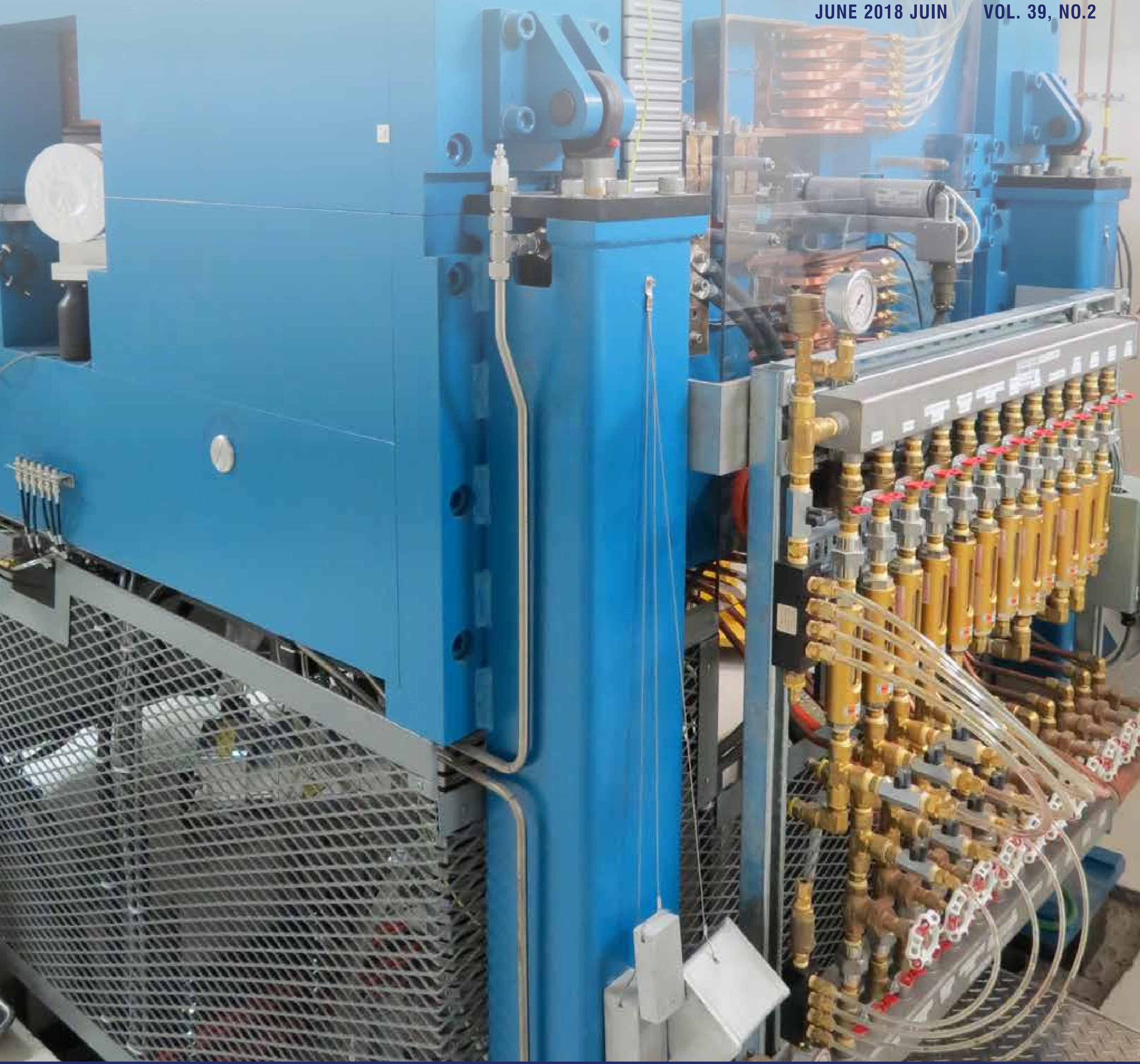
CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

JUNE 2018 JUIN VOL. 39, NO.2



• 38th CNS Annual Conference • 2018 Canadian Nuclear Achievements Awards
• History: John Cockcroft at the Montreal Laboratory • Medical Recovery by Low Dose Radiation Therapy

"I believe in made-in-Ontario electricity and made-in-Ontario jobs."

