuclear reactors.

several staff to transport, install and qualify the new vessel for operation.

Finally, the used vessel, complete with UNF, will need to remain on-site for cooling prior to shipping to a centralized dispositioning facility. Therefore, an on-site storage facility would be required.

These costs were annualized for each vSMR, applying a 5% discount rate where applicable, to provide an estimate of the annual operating costs for each vSMR (Table 5).

Table 5 Annual Operating Cost Summary

	LCFR	MSR	HGTR
Non-Fuel Operating Costs ($M/year)	3	4	4
Fuel Costs ($M/year)	0	1	3
Vessel Replacement Costs ($M/year)	0	11	14
Total Operating Costs ($M/year)	**3**	**16**	**21**

2.2.3 Used Nuclear Fuel Dispositioning Costs

Many of the SMR designs currently under development utilize a partially-closed or fully closed fuel cycle, where the UNF can be reprocessed for use in another SMR core. For simplicity, this analysis assumed a once-through fuel cycle for each vSMR, however UNF dispositioning cost estimates include reprocessing costs and a credit was given for the fissionable material in the UNF.

- The LCFR is not refueled during its 10 year operating life, therefore only one core of UNF is produced. As a result the UNF dispositioning costs are minimal at $5M.
- The HGTR is refueled 12 times over its 60 year operating life. This will produced significantly more UNF, therefore the dispositioning costs are roughly five times the LCFR estimate at $24 M.
- There was insufficient information available to estimate the UNF dispositioning costs for the MSR. Therefore, the HGTR costs were used as a high level estimate.

2.2.4 Decontamination and Decommissioning Costs

The final cost for consideration is the D&D costs to return the reactor site back to the community after operation. This cost is largely uncertain since few commercial reactors have completed D&D. Based on the Cost Estimating Guidelines published by the Generation IV Economic Modeling Working Group, D&D for a large nuclear power plant (NPP) is estimated to cost between 25% and 35% of the initial overnight capital costs [9]. The modularization and sealed vessel of the vSMR will simplify D&D, however there will also be a significant loss of economies of scale compared to D&D for a full sized NPP. Therefore, a conservative estimate of 40% the overnight capital costs was used to estimate the D&D costs of a vSMR.

2.3 Special Considerations for the North

Construction in the North presents unique challenges such as a lack of skilled workers, extremely limited infrastructure, permafrost and harsh environmental conditions. These challenges were accounted for by adjusting each on-site cost component one of two ways.

2.3.1 Labour Adjustment

According to Statistics Canada, average hourly earnings in Nunavut is $29.73/hr, approximately 26% more than the Canadian average ($23.57/hr)[14]. Therefore, the non-fuel operating costs were increased by 26% to reflect the higher labour costs in the North.

2.3.2 Construction & Maintenance Costs

The initial construction, as well as large maintenance projects (e.g. vessel replacement), will be significantly more challenging in the North. This is evident when the average levelised unit energy cost of diesel electricity in the United States[15] is compared to the cost of diesel electricity estimated in Section 2.1 of this report; $0.281/kWh and $0.466/kWh respectively. To account for this, all on-site costs except non-fuel operating costs were increased by 66%.

3 Key Findings

3.1 Economic Competitiveness

Based on the key parameters listed in Table 1and the special considerations presented in Section 2.3, the costs presented in Section 2 were levelised over the operating life of the generating facility to calculate the LUEC for each technology. The LUEC estimates can be compared to assess the economic competitiveness of the different facilities (Table 6).

Table 6 LUEC Comparison ($/kWh)

	Diesel	LCFR	MSR	HTGR
Capital Repayment	0.012	0.621	0.311	0.310
Fuel Cost	0.202	0.000	0.015	0.036
Operating Cost	0.251	0.044	0.205	0.247
UNF Dispositioning Cost	0	0.005	0.001	0.001
D&D Cost	<0.001	0.129	0.006	0.005
Total LUEC	**0.466**	**0.798**	**0.537**	**0.600**

The LUEC estimates for each of the vSMRs were calculated at a high level and have a large degree of uncertainty. However, based on the initial results the vSMRs do not appear to offer savings when compared with the LUEC for diesel.

- The LCFR is the only reactor that does not require any type of refueling during its operating life. This greatly simplifies on-site operations, however the economics are challenged by the higher levelised capital repayment cost due to the shorter operating life.
- The MSR and HTGR are between 15 and 29% higher than the cost of diesel electricity. The MSR has an advantage over the HGTR on fuel costs because of its longer fuel cycle. Although, the increased requirements related to liquid fuel increase the capital for the MSR relative to the HGTR.

With the promise of a national carbon tax by 2018 [16], diesel electricity in Canada is set to increase by at least $0.007/kWh initially, reaching $0.035/kWh by 2022[7]. By 2022,the cost of diesel electricity in the North will rise to at least $0.501/MWh[8], which is within 7% of the cost of electricity from a MSR ($0.537/MWh) and 20% of the HTGR cost ($0.600/MWh). Given the uncertainty in the vSMR estimates and the high probability that diesel fuel costs will continue to rise, the MSR and HTGR vSMR technologies are both strong alternate options for remote communities in the North looking to reduced reliance on price-volatile fossil fuels and decrease carbon emissions.

3.2 Additional Factors for Future Consideration

The analysis presented in the paper was performed at a high level with no specific community in mind. Before a decision is made about whether or not a vSMR should be deployed in a remote northern community several other factors must be considered.

3.2.1 Reliability

In general nuclear reactors are considered more reliable than diesel generators, operating continuously for up to two years. However, when maintenance is required reactors can be off-line for several weeks to months, especially if the outage was unexpected. Many vSMR designs have focused on simplifying operations, minimizing the number of points of failure to reduce maintenance requirements and the probability of an unexpected outage. However, the possibility of an outage still exists.

Because of this possibility, some consideration should be given to backup power options to ensure the community will not face an extended power outage. Initially, diesel generators could be used for backup power due to their low capital cost and proven success in the region. However, other alternatives (e.g. storage facility) should also be considered.

3.2.2 Infrastructure Requirements

According to a 2008 report by the Government of Nunavut, transportation to and from Nunavut communities consists of small airports operating on 50-year old technology and marine travel (through tidewater access) creating many transportation challenges [17]. The infrastructure in many communities would be insufficient to support the large construction project needed to install a vSMR. It is unclear who will be responsible for the required upgrades, and what the might cost be.

3.2.3 District Heating

Many communities have built district heating systems designed to capture the excess heat produced by the diesel generators and redirect it to buildings for space heating. In this analysis it was assumed that a vSMR could support any existing district heating, but would not result in any significant expansion/savings. Once a specific community is identified, detailed calculations related to district heating using a vSMR should be performed to verify this assumption.

3.2.4 Licensing Costs

There are five licenses required over the life of a nuclear reactor: license to prepare a site, license to construct, license to operate, license to decommission and license to abandon [18]. To date, no SMR has completed licensing in Canada, therefore costs are still highly uncertain. The CNSC did provide a high level estimate of licensing costs of a multi-unit fast reactor facility; $115 M for initial licensing, plus $9 M - $11 M annually [19]. However this SMR is much larger than the 30 MWth reactors considered in this paper, it is unclear how the licensing costs will scale with reactor capacity.

3.2.5 Modularization

The vSMRs considered in this analysis have a high degree of modularization, with the reactor vessel and all internal components fabricated off-site at a centralized facility and shipped to the reactor site as a single unit. This will require a complex supply change and a large centralized manufacturing facility to generate economies of replication.

The aerospace industry faces a similar situation when introducing a new aircraft into their fleet. In

7 National carbon tax will start at a minimum of $10/MT of CO_2 produced, rising to $50/MT CO_2 by 2022.

8 This assumes fuel and labour costs do not increase between now and 2022.

order to justify the initial investment the order book, which represents the backlog demand for the new aircraft, must be sufficiently large. Additional research is required to determine what the minimum order book is for a centralized vSMR facility and how costs would be impacted if that number is not reached.

4. Conclusion

Based on the economic analysis presented, vSMRs could be an excellent alternative to diesel generators for several communities in the North. A vSMR would decrease carbon emissions while protecting the community from the volatile price of diesel fuel, which is expected to increase over time. As more information becomes available for specific vendor designs and potential host communities, this analysis should be updated to capture the unique attributes of the vendor designs and the specific requirements of the host communities.

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Fusion Related Experimental Studies at the University of Saskatchewan

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Abstract

Recent studies at the University of Saskatchewan have been focused on basic tokamak physics and fusion technology development. The studies have been conducted on the Saskatchewan Torus-Modified (STOR-M) tokamak, the only tokamak in Canada at the present time, and on a newly developed dense plasma focus (DPF) device. Active control of the magnetohydrodynamic (MHD) instabilities and the plasma flow rotation has been achieved by resonant magnetic perturbations (RMP). Momentum injection from a tangentially injected compact torus (CT) to the STOR-M discharge has been observed. The energy resolved x-rays radiation has also been measured in the DPF device using an array of silicon photodetectors.

1. Introduction

The recent experiments conducted on the Saskatchewan Torus-Modified (STOR-M) tokamak have been aimed towards developing viable techniques to control various types of magnetohydrodynamic (MHD) instabilities and to modify plasma parameters such as plasma rotation velocities. Resonant magnetic perturbation (RMP) fields [1] have been used to induce reduced MHD fluctuation phase and compact torus injection (CTI) [2] has been used to alter the electron density in STOR-M. The ion Doppler spectroscopy (IDS) system recently installed in STOR-M allowed the non-intrusive measurements of toroidal plasma flow velocity. It has been found that RMP and CTI both induce significant changes in the plasma toroidal flow velocity in STOR-M. The importance of toroidal plasma flow in tokamaks is its stabilizing effects on edge turbulence, resistive wall modes (RWMs) and neoclassical tearing modes (NTMs) [3]. The plasma rotation is also important for decreasing error field penetration depth in tokamaks and thus enhancing tolerance to error fields as the result of inaccuracy of coil installation [4].

The use of RMP in tokamaks has drawn a great deal of attention through its applications in edge localized modes (ELMs) mitigation [5] and error field correction [6]. Mode stabilization is another attractive feature of RMP that has been successfully demonstrated in many tokamaks including the STOR-M tokamak [7, 8]. The mode stabilization leads to a significant reduction in frequency and amplitude of tearing mode fluctuations. It has been found that applying a current pulse through pre-configured helical windings with the same helicity as the magnetic islands in a tokamak plasma suppresses the magnetic fluctuations in the plasma. However, if the applied RMP field is too large, the islands in plasma will grow and mode locking may occur [9]. It is also known that both resonant and non-resonant RMP fields can affect the plasma rotation and the radial electric field (E_r) in tokamaks through a torque mechanism [10]. In STOR-M, a systematic study has been carried out to investigate the effects of RMP on MHD fluctuations and the plasma rotation.

A compact torus (CT) is a fully ionized high density plasmoid magnetically confined by its own magnetic field which can withstand a large acceleration force. CTI is one of the advanced methods with a potential to directly fuel the core of tokamak reactors. Localized fuelling can be achieved by controlling the CT velocity , providing a means to control the plasma density and pressure profiles which may also enhance bootstrap current density leading to modification of magnetic shear in the plasma core [11]. Improvement in plasma confinement and suppression of magnetic fluctuation by CTI have been reported previously [12]. In this study, the emphasis is on investigation of the effects of CTI on plasma flow and the momentum transfer from the CT plasma to tokamak plasma.

A new dense plasma focus (DPF) device with a stored energy up to 2 kJ has been developed at the University of Saskatchewan. The DPF device is a coaxial plasma gun that utilizes a pulse of high current discharge to compress the plasma to a high temperature and density. The DPF has been considered as an alternative to magnetic fusion approaches since DPF is capable of producing intense fusion neutrons. The high energy

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density pinch plasma in a DPF is also a good candidate as a multiple radiation source of ions, electrons, soft and hard x-rays, and neutrons, which are useful for industrial applications such as lithography, radiography, imaging, and radioisotope production [13, 14]. A series of experiments on ion beam emission, x-rays radiations, and electron beam emission have been carried out in DPF UofS-I. In addition, a unique design has been developed to enhance charged particles emissions and x-ray radiations from a plasma focus device. Feasibility of short lived radioisotopes such as N-13 and F-18 for medical applications in DPF UofS-I has been investigated theoretically and a new dense plasmas focus (DPF UofS−II) with a stored energy up to 20 kJ is currently being developed.