Doug Ford, as the then Ontario's new Premier-Designate, made this statement on June 21, 2018. He added "I made a promise to the people of Durham, and particularly to the workers here at Pickering, that we would stand up for their jobs, and the more than 7,500 jobs across Ontario that depend on this site."

Ford's promise will ensure (subject to regulatory approval) continued operation of Pickering to at least 2024. He continued to state "The clean electricity generated at the Pickering station will save consumers across Ontario millions and keep great paying jobs right here in Durham Region. I will never apologize for doing the right thing and fighting for Ontario jobs."

It will also save Ontario electricity customers $600 million by 2024.

Doug Ford was sworn in as Ontario's 26th Premier on June 29th. He won a landslide victory for the PC Party, effectively removing the long time (too long, IMO) governing [sic] Liberal party from even so much as an official status as a political party in Ontario. The NDP is now the official opposition. The too-small-to-notice-but-must-say-something-anyway Green Party demonstrated its ignorance by claiming Ford's decision was a bad one because Pickering "is well beyond its Best-Before date." Do the Greens need help them with the word "amortization"?

The Liberals spent their 15 years in power completely ruining Ontario's electricity system but the damage they did might be too difficult to fix, even by Doug Ford. Driven by ideology the Liberals wanted to phase out coal power generation, which is an admirable goal. But they did it in an idiotic manner by giving lucrative contracts to foreign companies to build wind and solar power plants, as well as to build a number of gas fired stations in order that wind and solar could work. Wind and solar serve only to complicate grid control (costing more to operate) and their output was exceedingly expensive; we paid dearly for the ill-thought contracts let out by the Liberals for nature's "free energy". We paid again for fast-responding gas fired generators (emitting GHG in the process) needed to even out the intermittent output of these feeble "Green" options. The Liberal's so-called Green Energy Act looks Brown. Despite the incompetence of the former Wynne/McGuinty governments, the reason we are not in serious trouble now, and in fact met the goal of phasing out coal is because of the investments made by Bruce Power to return idled nuclear units back to service.

And now, thanks to the Ford PC government, Pickering will continue to serve Ontario with low cost, clean (and truly Green) electricity.

Of course it wasn't just wind and solar that the Liberals messed us up with; they introduced a Cap-and-Trade program to raise prices for electricity even further, as well as gasoline and home heating fuels. Of course billions of dollars were collected by selling pollution credits to large businesses, some of which was returned to a few Ontario residents in the form of rebates for energy educing home improvements. The rebates to the few homeowners, however, are paid for by everyone in higher prices passed on by the companies who paid the government for the pollution credits. And there is not a shred of evidence that 'cap-and-trade' or the carbon tax has done anything to reduce carbon emissions in Ontario. After all, Ontario and all other Canadian provinces are geographically large and environmentally cold; people still need to get around and don't like freezing in the dark. Ontario's Auditor General stated "the cap-and-trade system could cost Ontario consumers and businesses $8 billion with negligible impact on carbon emissions." True and significant reductions in carbon emissions come from nuclear, not taxes.

Perhaps Doug Ford read my editorial on Carbon Tax (*Bulletin, March 2016 V.37 No.1*) or simply did his own thinking. Either way he has shown considerable sensibility in getting Ontario out of the carbon tax business. Ford's action may cost us in other ways, since it is contrary to the wishes of the larger Liberal Party in Ottawa. Time will tell, but for now, well done, Doug Ford!

In This Issue

Our 38th Annual Conference in Saskatoon was another success in participation, where the topic of Non-Power Reactor applications such as cyclotrons and Small Modular Reactors was a common theme. The Sylvia Fedoruk Centre's Cyclotron (cover page) is a good example, with an accompanying technical paper included.

Also, a remarkable medical use of radiation therapy, this time external rather than internal, is reported on a patient who recovered from Rheumatoid Arthritis.

Once again, Jim Arsenault has contributed a valuable account of Canadian Nuclear History with his article on John Cockcroft.

I hope you enjoy this edition of the Bulletin, perhaps while basking in the summer sunshine. Please share it with your friends and colleagues and encourage them to join the CNS!

From The Publisher

It's been in the air for a few years now. The winds of change were just starting to whisper. The clouds were just starting to part. And then it was upon us, not just a breeze but a full, fresh wind.

Its name is Small Modular Reactor.

It involves new reactor technology capable of dozens of uses to which nuclear power could never before be adapted. Just a year ago, governments began to respond to the emerging possibilities. In Canada, it manifested as the Canadian SMR Roadmap. Provincial governments began to assess how such technology could meet old energy needs in new ways.

Canadian Nuclear Laboratories (CNL) issued a request for expressions of interest and was promptly inundated with responses from a host of companies from Canada and around the world. It has transpired that there are a host of nations, energy users and institutions of all kinds that were extremely interested in new ways that nuclear science could fill new roles in meeting energy needs, both great and small.

The full size and importance of new technology was on full display at this year's 28 Annual CNS Conference in Saskatoon, June 3-6, 2018. The conference covered the full field of nuclear science and technology in Canada, but the clear main feature of the conference was about new technology.

One of the key difficulties with existing large nuclear power reactors is the length of time required for construction, and the associated problems of securing long term financing, managing changes due to design and regulatory "updates" and the many inconveniences of construction activities that go on for years. SMRs offer the prospect of changing that greatly. For some such reactors it may well be possible to prefabricate them in a dedicated QC facility and simply ship them to site for installation.

This is of obvious interest for small- to medium-sized utilities. Mike Marsh, President and CEO of SaskPower told the conference that Saskatchewan was too small a jurisdiction to accommodate a conventional large power reactor. Saskatchewan has a peak demand of only 3,800 MW. With any outage of such a large unit, the utility would be hard-put to find replacement generation for it. But SMRs of 100 MW or less would be much simpler and easier to accommodate. Thus Saskatchewan would be able to enjoy the immunity to present fossil fuel cost variability. Saskatchewan could enjoy the addition of electricity generation providing both reliable power and without gaseous emissions.

New Brunswick is another province of similar electrical demand; Premier Brian Gallant has launched New Brunswick's program of investigating new nuclear technology needed to replace its two ageing fossil-fired stations.

Mr. Marsh made it clear; the deciding factors for new technology will be cost and regulatory certainty. Canada is no stranger to SMR technology. Once upon a time, Atomic Energy of Canada Limited (AECL) developed the Slowpoke reactor in the 1970s. It was intended that Slowpoke could serve as a local supply of heat and power. Alas the prospect was killed by regulatory uncertainty. It was understood that regardless of size, the Slowpoke would be subject to the full scope of regulatory requirement as that of large power reactors. Thus instead of dozens of small reactors across Canada, Slowpoke was limited to barely half a dozen research reactors.

But that was then. In the past 10 years, the Canadian Nuclear Safety Commission (CNSC) has established consistency in its regulatory approach and has adopted strong, predictable standards of safety performance. It has also established reliable timelines for project consideration and approval. From its initial perception as a handicap, Canada's nuclear regulator has become a de facto competitive advantage. Its established independence from partisan politics has only enhanced its reputation as a strong, independent regulatory body.

That's why they're coming to Canada. Twenty-two companies are engaged in dialogue with the CNSC seeking preliminary approval of their designs with a view to construction of a demonstration reactor. One company has already received preliminary approval and is now preparing the detailed proposal for regulatory review. CNL is now doing due diligence on the various parties that have approached it for prototype siting and support. This due diligence process will be completed by the end of this summer.