This paper is outlined as follows. Section 2 provides technical details on the STOR-M tokamak and its diagnostics, the RMP coil configuration, the CTI gun, and the DPF device. Section 3 highlights the main results from RMP, CT injection, and DPF experiments. Conclusions are presented in section 4.

2. Experimental Setup

STOR-M is a small research tokamak in the Plasma Physics Laboratory at the University of Saskatchewan [15]. STOR-M has a major (minor) radius of 46 cm (12 cm). The machine is equipped with a feedback control unit to control the plasma horizontal position. The hydrogen plasma parameters during a typical STOR-M discharge are I_p (plasma current) = 20~30kA, V_l (loop voltage) = 3V, B_t (toroidal magnetic field) = 0.7T, n_e (electron density) = 0.5 ~ 1 × 10^{19} m^{-3} and τE (global energy confinement time) = 1ms. The STOR-M tokamak is also equipped with a set of diagnostics including rake probes for density (n) and temperature (T) measurements, a 4mm microwave interferometer for line-averaged electron density measurement, optical spectrometer for monitoring H_α and impurity radiation lines, a soft x-ray (SXR) camera for measurement of SXR emissivity profiles in the plasma, and several poloidal and toroidal Mirnov coil arrays to monitor MHD fluctuations.

An Ion Doppler Spectrometer (IDS) has been developed and installed on STOR-M. The IDS system is a non-invasive and standard diagnostic tool on many fusion devices for impurity ion flow and temperature measurement. To measure plasma flow, emission lines of impurities with bright intensity such as oxygen and carbon lines were chosen. Three different line emissions, C_{III} (4647.4 Å), C_{VI} (5290.5Å) and O_v (2728Å), were selected because they are in different ionization states and are distributed at different radial locations in the tokamak plasma. Experimental data show that C_{III} ions concentrates at the periphery region of the tokamak plasma (r = 7 cm) and C_{VI} ions are in the core (r = 0 cm) of the tokamak plasma. The most probable location for O_v ions is around r = 3cm.

RMP is an external magnetic field produced in STOR-M by driving a current I_{RMP} through two parallel sets of helical windings connected in series in such an arrangement that the currents through the two windings are equal in magnitudes but opposite in directions. The windings are wound in an (l = 2, n = 1) configuration and installed outside the vacuum chamber at a radius of 17cm. I_{RMP} is generated by a capacitor power supply comprised of a 50mF, 450V fast capacitor bank (for fast current ramp-up) and a 420mF, 100V slow bank (for maintaining current flattop). The RMP current is gated by a 1200A, 1700V IGBT (Insulated-gate bipolar transistor) switch. The helical windings are poloidally separated by 90°. By matching the helicities of the helical coil and (2, 1) tearing modes in the plasma, the resonance condition between the RMP field and the targeted tearing modes is established. However, when the helicities of helical coil and the (2, 1) tearing modes are mismatched, the resonant interaction does not occur. The direction of I_p and B_t defines the helicity of the magnetic islands in tokamaks. In the STOR-M tokamak, the direction of I_p is normally counter-clockwise and that of B_t clockwise (viewed from the top). The (2, 1) magnetic islands are formed on magnetic field lines with a twist similar to that of the RMP coil windings.

STOR-M is also equipped with the University of Saskatchewan Compact Torus Injector (USCTI). The working gas is hydrogen, same as that in STOR-M. High density CTs are formed and accelerated in a coaxial discharge gun and injected at a high velocity into STOR-M discharges using USCTI. CT is a magnetically confined plasmoid which releases its particle content into the tokamak plasma through magnetic reconnection. The electron density and the mass of CTs produced by USCTI are about 1 × 10^{21} m^{-3} and 0.5μg respectively. CTs are typically injected at high velocities (v_{inject} = 90-210 km s-1) from a tangential port into the STOR-M plasma. There are four magnetic probes installed along USCTI electrode to detect the magnetic field of CT at the formation region (z = 0) and the acceleration electrode (z = 22, 43 and 65cm) of USCTI. The collected magnetic signals are used to calculate the CT velocity from the signal delay using the time-of-flight method. In addition, the masses of CT and STOR-M tokamak plasma are similar. Therefore, the magnitude of directional momentum carried by CT from USCTI is about one order of magnitude higher than that in a STOR-M discharge considering that the tokamak plasma toroidal speed is around 10 km s-1.

The UofS-I DPF is a Mather-type plasma focus device, operated in argon gas. It has a cylindrical central copper electrode with a radius of 15 mm, and 16 cathode copper rods arranged like a squirrel- cage at radius of 50 mm. A quartz insulating tube of length of 30 mm was used to

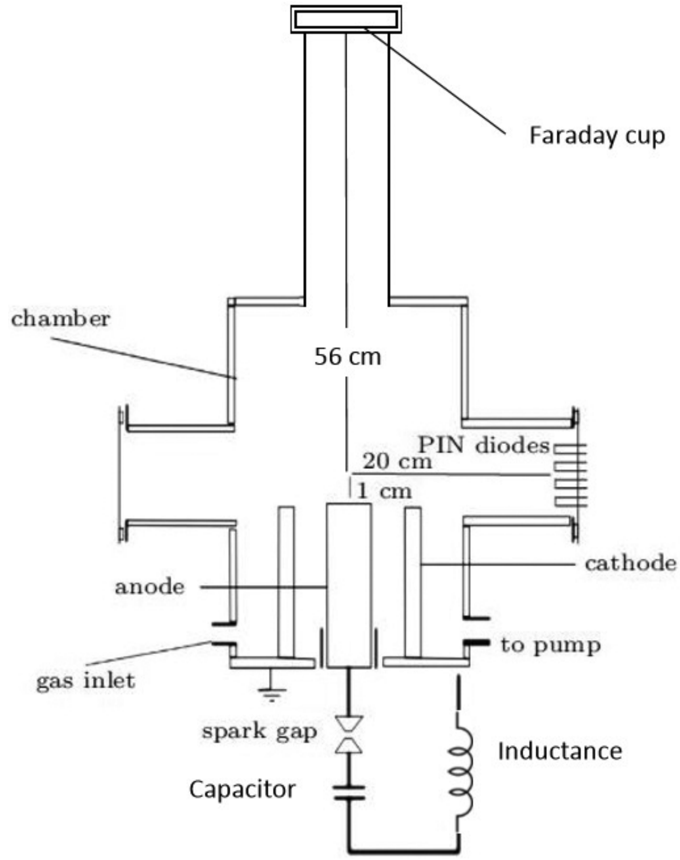


Figure 1: The schematic of the experimental set-up with the position of the pin diodes.

separate the electrodes at the base. This electrode assembly is housed in a stainless steel chamber pumped with a two-stage vacuum pump. An array of detectors (Model: BPX-65) were attached to the side of the chamber to measure x-ray emission used to deduce the electron temperature. The BPX-65 array consists of four silicon pin photodiodes capable of measuring radiation in the soft x-ray range. The array was placed 20 cm away facing the centre of the pinch location near the tip of the inner electrode. The photodiodes signals were transmitted through coaxial cables of equal lengths to the storage oscilloscope. The signals were cross-calibrated to confirm that the location of each photodiode does not affect the measured intensities. Figure 1 shows the schematic of the set-up with the position of the array of photodiodes.

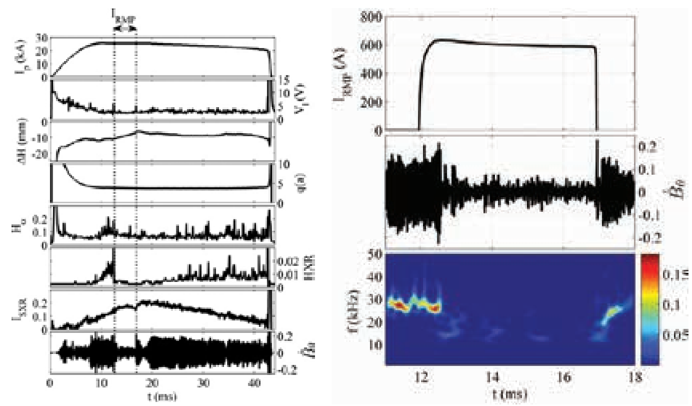
The signals were obtained simultaneously using the same trigger and 4 similar Tektronics oscilloscopes. Time resolved radiation of x-rays were measured using the four-channel diode x-ray spectrometer with windowless silicon pin diodes masked by cobalt foil filters with various thicknesses. The choice of the material and thickness of the filters was made to eliminate the dominant Cu-Kα line radiation at 8.05 keV from the copper anode bombarded by electron beams from DPF. The masking of cobalt filters allows transmission of x-rays in the energy range of 4-7.7 keV, thus, discriminating the Cu-Kα at 8.05 keV.

3. Experimental Results

3.1 RMP Experiment

The effects of RMP field on a typical STOR-M discharge (shot #246961) with high MHD activities have been investigated. During the discharge shown in Figure 2, an RMP pulse was applied at 12ms for a duration of 5ms during the plasma current plateau. Figure 2(a) shows the following plasma parameters (from the top panel downwards): plasma current I_p, loop voltage V_l, horizontal plasma ΔH, edge safety factor $q(a)$, H_α radiation intensity, hard x-ray (HXR) emission, SXR emission and Mirnov fluctuations. The key plasma parameters are I_p = 25.5kA, V_l = 2.5V and $q(a)$ = 3.7. The applied RMP current (I_{RMP}) is about 600A (I_{RMP}/I_p = 2.5%). RMP causes a clear reduction in the HXR emission level.

The toroidal flow velocities of O_v and C_{VI} impurities are also modified by RMP. Without applying the RMP field, the direction of toroidal flow of O_v and C_{VI} impu-



(a) (b)

Figure 2(b) shows the waveforms of I_{RMP}, the Mirnov signal, and the wavelet spectrum of a Mirnov signal. Mirnov oscillations are completely suppressed 0.5ms after applying RMP. The wavelet spectrum shows a clear reduction in MHD amplitude and frequency between 12.5ms and 17ms. The MHD frequency drops suddenly from 26kHz to 15kHz. After I_{RMP} is switched off, the MHD amplitude and frequency return to the original level prior to RMP. The spatial Fourier series analysis has been used to calculate the time resolved magnitudes of the poloidal modes (m = 1 to m = 4) of MHD fluctuations. It has been found that the m = 2 mode is prominent during this discharge.

Figure 2 (a): The effects of RMP on STOR-M discharge #246961. I_{RMP} was applied between 12ms and 17ms during the flat-top tokamak discharge current phase. (b) Time traces of I_{RMP}, Mirnov signal and wavelet spectrum of Mirnov signal. Mode suppression and frequency reduction are evident during RMP applied between 12ms and 17ms

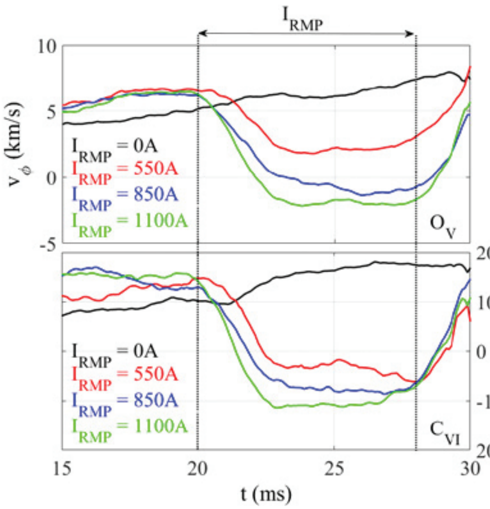
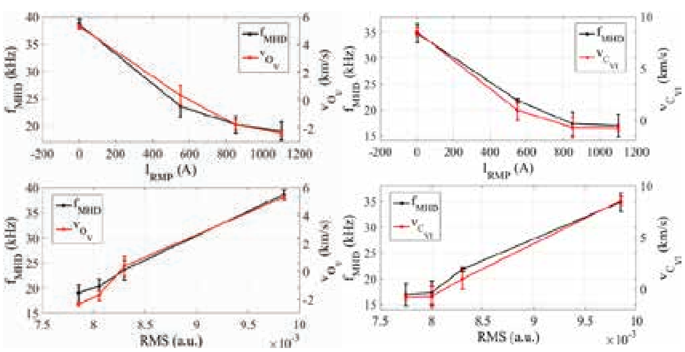


Figure 3: The waveforms of toroidal flow velocities of O_ν and C_{VI} ions at different RMP currents.

rity is in the counter-current direction (positive) as illustrated by the black lines in Figure 3. When RMP is applied at 20ms for a duration of 8ms, the toroidal flows of O_ν and C_{VI} gradually slow down. The velocity change becomes more significant with the increase of the RMP current. The O_ν and C_{VI} flows even reverse their direction at I_{RMP} = 850A and 1100A to the co-current direction (negative). This is similar to the experimental observations in other tokamaks [16, 17].