For years, our industry has talked about the prospects of a Nuclear Renaissance. But it was confined primarily to Asia; it was largely snuffed out in the OECD nations after the price of oil, gas and coal collapsed after the 2009 economic crisis and recession. But now, Canada is in a superb position to be a world leader in advanced SMR technology. Other countries are indeed looking to Canada's activities in this area.

But a new nuclear renaissance can be based on the natural advantage offered by SMR technology itself, filling new roles nuclear could not fulfil before. You won't find out about it in newspapers or popular magazines, and certainly not on vacuous television news programs.

You have to come to a Canadian Nuclear Society conference to find out.

CGH

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~ Cover Photo ~

View of the Sylvia Fedoruk Centre's Cyclotron used for medical isotope production, innovative radiopharmaceutical research and development , industrial investigations, training and research. It is located on the campus of the University of Saskatchewan, Saskatoon.

Photo courtesy of and used with permission of the Sylvia Fedoruk Canadian Centre for Nuclear Innovation Inc.

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bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

ISSN 0714-7074

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

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Toronto ON M6H 1L0
Telephone (416) 977-7620
E-mail: cns_office@cns-snc.ca
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Le Bulletin SNC *est l'organe d'information de la Société Nucléaire Canadienne.*

CNS provides Canadians interested in nuclear energy with a forum for technical discussion. For membership information, contact the CNS office, a member of the Council, or local branch executive. Membership fee for new members is $82.40 per calendar year, $48.41 for retirees, free to qualified students.

La SNC procure aux Canadiens intéressés à l'énergie nucléaire un forum où ils peuvent participer à des discussions de nature technique. Pour tous renseignements concernant les inscriptions, veuillez bien entrer en contact avec le bureau de la SNC, les membres du Conseil ou les responsables locaux. Les frais d'adhésion par année de calendrier pour nouveaux membres sont 82.40$, et 48.41$ pour retraités.

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

Printed by The Vincent Press Ltd., Peterborough, ON

Canada Post Publication Agreement #1722751

New reactor technology the key feature at Saskatoon Conference

by COLIN HUNT

CNS Past President Dan Gammage welcomes delegates to Saskatoon.

CNS President John Luxat opens the conference.

The importance of new nuclear technology in the form of small modular reactors (SMRs) was the principal focus of this year's Canadian Nuclear Society's 38th Annual Conference in Saskatoon this year.

For the first time in many decades, Canada's nuclear industry was engaged in discussions regarding the development and possible application of new, small reactors to meet Canadian energy needs. These issues were highlighted in the opening plenary sessions on Monday, June 4, 2018.

The strategy of the Canadian government regarding new technology was outlined by Daniel Brady, Deputy Director Nuclear Science and Technology, Natural Resources Canada. He outlined how the Canadian government is developing an SMR Roadmap to take Canada into a new energy future.

In 2017, the House of Commons Standing Committee on Natural Resources tabled for the House its report on the state of nuclear technology and development in Canada. The initiative to develop an SMR Roadmap was launched as a direct response to this Committee report by NRCan Minister Jim Carr in February 2018.

Mr. Brady outlined the steps taken to date to involve other interested groups across Canada in this process. These groups included industry technical and policy groups such as CNA, COG, CNS, and OCNI. Also included are electric utilities, provincial governments and aboriginal groups. He noted that a summary report of the Roadmap is expected in the fall of 2018.

In terms of practical technology development, Cory McDaniel, Vice President Business Development, Canadian Nuclear Laboratories (CNL), outlined the activities of CNL over the past year. In 2017, CNL issued a request for expressions of interest to any parties interested in partnering with CNL on new SMR demonstration projects.

The request resulted in 22 applicants coming forward for active discussions with CNL. Mr. McDaniel outlined four stages of these discussions: application, due diligence by CNL, formal negotiation, and project implementation. He indicated that CNL will have its due diligence completed on all interested applicants by the end of July 2018.

There are strong reasons why companies are interested in building prototype reactors in Canada, Mr. McDaniel stated. These reasons include Canada's strong nuclear regulatory environment, access to the North American market, a well-established supply chain in Canada, and the great need for new nuclear technology to meet new applications.