(a) (b)

Figure 4: Comparison between magnetic fluctuation frequency and the toroidal flow velocity of (a) O_ν and (b) C_{VI} impurities as functions of I_{RMP} and magnetic fluctuation amplitude (RMS value).

The frequency of magnetic islands and the toroidal flow of O_ν impurities are plotted in Figure 4(a) against the RMP current and MHD fluctuation amplitude (RMS values). The O_ν flow velocity changes almost linearly with the RMP current up to a value of 850A. Above I_{RMP} = 850A, however, the change in O_ν velocity slows down. The velocity of O_ν flow changes from 5.3km/s in the counter-current direction to 2.3km/s in the co-current direction when the RMP current is 1100A. Figure 4(b) illustrates the dependence of the island frequency and the C_{VI} flow velocity on the current I_{RMP} and on the RMS value of the magnetic fluctuations. Similar to the O_ν case, the relation is linear to RMP current value up to 850A. The toroidal flow velocity of C_{VI} varies from 8.5km/s (counter-current) at I_{RMP} = 0 to 0.75km/s (co-current) at I_{RMP} =1100A.

3.2 CTI Experiment

The injection velocity of the CT, which is a function of the acceleration bank voltage, is monitored by three magnetic probes along the acceleration section. The injection velocity of the CT is calculated by measuring the time of flight of the CT magnetic field signal at different axial locations along the acceleration section. The sample magnetic probe signals are shown in Figure 5(a). Figure 5(b) shows the change in the injection velocity with respect to the acceleration bank voltage. For each of the acceleration voltages, the injection velocity is calculated by averaging over 15 CT discharges. For the acceleration bank voltages lower than 18 kV (V_{acc} ≤ acceleration bank voltage. The injection velocity measurement results show that for V_{acc} ≥ increase in the CT velocity becomes saturated and the maximum injection velocity achieved for USCTI is ν_{inject} = 210 kms^{-1}. This magnitude of the velocity is large enough to overcome the magnetic field barrier and deposit fuel into the core of the STOR-M tokamak plasma.

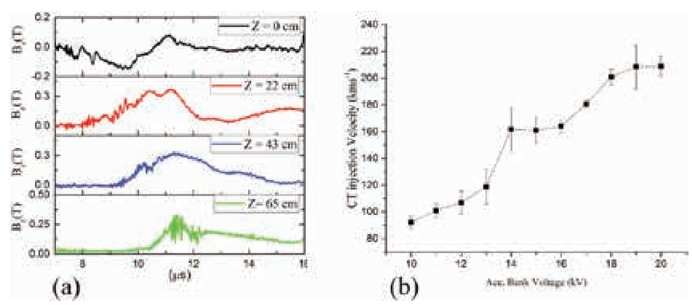


Figure 5: Magnetic probe signals along the acceleration region (a), and the injection velocity vs. acceleration bank voltage (b).

The waveforms of the STOR-M plasma parameters during CTI are shown in Figure 6. The direction of the plasma current in this discharge is in the clockwise (CW) direction (viewed from the top). The CT is injected at t = 15 ms during the flat top of the plasma current. The line-averaged electron density (n_e) increasedfrom0.9×10^{13} cm^{-3} to1.26×10^{13} cm^{-3} within 1.8 ms after CTI. It is also shown that the H_α starts to move outwards at the time when the density starts to increase. The outwards shift of the plasma position may be a result of an increase in the thermal energy content in the tokamak plasma. As shown in the last trace in Figure 6, H_α radiation level decreases by ≈30% after a delay of 2 ms after CTI (due to increased confinement and thus reduced fuel recycling from the wall) and

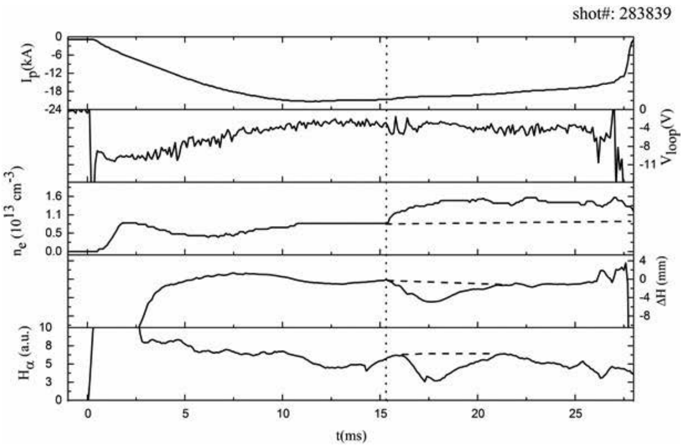


Figure 6: Waveforms of plasma parameters in a STOR-M tokamak discharge during the CTI experiment. The discharge current is in the CW direction. The vertical line indicates the CTI time.

returns to a nominal level after 3 ms. Improvement of the particle confinement and an increase in the global energy confinement in the STOR-M tokamak after CTI have been reported previously for normal (CCW) plasma current direction and the recent results for the revered (CW) plasma current direction presented in Figure 6 confirm those observations [12].

The CTs were injected to the tokamak discharges with plasma current in the CW and counter-clockwise (CCW) directions to investigate the role of momentum injection into the tokamak plasma by CTI. In both cases, CT was injected in the same CCW direction. IDS measurements for both of the CCW (Figure 7(a)) and the CW plasma current (Figure 7(b)) directions show that the toroidal flow has been changed toward positive direction for both cases after CT injection. The positive (negative) flow velocity is defined in the CCW (CW) direction. USCTI always injects CTs in the positive (CCW) direction so

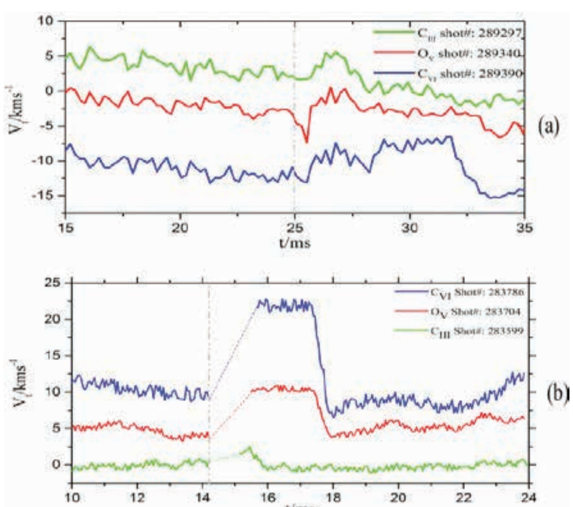


Figure 7: Plasma rotational flow measurements after CTI for CCW (a), and CW (b) current directions. The dotted vertical line indicates the CTI time.

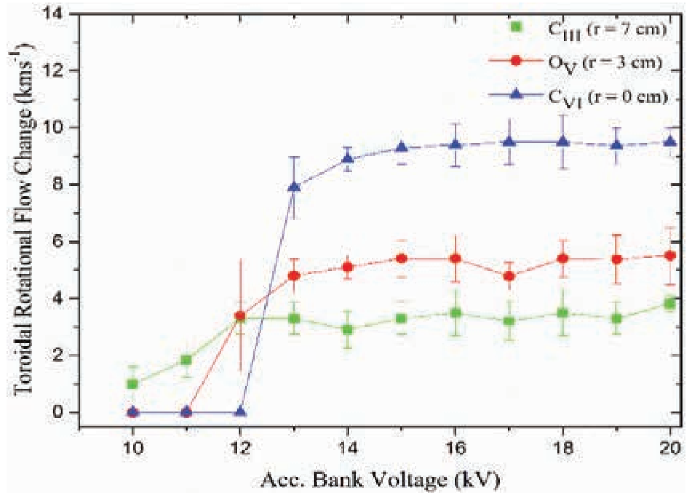
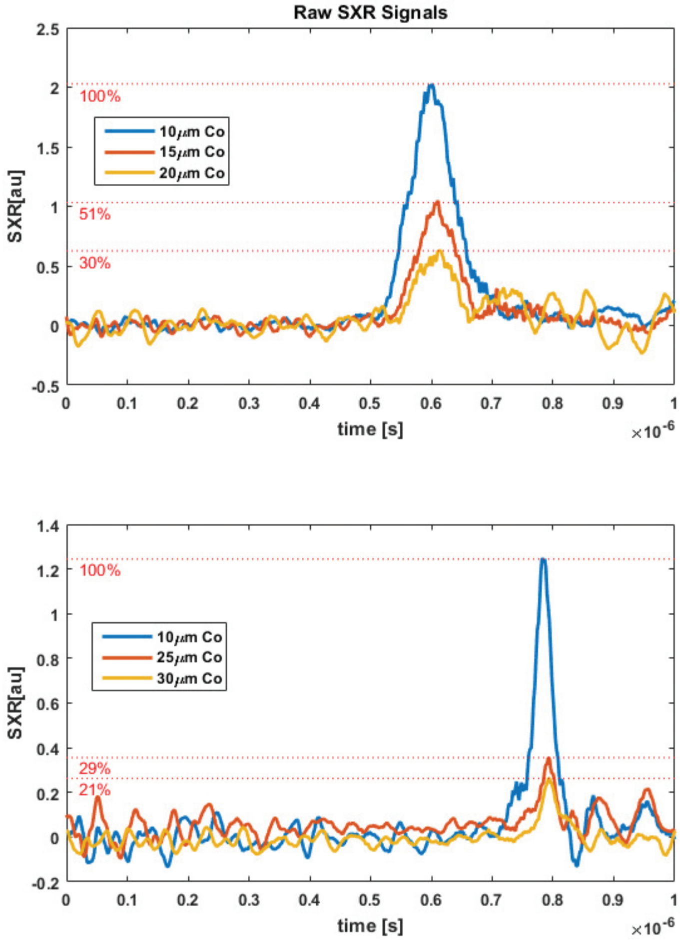


Figure 8: The change in toroidal rotational flow velocity for C_{III}, O_ν and C_{VI} ions with respect to the acceleration bank voltage of the CT injector.

the injected CT momentum of the CT is in the positive direction (CCW). As shown in Figure 7 (both cases), the velocity of the C_{III} ions, which are concentrated in the outer tokamak region, increases ≈ 2 kms after injection and lasts for 2 ms before dropping back to the normal level. The velocity of the O_ν and C_{VI} increases about 5 km s^{-1} and 8 km s^{-1} respectively and last longer compared to the C_{III} ions. The change in the toroidal flow in the outer area is short lived, possibly due higher collisionality in that outer region where the temperature is lower.

Figure 8 shows the change in the toroidal rotational flow velocities of the impurity ions after CT injection as functions of the acceleration bank voltage. For low acceleration bank voltages corresponding to low injection velocities, there is no change in the flow velocity of C_{VI} ions which are concentrated at the core of the tokamak plasma. It is possible that the CT does not reach the core of the tokamak plasma at low CT injection velocities due to low acceleration bank voltages. For the flow of C_{III} ions at the outer region of the tokamak plasma, changes in the rotational flow velocity have been observed even at low acceleration voltages. The increase in the rotational flow velocity for all of the impurity ions saturates beyond V_{acc} = 15 kV. It is anticipated that momentum injection will be increased by increasing the injection velocity of the CT, but these results show that the increase of the momentum injection does not follow the increase of the injection velocity of CT as measured. It should be noted that the CT penetration depth depends on the CT velocity and its mass density. In addition the momentum of CT is proportional to the CT mass. As reported previously, the mass loss of the accelerated CT tends to increase with the injection velocity in the injector [18]. Either the increase of the mass loss or other unknown effects contributed to the saturation of the momentum injection at the high CT injection velocities.



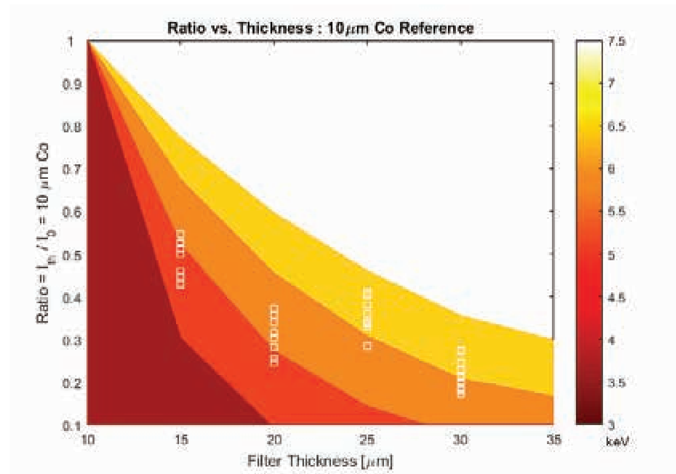


Figure 9: Left panels: The wave forms of the x-ray raw signals (left) for five Co filter thicknesses at two different operating pressures. The peak ratios (normalized against the peak for 10 μm filter) are also marked. Right panel: The calculated x-ray intensity ratios for different filter thickness (horizontal axis) and for different electron temperatures (color coded). Over the calculated ratio plot, the measured intensity ratio data points and range, as well as the most probable electron temperatures for each filter thickness are also marked.

3.3 DPF Experiment

Argon gas at 5m Torr (1mTorr = 0.133 Pa)was used in this experiment and the charging voltage was 20kV. Four different cobalt filter thicknesses were used in front of a windowless silicon diode arrays. Each data point of the measured x-ray intensity is averaged over 10 shots. Figure 9 (left) shows the raw signals obtained using foils of five thicknesses of filters (between 10 μm and 30 μmm, with a thickness increment of 5 μm). The different x-ray signals peak at approximately the same time. The amplitude ratios between the selected and the thinnest (10 μm) cobalt foil filter are marked in the diagrams too.

Those ratios were used to derive the electron temperature. Figure 9 (right) shows the calculated ratios of the signals based on the filter thicknesses, the sensitivity of the silicon-pin photodiode and the transmission of the foil filters of different thicknesses over the photon energy range of 1-10 keV. The calculated ratio is sensitive to the emission spectrum which depends on the electron temperature as shown in the colour bands. The measured intensity ratio is plotted over the calculated ratio and the most probable temperature range are also marked for each filter thickness. Considering the spread of the data points (reproducibility of DPF discharges is generally not high) for the same filter thickness and the different average temperatures for different filter thickness, an electron temperature of 5.4 ± 1.6 keV can be concluded.

4. Conclusions

A series of experiments on the STOR-M tokamak has been carried out to investigate plasma stability and toroidal flow of several impurities in the tokamak plasma. The first experiment was conducted using RMP excited by an (l = 2, n = 1) helical coil. It has been observed that RMP reduces the amplitude and the frequency of the (2, 1) tearing mode, which is the dominant MHD mode in the STOR-M tokamak. The flow measurements of O_v and C_{VI} impurity lines revealed that the flow direction changes towards the co-current direction during the time when RMP is turned on. The changes in the flow velocity for both impurity lines depend on the RPM current. The changes in flow/rotation velocities are nearly proportional to RMP current when I_{RMP} < 850A and shows some saturation with further increase in I_{RMP}. In the second STOR-M experiment, the effect of tangential CT injection on impurity flow velocity has been studied. It has been observed that the toroidal flow velocities of impurity ions change towards the CT injection direction independent of the intrinsic flow direction which can be change by reversing the tokamak discharge direction from CCW to CW direction. This is the first demonstration of the transfer of the CT momentum into the tokamak plasma.

The second set of experiments was conducted on the UofS-I dense plasma focus device operated in argon gas at the 5 mTorr pressure and at the bank voltage of 20 kV. The electron temperature 5.4 ± 1.6 keV has been measured using an array of four-channel x-ray diodes masked with Co filters of different thicknesses.

5. Acknowledgments

This work was sponsored by the Natural Sciences and Engineering Council of Canada (NSERC) and the Sylvia Fedoruk Canadian Center for Nuclear Innovation.

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Exploring the SMR Opportunity – CNL Begins Discussion on Canadian Deployment

Given the growing desire for clean, safe, low-carbon energy sources, there is renewed interest in nuclear technology as a potential solution. In addition to the large, grid connected systems, many in remote locations, island nations or large industrial sites have begun to focus their attention on small or very small modular reactors (SMR / vSMR). These new reactor technologies provide an alternative to traditional nuclear reactors, and a broad range of applications.

While technologies vary, SMRs range in physical size and electrical output, making them suitable for applications which require a small footprint or a relatively small amount of power. They are designed to be purchased and constructed in a modular method, meaning that additional units could be added as needs change in time. This modular approach could also drive down costs through volume manufacturing, which in turn helps reduce the risk for investors. It is worth noting that the definition of SMR includes designs which vary in electrical output from as high as 300 MW for grid-connected reactors, down to 3 MW which could be best suited for remote or industrial applications.

Much more than simply electricity generation, SMRs could be part of an overall energy scheme that includes district heating, co-generation, energy storage, desalination, and hydrogen production among others. These traits are particularly attractive to remote off-grid applications in northern communities or industrial sites, such as mines, where consistent, reliable and low carbon, clean energy is needed.

Canada is uniquely positioned to benefit from small modular reactor deployment. With more than 250 remote communities in Canada`s north, and the growth in extractive industries CNL believes that the time is right for this technology. Given the high cost and challenging logistics for fuel transportation to some of these isolated locations, an SMR is not only though to be cost-competitive but also more reliable and with a far smaller environmental footprint.

A CNL study analyzed the potential off-grid market for SMRs in Canada in 2025. This market includes remote communities, remote mining projects, oil sands extraction and upgrading projects, co-generation facilities, and district heating applications. This study found that if SMRs are economically competitive with fossil fuel burning generators (which they are expected to be), then the potential market for off-grid SMRs in Canada reaches over 600 power plants, with a total power demand of 35 GWe. Most of these power plants require an installed capacity of less than 5 MWe, falling into the vSMR category.

The SMR industry is in the early stages of establishing a foothold in the power market. Although there are three operating small reactors globally and more under some stage of construction, the majority of SMRs are in the early stages of design. Many of the SMR technologies under development that have entered the Canadian licensing process are new nuclear technologies for Canada. The SMR research program at CNL to date has been focused on capability and knowledge development for various non-water cooled reactor technologies to provide support to the regulator and generate information that may be useful to policy makers.

Canadian Nuclear Laboratories' long-term vision is to be a recognized hub for SMRs, and position Canada as a world leader in the technology. With the site identification and selection process beginning now, CNL is reaching out to the SMR developer community, potential industrial users and host communities to better understand how they view the technology, determine the market interest, and gather information which will guide CNL's science program over the years ahead.

On June 1, CNL officially launched a process to gather input which will shape the development of our SMR strategy and inform discussions with our stakeholders going forward. This effort is not limited to SMR technology developers and the nuclear supply chain, but also at potential host communities, industrial users and other interested stakeholders. It is important to CNL that we obtain a 'big picture' understanding of the opportunities and the challenges that lie ahead, and are asking you to participate in the process.

CNL invites anyone interested in sharing their views to visit www.cnl.ca/SMR and complete the short form, either online or submit a scanned hard copy. Comments are welcome until July 31.

Confusion with the IAEA reactor performance data in the PRIS

By: Donald Jones, P.Eng., retired nuclear industry engineer, 2017 July

When the author was preparing an article on the performance of Ontario's CANDU nuclear units (reference 1) he wanted to include some idea of the amount of energy being curtailed by a unit at the Bruce Nuclear Generating Station due to load cycling. To do this required a close look at the published performance indicators in the Power Reactor Information System (PRIS) database of the International Atomic Energy Agency (IAEA)(reference 2) and this revealed some discrepancies.

The performance of some of Ontario's nuclear generating stations is affected by the surplus baseload generation (SBG) in the province (reference 1). Some nuclear units saw electricity output reductions during periods of SBG. This means the CFs (Capacity Factors) are not a true performance indicator for those units (reference 3). A better metric of performance in these cases would be the Unit Capability Factor (UCF – used by Ontario Power Generation and by Bruce Power). The Energy Availability Factor (EAF) is another performance indicator and is shown in the Power Reactor Information System (PRIS) database of the International Atomic Energy Agency (IAEA), (reference 2). The EAF adjusts the available energy generation for energy losses attributed to plant management, planned and unplanned, and for external energy losses beyond the control of plant management (like load cycling/load following, grid failures, earthquakes, cooling water temperature higher than reference temperature, floods, lightning strikes, labour disputes outside the plant etc.) while the UCF only includes energy losses attributed to plant management and excludes those external losses beyond control of plant management. The UCF seems a much better indicator of how well the unit is being managed than either CF or EAF. The UCF rather than the CF would also be the more appropriate number to use when calculating the Equivalent Full Power Hours (EFPHs) on the reactor pressure tubes of Bruce units that use steam bypass at constant reactor power since steam bypass operation does not affect the EFPHs on the pressure tubes. Only reactor power changes would do that.

For Ontario there should be little significant difference between CF, UCF and EAF for units that do not load cycle (an external energy loss) since other external energy losses will be close to zero. For units that load cycle the UCF will be higher than the EAF and higher than the CF but the EAF should not be significantly different from the CF. The UCF and the EAF are based on reference ambient conditions so, unlike the CF, they cannot exceed 100 percent. In some cases the CF can be more than the UCF and the EAF if the cooling water temperature is lower than the reference temperature and that increases the electrical output of the unit.

Now let's see where the confusion arises. Take an example from the PRIS data. Bruce B unit 5, a load cycling unit, has a 2016 annual CF of 94 percent and an EAF of 97.4 percent. However, the EAF of 97.4 percent must really be a UCF since the UCF for a load cycling unit must be greater than the CF but the EAF should not be significantly different from the CF since load cycling is accounted for in the EAF, but not in the UCF. For Ontario the only external energy loss would be from load cycling since other external energy losses would be normally near zero. For the Darlington and Pickering units that do not load cycle the CFs and EAFs (really UCFs) in the PRIS are not significantly different.

Outside Ontario, for example, the EAFs for Korean units for 2016 are "real" EAF numbers since their shutdown due to the major earthquake (reference 4) must have been included as an external energy loss. However for France, where load following is routine, PRIS shows some French units with EAFs considerably higher than CFs which means that the PRIS is using UCFs and not EAFs, just like Ontario. Hence the confusion. The CFs (or Load Factors as PRIS calls them) have been correctly calculated by PRIS from the PRIS Electricity Supplied (net generation) and the Reference Unit Power (net) so the anomaly is only with the EAFs.

To summarize, the PRIS database should use UCFs instead of EAFs as performance indicators for all countries.

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Publisher's Note: The CNS Nuclear Canada Yearbook commenced using PRIS data this year. Data was no longer available from the CANDU Owners Group, and data from public sources such as Nuclear Engineering International or Nucleonics Week had become either incomplete or late in publication.