"CNL has a long history of nuclear prototype development," Mr. McDaniel said. He noted the sequence

Technical Program Chair Paul Spekkens briefs the Session Chairs.

Conference Treasurer Mohinder Grover and Conference Sponsor Gordon Hadaller, Stern Laboratories.

of these projects stretching back to the late 1940s: ZEEP, NRX, NRU, ZED 2, WR1, Slowpoke, NPD2, and Douglas Point.

The 22 applicants themselves are diverse in terms of technology and origin. Many of them are located outside Canada. They include a full range of technologies, including proposals for molten salt and fusion technology. They also include a full range of reactor sizes from projects of a very small size of a few megawatts to larger SMR proposals of up to 100 MW.

Mike Marsh, President and CEO of SaskPower, discussed new SMR technology from the perspective of a prospective buyer.

"We are an active participant in the development of the pan-Canadian SMR Roadmap", Mr. Marsh said. "Saskatchewan is a relatively small grid with a peak demand of 3,800 MW."

However, it is growing rapidly with 6 per cent load growth in 2017. Right now, high load growth is expected to continue for some years to come. Mr. Marsh noted that the province's electrical grid is now in need of significant reinforcement.

Saskatchewan has the joint problems of a small population of 1.1 million and a very large service area. Saskatchewan is therefore too small a jurisdiction to accommodate easily a large conventional power reactor such as CANDU 6.

In terms of existing generation, Saskatchewan generates 75 per cent of its electricity from coal and natural gas. Mr. Marsh indicated that much of the coal-fired generation is expected to be retired over the next 10 years. At this time, the utility is planning to have 50 per cent of its generation from gas-fired sources, and 50 per cent from renewables.

With respect to SMRs, Mr. Marsh said SaskPower is looking at supply opportunities by 2030. The key factors for SaskPower in considering SMR prospects will be project cost and regulatory impacts.

In support of the opening plenary focus, there were an extensive number of technical paper sessions throughout the conference on SMR physics and technology development. These included the wide variety of possible applications from off-grid use in isolated

21st Annual Meeting of the Canadian Nuclear Society

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communities and industrial sites to utility applications as either stand-alone or multiple unit deployment. The technical sessions included specific SMR proposals under development, licencing activity, and technical aspects of thermal-hydraulics and safety.

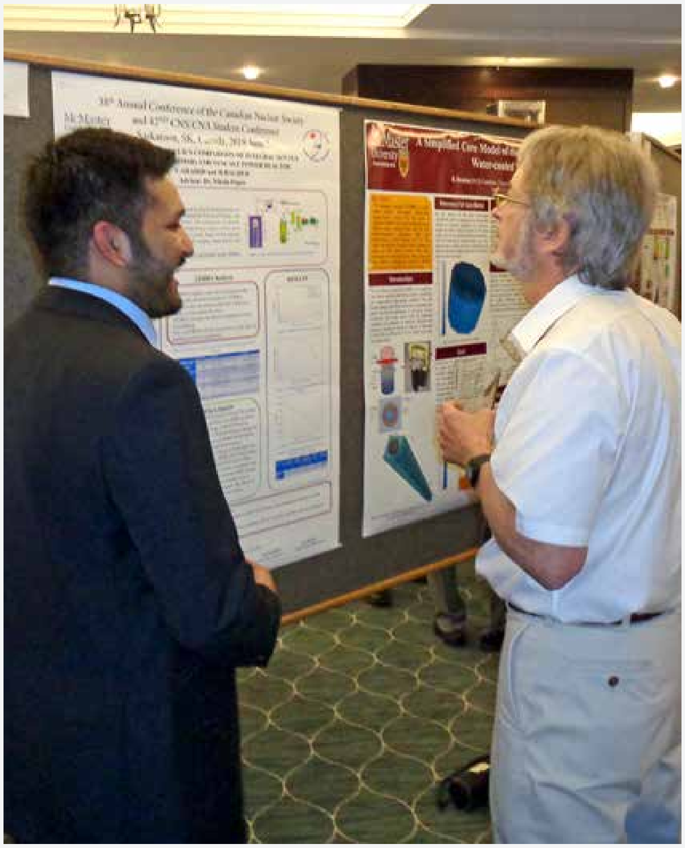
Included with this year's conference was the 42nd CNS/CNA Student Conference. This year, the Student Conference held again its poster session, with 47 posters presented on a wide variety of nuclear science topics.

The CNS Annual Conference was well supported this year with both the CNS and the CNA holding their Annual General Meetings at the conference. A total of more than 300 delegates attended the conference with approximately 100 technical papers presented.

The conference attracted a large number of sponsors from Canada's nuclear industry as well. Sponsors included: Host Sponsor Ontario Power Generation (OPG), and Major Sponsor SaskPower.

Sponsors also included: the Canadian Nuclear Association (CNA), SNC-Lavalin, Tourism Saskatchewan, Cameco Corporation, Westinghouse, The Fedoruk Centre, the Nuclear Waste Management Organization (NWMO), Canadian Nuclear Laboratories (CNL), Kinectrics, L3_MAPPS, TetraTech, BWXT, City of Saskatoon, Stern Laboratories, Terrestrial Energy, the McMaster Nuclear Reactor, the Canadian Institute for Non-Destructive Evaluation (CINDE), and the Saskatchewan Research Council.

Student Poster Session



2018 Canadian Nuclear Achievement Awards

by RUXANDRA DRANGA, CNS-CNA Honours and Awards Chair

On June 5, the CNS and CNA jointly recognized a number of individuals and teams for their outstanding contributions within the Canadian Nuclear industry and the Canadian nuclear research and academic communities, during the 2018 Canadian Nuclear Achievement Awards. The awards ceremony was held in Saskatoon, Saskatchewan, during the 38th Annual Canadian Nuclear Society Conference and 42nd CNS/CNA Student Conference. This year, awards were presented for five 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 Mr. Daniel Gammage, CNS President (2017-2018).

The **Ian McRae Award of Merit** was presented to **Dr. Joanne Ball**. Dr. Ball is an internationally recognized research scientist, senior manager and nuclear safety advocate with 26-plus years of leadership at Atomic Energy of Canada Limited and Canadian Nuclear Laboratories. Dr. Ball was instrumental in mobilizing international effort through the Nuclear Energy Agency's highly successful Behaviour of Iodine Project. Her international credentials have been repeatedly recognized through her appointment to leadership roles in many OECD technical committees. She is recognized by many of the world's senior experts for nuclear safety research as an effective leader in international co-operation for nuclear safety. Dr. Ball is also very well-known across the Canadian nuclear industry for her contributions via a number of CANDU Owners Group Technical Committees. Through her roles as respected scientist, senior corporate manager and industry leader, Dr. Ball has had a highly positive influence on many young women in Canada's nuclear industry, as well as being a great mentor for many young scientists, engineers and nuclear leaders.

Four individuals and one team received the **Harold A. Smith Outstanding Contribution Award**: **Mr. Engin** Özberk, **Dr. Jovica Riznic**, **Mr. Richard Didsbury**, **Dr. Aamir Husain (posthumous)**, and the **Current and Past NRU Operations and Support Staff**.

Mr. Engin Özberk is currently serving as the Special Advisor to the CEO, Mitacs, and to the Vice-President of Research, University of Saskatchewan. He has more than 40 years of R&D and project management experience in light metals, base metals and the nuclear industry, having participated in or led numerous major metallurgical and chemical engineering projects within Canada and internationally. He has been a pioneer of nuclear development in the Western Canada region, in the mining sector and in education, where he was one of the early supporters of the UNENE Program. In addition to chairing numerous international conferences, symposia and professional development courses in Canada and abroad, Mr. Özberk is also a member of the Founding Board of the Sylvia Fedoruk Canadian Centre for Nuclear Innovation. As a Board member, Mr. Özberk brought his extensive knowledge of the nuclear sector and broad insights connecting research, innovation, and industry, helping to develop the Fedoruk Centre's strategic plan, and build capacity for individuals living in Saskatchewan to participate in nuclear-related science and technology activities.