Breathing Radon by Don Wiles[1]

Three years ago I wrote a short article for the Bulletin (2) which described the production and purification of radium bromide as it was done in 1948. That article described how the purified RaBr2 was powdered and put into weighed glass tubes for storage. It also mentioned that frequently bits of radium bromide got stuck to the outside of the tube, and became volatilized when I sealed the tube. This was quite exciting at the time, because the flame touching the radium gave rise to a startling red 'flame test'. (I occasionally wonder if perhaps I am the only chemist alive in the world who has seen the Radium flame test!).

Aside from all that drama, there came another consequence, in that I unavoidably inhaled some of the volatilized radium. Since radium is chemically similar to calcium, it is clear that radium will deposit in human bones, and likely stay there. No one noticed (or cared) at that time, and it became interesting only when, at MIT, I came to the attention of Prof. Robley Evans, who was probably the world's foremost health physicist working on radiation exposure. He was developing a device for measuring the radon in people's breath. On learning that I was apparently breathing out about 25 times the legal maximum of radon, he needed me to help calibrate his new devices.

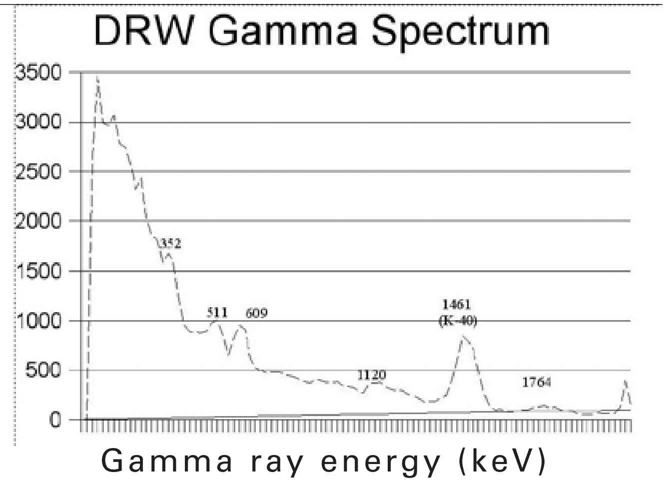
This then led to my being measured for radium by the MIT Medical unit. I was measured several times, and once in Chicago, before being measured here in Ottawa. Unfortunately, most of the data have been lost, although some spectra remain, as in the accompanying figure, which shows the intensity of each of the gamma rays measured. This measurement was done in Ottawa in 2001, and shows several gamma rays from 214Bi and 214 Po – decay products from 226 Ra.

^{238}U ...... ^{226}Ra ^{222}Rn ^{218}Po ^{214}Pb ^{214}Bi ^{214}Po ^{210}Pb .....

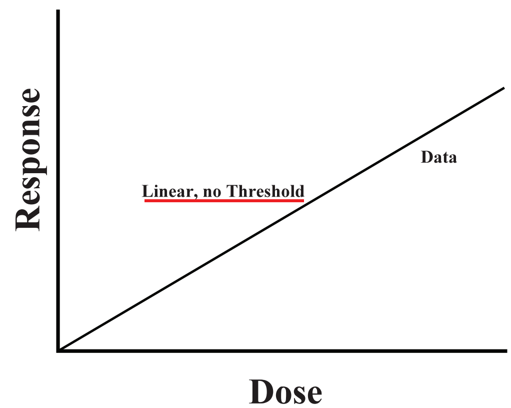
α α α βγ βγ α

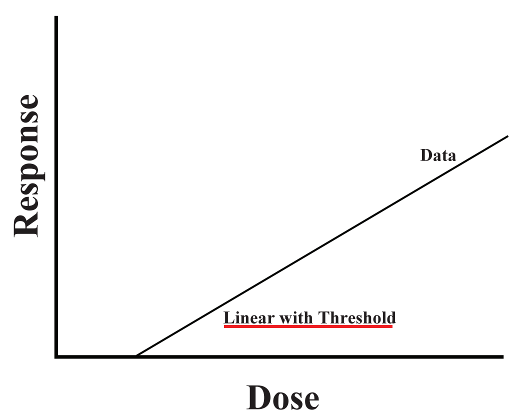
It is evident now that the level of 226Ra in my bones is less than the normal level of 40K, which is likely in everyone's body. A difference is that 40K has no decay products and emits only one beta particle, while 224Ra and its products give series of several alpha particles and several beta- gamma decays. A crude calculation can be done to suggest that the 'biological half-life' of radium in bones is about 120 years.

Now what might this mean? Since I have carried this level of radiation for many decades, and remain healthy, it should be clear that (for me at least) the current international dose-response curve – linear - no threshold – is inappropriate. It seems likely that a threshold must apply, and likely to all humans. It is obvious that all living species have survived for millions of years in the presence of natural radiation. These curves are shown below. Current measurements on animals suggest (3) that the threshold might be at the level of 800 - 1000 mGy/year.



It is not yet clear whether 'hormesis' (a beneficial effect at low doses) might apply, although intuitively it makes some sense.





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Annual General Meeting

by Fred Boyd

The 20th Annual General Meeting for the Canadian Nuclear Society, as an incorporated, non-profit organization, for its fiscal year 2016, was held Sunday afternoon, June 4, 2017, in Niagara Falls, Ontario. The meeting included reports on the operating year from June 2016 to June 2017.

As has been the practice this was immediately prior to the opening reception of the CNS 2017 Annual Conference.

CNS Secretary, Colin Hunt, opened the meeting by reporting that the 36 members present and 6 proxies constituted a legal basis for the meeting. He then asked for approvals of the Agenda and of the Minutes for AGM 19, which were quickly given. He then turned the meeting over to President, Peter Ozemoyah, CNS President, for his report on operating year 2016-2017.

Dr. Ozemoyah, greeted the audience and noted that the meeting was being "streamed" for members not physically present. (Subsequently it was reported that 57 members connected for some, or all, of the broadcast.)

He then presented his report which is reprinted in this issue of the CNS Bulletin.

Election of officers:

Past president Paul Thompson reported on the election of Officers and Council members that, for the first time, had been conducted electronically over the period April 24 to May 8, 2017.

Candidates names and brief CVs had been posted on the members website. Approximately 30 percent of members participated in the election, which he commented was "remarkable". Although all candidates received a respectable number of votes he stated that the initial account was clear. (The final results are printed in this issue of the Bulletin)

He presented a motion to accept the election results for the 2017-2018 Executive and Council which was quickly given.

Financial Report

CNS Treasurer, Mohamed Younis, tabled his Treasurer's Report for fiscal 2016. He noted that the Canadian Not-for-Profit Act allows an organization of

the (financial) size of the CNS to have an independent Chartered Professional Accountant do a "Review Engagement", a limited version of a full audit.

Although the original budget for 2016 anticipated a deficit of $5K the actual expenses were less than predicted and the revenue higher, resulting in a net revenue of $356 for fiscal 2016 versus a predicted deficit of about $88K. He stated that CNS Council had approved the Financial Statement.

In closing he thanked Brian Blosser of Blosser and Associates and his staff and Ken Smith, CNS Financial Administrator, for their excellent work in dealing with the accounts of the Society.

Then followed short reports from Divisions, Committees and Branches. Most of these will be posted on the members section of the CNS website.

A new venture proposed by Ron Thomas, chair of the Branch coordinating committee, will see an invited speaker from the UK come to Canada to speak to several branches about the program in that country to be followed by a CNS member reciprocating by visiting the UK.

With the formal business completed, Peter Ozemoyah passed the symbolic gavel to incoming president, Dan Gammage, who reciprocated by giving the retiring president a plaque commemorating his service to the Society.

Then Dan Gammage outlined some of his plans for the 2017-2018 period

The AGM was adjourned close to the planned hour of 5:00 p.m. in time for the opening reception of the 2017 Annual Conference.

President's Report for 20th CNS Annual General Meeting (June 04, 2017)

It has been a very challenging, exciting and fruitful year for me as President, for the CNS, and for the nuclear industry. What with the ongoing refurbishment at Darlington, the several joint ventures between industries of various countries, the unfortunate situation with Westinghouse, the Hanford sinkhole incident, ... As usual, the nuclear industry never lacked excitement throughout the year.

The CNS year started after the 19th Annual General Meeting on 19th June 2016 in Toronto. This was followed immediately with the 36th Annual Conference at the same venue. It was a great conference with the 2015 Nobel Laureate in Physics (Arthur McDonald) delivering a talk on the topic that won him the Nobel Prize.

A number of other successful conferences and courses were held during the year. Among them were:

- CNS CANDU Reactor Technology & Safety Course,
- 4th International Technical Meeting on Small Reactors (ITMSR-4)
- 3rd Canadian Conference on Nuclear Waste Management, Decommissioning and Environmental Restoration
- 13th International Conference on CANDU Fuel

Many thanks to the volunteers that made these possible.

In the 2012/2013 Council Year, the CNS launched the Nuclear 101 Course. The success of this course since then has resulted in putting on the course at least twice a year. Great job by the Education and Communications Committee (ECC), the custodian of the course. As a result of this success, and due to demand from the nuclear industry, the CNS, through the ECC, is concluding the process of putting on a new course – **Nuclear Safety Culture Foundation Course**. We look forward to the start of this initiative.

Before the end of the 2015/2016 Council Year, the CNS Executive took the initiative to visit some stakeholder industries. The initiative termed "Relationship Visits" was for CNS to establish a better working relationship with the Management of these various establishments by understanding their needs and rehashing areas of common interest. This initiative was continued in the 2016/2017 Council Year, and has so far proven to be a very successful venture. Thanks to Paul Thompson who was given the mandate to spearhead the initiative, and who has done a great job of it. This Council Year, the team has visited 10 establishments, including the three Utilities – OPG, Bruce Power, and NB Power. The visits fit well into the 2017-2022 Strategic Plan of the Society. The Strategic Plan Committee led by Jacques Plourde has put together an achievable and realizable 5-year plan for the CNS. The committee is also overseeing the implementation of the plan.

In my acceptance speech at the last AGM, I promised to visit all the Branches as much as is logistically possible. I was able to visit 6 out of the 10 active Branches. The ones not visited were due to logistic issues within the Branches. In addition to visiting the Branches, efforts in encouraging Branch activities continued. During the year, the Branch Affairs and the International Liaison Committees jointly established a new initiative. It involves having an expert from one of our sister International Societies coming to give talks in our Branches, with a reciprocal visit from one of our experts to the sister Society the following year. Arrangements have been concluded to have the first Speaker come from the Nuclear Institute (Britain) in October/November this year. The expert will speak in at least five CNS Branches. Reciprocally, CNS expert will be going to Britain in 2018. This initiative is great for the Branches which have been marvelous throughout the year.

In 2012, the CNS for the first time participated in the Federal Government's request for expressions of interest in AECL. Since then, the Society has actively participated in similar Hearings. This year, CNS was invited by Parliament to make presentation before the House Standing Committee on Natural Resources. Another Intervention presentation by CNS on NB Power license extension was in May this year. The CNS President, Secretary, and Communications Director represented CNS at the Hearing, and presented intervening paper on behalf of the CNS

In Paul Thompson's report last year, he concluded by saying *"......I offer to him (incoming President Peter Ozemoyah) my continuing support throughout the coming year ....."* I will say here that Paul kept that promise; and I am making the same promise to the incoming President Daniel Gammage.

It has been a great year for me. I hope it was for you too.

Peter Ozemoyah (PhD)
CNS President, 2016/2017

Concluding Comments by 2017-2018 President, Dan Gammage

At the end of the AGM, newly installed President, Dan Gammage, spoke briefly of his focus for the CNS during his tenure. Dan departed for a trip shortly after the 2017 Conference. Since he spoke from brief hand-written notes the following is drawn from those notes and not his actual words.

I wish to thank the members of the CNS who voted for me as 2ND V.P. two years ago that led to my being appointed President for the 2017-2018 year.

The past 12 months have been very successful for the Society. The Strategic Plan, developed under the leadership of (former president) Jacques Plourde was formally adopted. I intend to implement the major points of that Plan

CNS increased its visibility both with the public and especially with the nuclear community. Further, it intervened at hearings held by the Canadian Nuclear Safety Commission and federal parliamentary committees. This activity I fully support.

I plan, with past-president Peter Ozemoyah and former president Paul Thompson to continue meeting with senior officials of the various organizations involved with Canada's nuclear program. Our message will be "What can the CNS do for you".

Personally, I hope to visit all, or most, of the CNS Branches, dependent on our respective schedules.

I support the proposed "Nuclear Safety Culture course". And, I invite all members to suggest other programs and activities relevant to our basic objectives.

In closing I ask all members to participate in the Society and to increase its visibility.

Now, in closing, let us all join in the opening reception of the 2017 Annual Conference.

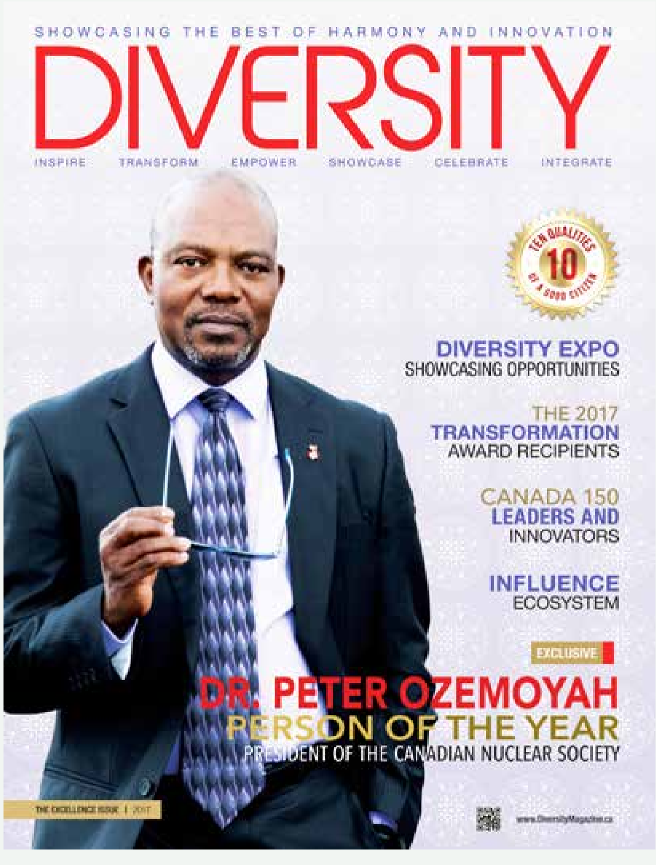
Dr. Peter Ozemoyah Named Person of The Year

The Transformation Institute For Leadership and Innovation, Silvertrust Media and Diversity Magazine have named Dr. Peter Ozemoyah, President of Canadian Nuclear Society (2016-17) as Person Of The Year, with a spotlight on the cover of Diversity Magazine.

Dr. Ozemoyah has also been selected for the prestigious Canada 150 Leadership & Innovation list, which will culminate in a coffee table book that will be in libraries and book stores later this year, a documentary film, biography series, interstitials and online specials as a part of the Envision Canada initiative.

The prestigious Transformation Awards gala was on Friday, June 16th 2017, at Royal York Hotel. Presented by the Transformation Institute For Leadership & Innovation, Silvertrust Media and Diversity Magazine, the event honoured 12 highly accomplished individuals who are an inspiration to present and future generations. Extraordinary Canadians on the Canada 150 Leadership and Innovation list were also recognized to commemorate Canada's 150th anniversary. The 150 high achievers will be featured in a world-class coffee table book and a multimedia presentation as a part of Envision Canada. Dr. Peter Ozemoyah, President of the Canadian Nuclear Society was named the 2017 Person Of The Year. He is featured on the cover of a special edition of Diversity Magazine.

The 2017 Transformation Awards recipients are: Leadership Award, Dr. Ajay Virmani, CEO of Cargojet; Lifetime Achievement, General Roméo Dallaire, Humanitarian & Retired Senator; Entertainment Award, Cameron Bailey, Artistic Director, Toronto International Film Festival; Professional Excellence, Raj Kothari, Managing Partner, PwC; Development Award, Heather Yang, President, Anderson College.



Safety Aspects of Nuclear Power Plants in Human Induced External Events: Margin Assessment

Safety Reports Series No. 88

This publication describes the procedures for calculating the margins of nuclear power plants in relation to human induced external hazards. It focuses on plant and systems performance evaluations. A two level approach for margin assessment is provided. The first level consists of a deterministic procedure in which, for each scenario, the existence of at least one undamaged success path to comply with the fundamental safety function is investigated. This procedure can be subsequently extended to calculate probability measures such as conditional core damage probability and the conditional probability of spent fuel damage. In the most elaborated stage, probabilistic safety assessment (PSA) techniques are introduced, giving consideration to the probabilistic aspects of the hazards and of the capacity of structures, systems and components (fragility). Event tree and fault tree models are used to compute PSA metrics, such as core damage frequency, large early release frequency and frequency of spent fuel damage.

STI/PUB/1723, 102 pp.; 13 figs.; 2017; ISBN: 978-92-0-111415-0, English, 42.00 Euro

Electronic version can be found: http://www-pub.iaea.org/books/iaeabooks/10914/Safety-Aspects-of-Nuclear-Power-Plants-in-Human-Induced-External-Events-Margin-Assessment

The IAEA is pleased to announce the publication of:

Safety of Nuclear Fuel Reprocessing Facilities

IAEA Safety Standards Series No. SSG-42

This publication provides guidance on meeting the requirements of IAEA Safety Standards Series No. NS-R-5 (Rev.1) relating to nuclear fuel reprocessing facilities. It covers the lifetime of these facilities, from site selection through to decommissioning, concentrating on the design and operational phases. It applies to facilities that reprocess spent fuel and other material from nuclear power plants that use metallic and oxide fuels, including materials from mixed oxide fuel (MOX) and breeder reactors. It covers the safety issues relating to: the handling of spent fuel; mechanical treatment and the dissolution of spent fuel in acid; the separation of uranium and plutonium from fission products using solvents; the separation and purification of plutonium and uranium; and the production and storage of solutions and oxides to be used as feed material to form fresh uranium or mixed (UO2/PuO2) oxide fuel.

STI/PUB/1744, 119 pp.; 6 figs.; 2017; ISBN: 978-92-0-103016-0, English, 51.00 Euro

Electronic version can be found: http://www-pub.iaea.org/books/iaeabooks/10994/Safety-of-Nuclear-Fuel-Reprocessing-Facilities

Operating Experience with Nuclear Power Stations in Member States (2017 Edition)

Operating Experience (CD)

This CD-ROM contains the 48th edition of the IAEA's series of annual reports on operating experience with nuclear power plants in Member States. It is a direct output from the IAEA's Power Reactor Information System (PRIS) and contains information on electricity production and overall performance of individual plants during 2016. In addition to annual information, the report contains a historical summary of performance during the lifetime of individual plants and figures illustrating worldwide performance of the nuclear industry. The CD-ROM also contains an overview of design characteristics and dashboards of all operating nuclear power plants worldwide.

STI/PUB/1792; 2017; ISBN: 978-92-0-154417-9, English, 75.00 Euro

Electronic version can be found: http://www-pub.iaea.org/books/IAEABooks/12246/Operating-Experience-with-Nuclear-Power-Stations-in-Member-States-in-2016

Publications

Opportunities for Cogeneration with Nuclear Energy

IAEA Nuclear Energy Series No. NP-T-4.1

This publication presents a comprehensive overview of various aspects relating to the application of cogeneration with nuclear energy, which may offer advantages such as increased efficiency, better cost effectiveness, and reduced environmental impact. The publication provides details on experiences, best practices and expectations for the foreseeable future of cogeneration with nuclear power technology and serves as a guide that supports newcomer countries. It includes information on systems and applications in various sectors, feasibility aspects, technical and economic details, and case studies.

STI/PUB/1749, 91 pp.; 32 figs.; 2017; ISBN: 978-92-0-103616-2, English, 58.00 Euro

Electronic version can be found: http://www-pub.iaea.org/books/iaeabooks/10877/Opportunities-for-Cogeneration-with-Nuclear-Energy

Safety Aspects of Nuclear Power Plants in Human Induced External Events: General Considerations

Safety Reports Series No. 86

This publication gives the general roadmap on how to perform the design and evaluation of the protection of nuclear power plants against human induced external hazards, consistent with IAEA Safety Standards. The publication concentrates on an overall view of the methodology and on the important considerations for its application to existing and new nuclear power plants. Topics covered include elements of the design/evaluation approach, developed in five phases: event identification; load characterization; design and assessment approaches; plant performance assessment and acceptance criteria; and operator response. The publication provides an approach to the assessment of extreme human induced external events which is fully consistent with the methods used for evaluation of nuclear facilities subjected to extreme natural events, such as earthquakes and floods.

STI/PUB/1721, 88 pp.; 3 figs.; 2017; ISBN: 978-92-0-111015-2, English, 41.00 Euro

Electronic version can be found: http://www-pub.iaea.org/books/iaeabooks/10913/Safety-Aspects-of-Nuclear-Power-Plants-in-Human-Induced-External-Events-General-Considerations

Nuclear Power Reactors in the World

2017 Edition

Reference Data Series No. 2

This is the 37th edition of Reference Data Series No. 2, which presents the most recent reactor data available to the IAEA. It contains summarized information as of the end of 2016 on power reactors operating, under construction and shut down as well as performance data on reactors operating in the IAEA Member States. The information is collected through designated national correspondents in the Member States and the data are used to maintain the IAEA's Power Reactor Information System (PRIS).

IAEA-RDS-2/37, 79 pp.; 6 figs.; 2017; ISBN: 978-92-0-104017-6, English, 18.00 Euro

Electronic version can be found: http://www-pub.iaea.org/books/IAEABooks/12237/Nuclear-Power-Reactors-in-the-World

GENERAL news

(Compiled by Colin Hunt from open sources)

Terrestrial Energy Commences Work to Explore Siting the First Commercial IMSR® Power Plant at Canadian Nuclear Laboratories

Terrestrial Energy, a vendor of Advanced Reactor power plants has commenced a feasibility study to explore siting the world's first commercial Integral Molten Salt Reactor (IMSR®) power plant at Canadian Nuclear Laboratories (CNL). The study is being conducted by CNL. A key piece of their vision is to create a technology hub at CNL to support the commercialization of small modular reactors, a potentially transformative technology.

"This is an important milestone for Terrestrial Energy. It maintains our momentum for 2020s deployment of IMSR® power plants," said Simon Irish, CEO of Terrestrial Energy. "We are pleased to be working with CNL to begin the process to identify a suitable location on the CNL site to build the first commercial IMSR® power plant."

"Supporting the research, licensing and siting of Canada's first advanced reactors is an important part of CNL's long-term plan," said Mark Lesinski, President and CEO at CNL. "We are excited to begin these efforts by supporting these studies for Terrestrial Energy's IMSR® commercial power plant."

The work is being carried out in parallel with an industry wide Request For Expression Of Interest (RFEOI) recently launched by CNL. The responses to the RFEOI will inform a roadmap that takes in account the considerations of reactor developers, the supply chain, end users and other stakeholders.

The parties are cooperating under a business framework set out in a 2016 Memorandum of Understanding (MOU) agreed between Terrestrial Energy and CNL. It facilitates a collaborative working relationship to conduct testing and validation activities to support Terrestrial Energy's engineering program for IMSR® deployment. It covers a broad set of CNL's nuclear services including reactor physics, thermal hydraulics, metallurgy, chemistry, waste management and decommissioning. The MOU is non-exclusive; CNL is not restricted from building other nuclear reactor systems at its facilities, and Terrestrial Energy is not restricted from building IMSR® power plants at other locations.

Bruce Power First Canadian Company to Win Innovation Award at The Nuclear Energy Institute's Nuclear Energy Assembly

Bruce Power received a Top Innovative Practice Award (TIP) for its work with Nordion on the production of Cobalt-60 at the Nuclear Energy Institute's (NEI) Nuclear Energy Assembly in Scottsdale, Arizona.

Running May 22-24, NEI's 64th annual Industry Conference and Supplier Expo: Nuclear Energy Assembly is the annual conference of the nuclear technologies industry that brings together leaders from all levels. A highlight of the conference is the TIP Awards, which are the nuclear industry's highest recognition of excellence. Since 1994, the TIP Awards have recognized the new and creative ideas and techniques developed by the nuclear industry's talented workforce direct impact on improving the safety and reliability of the nuclear energy industry.

"We are thrilled to be the first and only Canadian company to receive a TIP Award," said Mike Rencheck, Bruce Power's President and CEO. "Bruce Power takes great pride in receiving this award, and in our partnership with Nordion. Our 2016 agreement with Nordion allows us to make Cobalt-60, which sterilizes more than 40 per cent of the world's single-use medical devices, such as sutures, gloves and syringes and saves lives by treating cancer patients."

Canadian Government Called on to Reaffirm Nuclear Support

A cross-party committee has called on the Canadian government to reaffirm its long-standing support for the nuclear sector, including the commercialization of small modular reactors (SMRs). The House of Commons Standing Committee on Natural Resources made its recommendations in a report, **The nuclear sector at a crossroads: Fostering innovation and**

energy security for Canada and the world, which it tabled before the government on 9 June.

The report, which concludes a broader study on innovation, sustainable solutions and economic opportunities in the country's oil, gas, mining and nuclear sectors, is based on evidence from experts from industry, government, academia and civil society.

The 44-page document looks into: nuclear materials and facilities governance, safety and waste management; the state of the nuclear energy industry in Canada and abroad; and the future of Canadian nuclear R&D. Its seven recommendations focus on: nuclear regulatory and safety practices; R&D and innovation; the development and commercialization of next-generation nuclear technologies; and leveraging non-power nuclear applications for national benefit, calling for the establishment of a nuclear innovation council to achieve this.

Committee chairman James Maloney said Canada had been a "bold trailblazer" in nuclear technology and research for over 70 years, and had a "proud history" of providing the "safest technology" and "unsurpassed" expertise.

"Based on our study, it is clear that the federal government, working with partners in industry and other levels of government, can and must ensure that the future of the Canadian nuclear sector remain supported," he said. "The government should also make certain that researchers continue to have access to the tools needed to excel in their innovation activities."

SNC-Lavalin Awarded Nuclear Maintenance Contracts in South Korea and China

SNC-Lavalin announced that it has been awarded a fuel channel inspection (FCI) contract from Korea Hydro and Nuclear Power Company Ltd. (KHNP) and a fuel channel reconfiguration contract from China's Third Qinshan Nuclear Power Company Ltd. (TQNPC).

SNC-Lavalin will conduct inspection of the fuel channels of KHNP's Wolsong units 1 and 3 this year and will also undertake the reconfiguration of the fuel channels of TQNPC's Qinshan units 1 and 2 this year and next year. As the original equipment manufacturer of CANDU nuclear technology, SNC-Lavalin is uniquely qualified to conduct these two key mandates.

Using a proprietary tooling system, designed by in-house experts and built specifically for this application, SNC-Lavalin will send field crews to the customer sites to conduct fuel channel inspections and perform any necessary maintenance required to reconfigure and redirect channel elongation.

"Winning these two contracts is further evidence of SNC-Lavalin's strong presence in the East Asian nuclear market," said Preston Swafford, Chief Nuclear Officer and Executive Vice-President, Nuclear. "We are pleased at the confidence our customers continue to show us in this increasingly competitive market."

China Had 20 Nuclear Reactors Under Construction at End-March

China had 20 nuclear reactors under construction at the end of March, with a total capacity of 23.11 gigawatts (GW), the China Nuclear Energy Association said on Thursday.

China had 36 reactors in full commercial operation at the end of last month, with a total capacity of 34.72 GW, said association chairman Zhang Huazhu, speaking at the group's annual assembly in Beijing.

The two combined equate to just under 58 GW, in line with China's target for capacity on line by 2020, but China also aims to have a further 30 GW of nuclear reactors under construction by the end of 2020. Zhang warned the overall target would not be easy, especially after construction of new reactors slowed following a nationwide safety review prompted by Japan's Fukushima disaster in 2011. Half of the 20 new units under construction at end-March are advanced "third-generation" reactors, Zhang said.

Nuclear Construction Reaches 25-Year High

The nuclear industry brought more than 9 GWe of new plant on line last year, the largest annual increase in 25 years, according to a new World Nuclear Association report, putting it on track to achieve the Harmony goal of providing 25% of electricity in 2050 using 1000 GWe of new capacity.

In the *World Nuclear Performance Report 2017*, the Association detailed power generation and construction achievements for the previous year.

The ten new reactors which came on line in 2016 added 9.1 GWe to global capacity and took the total nuclear capacity supplying electricity to the grid past 350 GWe for the first time ever. This does not include around 40 GWe of operable nuclear plant that remains offline in Japan and is making slow progress towards restart.

Growth in nuclear power is being led by China, where five of the ten new reactors are located. "This trend is likely to continue in the coming years with around a third of reactors currently under construction being located in China," said Agneta Rising, the Association's director-general.

Chinese industry constructed its new reactors in 5 years and 9 months on average. Series build is a major factor in this. A case study showed that 912 issues were identified during the construction of Yangjiang 1-3. Successfully addressing these helped unit 4 to be built more than ten months more quickly than unit 1.

Steady performance is a feature of nuclear power plants and this continued across the fleet with a global average capacity factor of 80.5%, down just slightly on last year's 81%. According to the report, 64% of the world's reactors operated at an average of 80% of their full potential across the entire year. Only 8% of reactors achieve below 50% of their potential output.

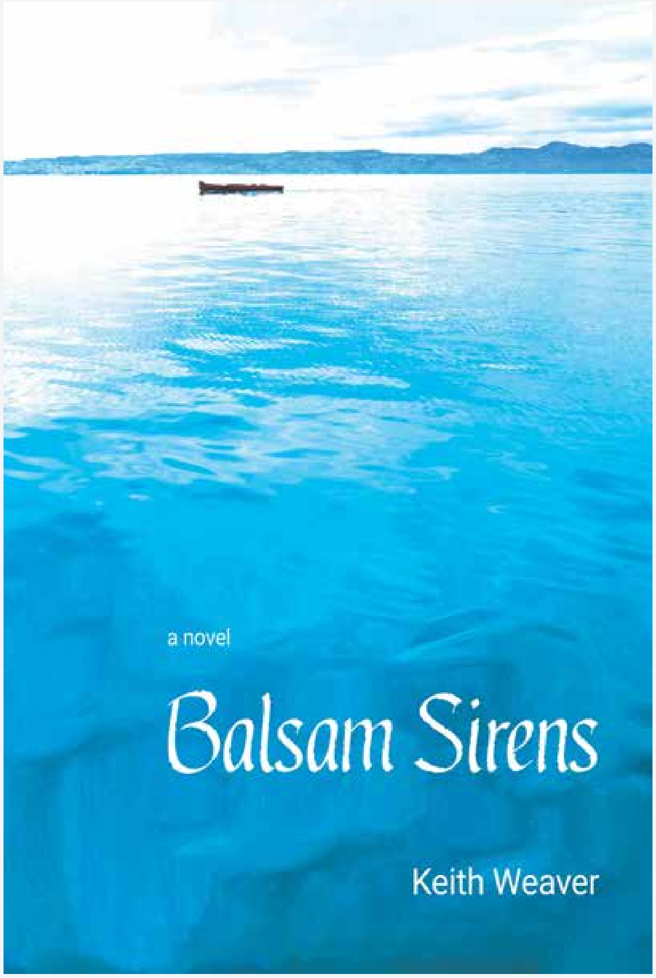
The report states that "there is no significant age-related trend in nuclear reactor performance" with older units achieving the same level of performance as newer ones. It highlights the case of Heysham II-2 in the UK, a reactor that has operated since 1988 and in 2016 completed a record-breaking run of 941 days generating electricity without interruption.

Total nuclear power generated worldwide was up for the fourth year in a row, to 2476 TWh in 2016, which broadly keeps pace with the overall growth of the electricity system. Figures for global electricity of all kinds take longer to compile, but the latest data, for 2014, shows nuclear maintaining a 10.6% share of electricity.

Third Novel from CNS Member Keith Weaver

By Ric Fluke

If you need a break from reading all those detailed drawings and technical specifications, or you just want to relax with a novel that has nothing to do with nuclear science, then I recommend *Balsam Sirens,* the third novel by retired nuclear engineer and [*very*] long time CNS member Keith Weaver.



Balsam Lake is in rural Ontario, one of the Kawartha's and close to where Keith grew up. It is a quiet resort area, calm and relaxing and perhaps even exotic (Keith muses whether such a familiar place could even be exotic). *Balsam Sirens* weaves together intrigue, threads of local history, treasure hunting, the wiles of a psychopathic villain, and an impressive body count. It is a story of things not being what they appear.

In what appears to begin as a routine investigation into the death of a local family member things soon go horribly astray - and dangerous! Aside from some amusing philosophies regarding the causes of parricide, not to mention some amusing idiosyncrasies of some of the characters, a private investigator finds himself precariously close to being the next victim and must take extreme actions to protect himself, his wife and his client over a course of unthinkable events while unravelling the mysteries.

Balsam Lake is available at Amazon, Indigo, or from the author (krweaver503@gmail.com).

Other novels by Keith Weaver are *An Uncompromising Place* and *The Recipe Cops.* And yes, a fourth novel is coming!

CNS Executive Committee for 2017-2018

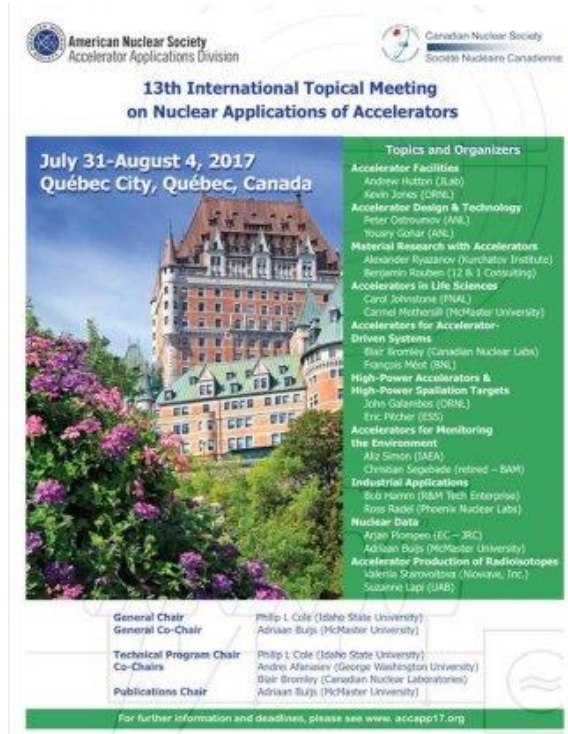
President	Dan Gammage
Past President	Peter Ozemoyah
1st Vice President	John Luxat
2nd Vice President	Keith Stratton
Secretary	Colin Hunt
Treasurer	Mohamed Younis

Members of CNS Council for 2017 – 2018

Parva Alavi	Eleodor Nichita
Andew Ali	Peter Ottensmeyer
Ruth Burany	John Roberts
Chris Claravino	Ben Rouben
Peter Easton	Wei Shen
Mohinder Grover	Nicholas (Nick) Sion
Emma Hauch	Keith Stratton
Jerry Hopwood	Jerzy Szpunar
Colin Hunt	Ron Thomas
Paul Jones	Aman Usmani
Raphel Kouyoumdjian	Kamal Verma
Wilson Lam	Mohamed Younis
John Luxat	Stephen Yu
Kris Mohan	

American Nuclear Society
Accelerator Applications Division

Dear Colleagues,



AccApp'17 is the thirteenth international topical meeting on the applications of accelerators; it is being organized by the Accelerator Applications Division of the American Nuclear Society (ANS) and the Canadian Nuclear Society (CNS). **AccApp'17 will be held at the Hilton Québec Hotel, in Québec City, Québec, Canada July 31-August 4, 2017.**

The purpose of these topical AccApp meetings is to provide an international forum for discussing the various applications of particle accelerators. Meetings are focused on the production and utilization of accelerator-produced neutrons, photons, electrons and other particles for scientific and industrial purposes; production or destruction of radionuclides significant for energy, medicine, defense, or other endeavors; safety and security applications; medical imaging, diagnostics, and therapeutic treatment.

One of the great strengths of the AccApp meetings is the dissemination of knowledge on the diverse applications of accelerators. The conference provides an opportunity for nuclear physicists, accelerator physicists, nuclear engineers, and other experts in the international community to meet and discuss their research face-to-face. These interactions can help establish good working relationships and collaborations to solve common problems across multiple disciplines. Also, old friendships can be cultivated and new ones established.

You are cordially invited to participate in AccApp'17 by submitting an abstract, making an oral or poster presentation, and submitting a full paper for publication in our conference proceedings. For further information (including deadlines and registration), please see the conference webpage at www.accapp17.org. The deadline for abstract submission (200 word limit) is March 31, 2017.

Full papers (10 pages or less) are due on September 10, 2017. For each extra page beyond 10 pages, there will be charge of $100 per page. The templates for both the abstract and the full paper can be found on www.accapp17.org. The downloadable high-resolution poster can be found on www.accapp17.org.

We are looking forward to seeing you in la belle ville de Québec!

Philip Cole (colephil@isu.edu)
General Chair of AccApp'17

Adriaan Buijs (buijsa@mcmaster.ca)
General Co-Chair of AccApp'17

American Nuclear Society
Accelerator Applications Division

Canadian Nuclear Society
Société Nucléaire Canadienne

13th International Topical Meeting on Nuclear Applications of Accelerators

Topics and Organizers

Accelerator Facilities
Andrew Hutton (JLab)
Kevin Jones (ORNL)

Accelerator Design & Technology
Peter Ostroumov (ANL)
Yousry Gohar (ANL)

Material Research with Accelerators
Alexander Ryazanov (Kurchatov Institute)
Benjamin Rouben (12 & 1 Consulting)

Accelerators in Life Sciences
Carol Johnstone (FNAL)
Carmel Mothersill (McMaster University)

Accelerators for Accelerator-Driven Systems
Blair Bromley (Canadian Nuclear Labs)
François Méot (BNL)

High-Power Accelerators & High-Power Spallation Targets
John Galambos (ORNL)
Eric Pitcher (ESS)

Accelerators for Monitoring the Environment
Aliz Simon (IAEA)
Christian Segebade (retired – BAM)

Industrial Applications
Bob Hamm (R&M Tech Enterprise)
Ross Radel (Phoenix Nuclear Labs)

Nuclear Data
Arjan Plompen (EC – JRC)
Adriaan Buijs (McMaster University)

Accelerator Production of Radioisotopes
Valeriia Starovoitova (Niowave, Inc.)
Suzanne Lapi (UAB)

General Chair	Philip L Cole (Idaho State University)
General Co-Chair	Adriaan Buijs (McMaster University)
Technical Program Chair	Philip L Cole (Idaho State University)
Co-Chairs	Andrei Afanasev (George Washington University)
	Blair Bromley (Canadian Nuclear Laboratories)
Publications Chair	Adriaan Buijs (McMaster University)

For further information and deadlines, please see www. accapp17.org

Calendar

2017

July 31-Aug. 4 — **13th International Topical Meeting on Nuclear Applications of Accelerators (AccAPP17)**
Hilton Quebec Hotel,
Quebec City, QC
accapp17.org

Sept. 17-20 — **2nd CNS Conference on Fire Safety and Emergency Preparedness for the Nuclear Industry**
Toronto Marriott Downtown
Eaton Centre Hotel
Toronto, ON
cns-snc.ca/events/2cfsep/
cns-snc@on.aibn.com

Sept. 24-27 — **Global 2017 International Fuel Cycle Conference**
Sheraton Grande Walkerhill
Seoul, South Korea
global2017.org/congress/index3.php

October — **CANDU Fuel Technology Course**
Hilton Garden Inn Toronto/Ajax
Ajax, ON
cns-snc.ca/events

October 1-4 — **CANDU Maintenance & Nuclear Components Conference (CMNCC)**
Toronto Mariott Down
Eaton Centre Hotel
Toronto, ON
cns-snc.ca/events/cmncc-2017/

Fall — **CANDU Thermal Hydraulics Course**
Toronto, ON
cns-snc.ca

Nov. 12-16 — **2017 ANS Winter Meeting and Nuclear Technology Expo**
Washington, DC, USA
ans.org/meetings/c_1

2018

February — **CNA Nuclear Industry Conference and Tradeshow**
Westin Hotel
Ottawa, Ontario
cna.ca/2018-conference

March — **CANDU Technology & Safety Course**
cns-snc.ca

April 22-26 — **PHYSOR 2018**
Cancun, Mexico
physor2018.mx

May 2018 — **Nuclear 101**
cns-snc.ca

June 3-6 — **38th Annual CNS Conference & 42nd Annual CNS/CNA Student Conference**
Sheraton Cavalier Hotel
Saskatoon, SK
cns2018conference.org

June 17-21 — **ANS Annual Meeting**
Philadelphia, PA
ans.org/meetings

Sept. 30-Oct. 3 — **PBNC 2018**
San Francisco, CA, USA
pacificnuclear.net/pnc/pbnc
ans.org/meetings/c_2

Fall — **Waste Management, Decommissioning and Environment Restoration for Canada's Nuclear Activities**
cns.snc.ca

Fall — **International Conference on Simulation Methods in Nuclear Engineering**
cns-snc.ca

Fall — **International Technical Meeting on Small Reactors**
cns-snc.ca

Nov. 11-15 — **2018 ANS Winter Meeting**
Orlando, FL, USA

2019

February — **CNA Nuclear Industry Conference and Tradeshow**
Westin Hotel
Ottawa, Ontario
cna.ca/2019-conference

March — **CANDU Technology & Safety Course**
cns-snc.ca

May — **Nuclear 101**
cns-snc.ca

June — **39th Annual CNS Conference & 43rd Annual CNS/CNA Student Conference**
cns2019conference.org

CANADIAN NUCLEAR SOCIETY ®
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11th International Conference on CANDU® Maintenance and Nuclear Components

Delivering **Clean Energy** through CANDU® Life Extension

October 1-4, 2017 · Toronto Marriott Downtown Eaton Centre Hotel · Toronto, ON Canada

CALL FOR PAPERS

The CMNCC 2017 Technical Program Committee invites the submission of 300-word abstracts of papers pertaining to the technical focus of the conference. Abstracts covering, but not limited to, the following topics will be considered for presentation.

CANDU® Refurbishments

Benchmarking Programs
- Performance
- Maintenance
- Component Degradation and Life Management

Operational Experience (OPEX)
- Degradation of Major Components
- Lessons Learned
- Best Practices

Aging Management and Equipment Reliability
- Pump Motors and Pump Seals
- Heat Transport System and feeders
- Steam Generators and Heat Exchangers
- Fuel Channels
- Inspection Tooling
- Instrumentation & Control

Power Derating Mitigation
- NOP/ROP – Extreme Value Statistics (EVS)
- Reactor Inlet Header Temperature Reduction
- Steam Generator Cleaning
- 37 M and other Fuel-Design Strategies

Post-Fukushima Strategies
- Emergency Mitigation Equipment (EMS)
- Hydrogen Mitigation
- Containment Exhaust Venting

Succession Planning & Attracting Young Professionals to the Industry

Abstract Submissions

Abstracts of proposed presentations are to be no more than 300 words in length and are to be submitted online through the link on the Call for Papers page of the conference website.

The deadline for abstract submission is **June 1, 2017**.

Conference Proceedings

Submission of full papers for the Conference Proceedings is preferred, however as a minimum speakers' PowerPoint slide presentations are required for inclusion.

Author Notification

All abstracts will be formally reviewed and assessed by the Technical Program Committee and presenters will be notified of the results of the Committee's review by June 15, 2017.

Important Dates

Abstract submissions due	June 1, 2017
Author notification of review results	June 15, 2017
Draft papers/presentations due	July 14, 2017
Early registration deadline	July 31, 2017
Final paper/presentation acceptance	August 18, 2017
Hotel reservation cut-off date	August 30, 2017
CANDU Configuration Overview Course	October 1, 2017
The Conference	October 1-4, 2017

Hotel Accommodation

The Toronto Marriott Downtown Eaton Centre Hotel is the conference location and official provider of accommodation for CMNCC 2017 participants. A block of rooms is available at the preferred rate of $249/night plus taxes. Reservations can be made through the link on the Hotel Accommodation page of the CMNCC website or by calling Marriott Reservations at 1-800-228-9290 and providing the group code: **Canadian Nuclear Society**.

Toronto Marriott Downtown Eaton Centre Hotel
525 Bay Street, Toronto, ON M5G 2L2

Reservations

Marriott Reservations: 1-800-228-9290
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For everything you need to know about CMNCC 2017 go to

www.cmncc2017.org

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For information on CNS activities and other links – Pour toutes informations sur les activités de la SNC

http://www.cns-snc.ca

Do We Make Things Harder for Ourselves

by NEIL ALEXANDER

On falling through glass and communicating about nuclear power

Many of us are scientists and engineers so it is easy for us to think that if people understood the facts they would be more supportive of nuclear power.

But after decades of trying to "educate" people we are in a situation where society is turning its back on us even though our technology has an essential role in solving the problem, greenhouse gas production, that those same people believe will destroy the planet.

Perhaps we have been getting our messaging wrong.

Lets look at this idea that people make decisions based on fact.

I have a fear of heights. As a result of this fear, I cannot stand on the CN Tower's glass plate. I have tried. I have closed my eyes and tried to walk onto it. I have run at it to see if I might end up on it before I can stop. I have walked backward in the hope of surprising myself by suddenly seeing my feet are already on it…I just can't do it.

Explanation of the facts will not help. I already know them. I trained as a materials scientist so I understand that the glass will hold me even though it is transparent. As an observant human being I am conscious of the fact that I have not seen people routinely drop through the glass plate to the side walk below. My fear is not rational. It is not based on fact. And knowing more facts will not change it.

Being a materials scientist links to my next story about how we might accidentally use our knowledge to scare people. Cracks grow in materials because they have sharp points. On aircraft skins when a crack got to a certain length they just drilled a hole in both ends and sent the plane on its way with the cracks blunted and stable. So when I saw a 6 inch crack in the wing just outside my window with neat little drill holes in it I was assured that my plane had been properly maintained. I shared this good news with the person in the seat next to me whose response was different to mine. Had I known that he had avoided flying for the first 40 years of his life because flying terrified him I might have approached the situation differently. But how was I to know?

Now you are probably thinking that I must be really stupid and possibly you are right but, with respect, we do this all the time in the nuclear industry. Malcolm Grimston, a social scientist at Imperial College London, talks a lot on this subject and points to how we deal with the waste fuel problem. Don't worry ….We will wrap it in steel and wrap that in copper and then concrete and then shove it a kilometre underground. If they were scared of used fuel before their fears have just been confirmed.

But my favourite is ALARA. We think it's a way of keeping our people safe and it is. But the public, already irrationally fearful of radiation, just has their fears confirmed.

Don't start me on core damage frequencies……I am too busy worrying about a rumour I heard that people are dying in the CN tower and the Government is covering it up.

The author while believing strongly in the safety culture of the nuclear industry, and being sore afraid of heights, spent the middle years of his life as a paraglider pilot. How logical is that?


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What is your vision for SMR technology in Canada. What role will you play in making this vision a reality?

www.CNL.ca/SMR

Canadian Nuclear Laboratories (CNL) has begun a process to explore the possibilities for Small Modular Reactor (SMR) deployment in Canada. As part of this effort we are gathering input from researchers, technology developers, nuclear supply chain members and interested community stakeholders.

Your participation through a short survey will help us identify the challenges and opportunities faced in bringing an SMR to successful deployment. We would like to have your input and invite you join the discussion at www.CNL.ca/SMR.

Submission deadline: July 31.