Dr. Jovica Riznic is currently a Technical Specialist in the Operational Engineering Assessment Division at the Canadian Nuclear Safety Commission. Dr. Riznic has distinguished himself by his prolific and seminal contributions to the technical nuclear community in areas such as heat transfer, nuclear reactor thermalhydraulics, fluid-structure interactions, reliability, safety, and fitness-for-service of nuclear power plants. His work is recognized both in Canada and internationally, and many of his papers have served as the foundation for new research programs. A recent example is the textbook he published on steam generators for nuclear power plants, which is one of the most innovative and complex books in the open domain, considering steam generators from design, manufacturing, operational experience, materials degradation and inspection, to fitness-for-service and modern regulatory requirements. Throughout his 30-year career, Dr. Riznic has been a tireless promoter and supporter of the Canadian nuclear industry and an active educator and mentor to many students at the CNSC and within the UNENE Program.

Mr. Richard Didsbury retired from Canadian Nuclear Laboratories in 2016 after 35 years of contributions to Science and Technology, engineering, and project management. Mr. Didsbury's technical career has been marked by his important contributions to diverse technical areas, from fuel-cycle analysis to the development of digital instrumentation and control for CANDU plants, and the implementation of project and engineering tools to significantly decrease the cost of CANDU design and construction through increased integration of information. For example, he led the multidisciplinary team that developed and delivered software tools to support the Qinshan project through design engineering to the build and commissioning phases. Mr. Didsbury was also instrumental in the preparations of AECL/CNL's R&D

organization for transition to the GoCo model. He was also a pivotal player in shaping what became NRCan's Federal Nuclear Science and Technology Program, to the significant on-going benefit of Canada's nuclear sector.

The award for **Dr. Aamir Husain** was presented posthumously. **Dr. Husain** had over 35 years of experience in the nuclear field, retiring from Kinectrics in 2017 as Technical Director - Nuclear Waste. Throughout his career, Dr. Husain has made significant contributions to the Canadian nuclear industry in a wide range of technical areas, including radioactive waste management, activity transport, radiation protection, decommissioning and decontamination, and chemical cleaning. Dr. Husain was also an active contributor to various ISO and CSA standards, COG Working groups and IAEA technical documents. An excellent example of Dr. Husain's technical contributions is his non-intrusive characterization work for the radionuclide content of low- and intermediate-level nuclear-waste packages. This work resulted in determination of a number of scaling factors which allow for characterization of difficult-to-determine radioisotopes in waste packages based on measured values for the readily-determined isotopes. These methods have been used for decommissioning activities and for developing waste strategies to deal with short and long-term radioactive waste in Canada. The award was received by his two sons Sulman and Adnan Husain.

The final Outstanding Contribution Award this year was presented to the **Current and Past NRU Operations and Support Staff.** For over 60 years, the NRU reactor at Chalk River was an essential part of CANDU reactor development and associated technologies. It also made significant contributions to the medical radionuclide industry, playing a critical role in the global production of molybdenum-99, as well as other radiopharmaceuticals which enabled medical treatments for over 500 million patients worldwide. In addition, NRU provided the neutron source needed to conduct research across a wide spectrum of applied and basic sciences, from material sciences to physics and biological research. The success and longevity of NRU, and its safety and reliability, would not have been possible without the sustained and dedicated effort of the outstanding team of experimenters, operations, maintenance, safety and support staff who have supported the reactor over its 60+ years of operation. This award celebrates the contributions of hundreds of current and former operations and support staff at NRU who ensured its continuous operation for over 60 years and made it possible to achieve such remarkable results.

The **Bruce B Cobalt Harvest Team** and the **CNL Physics and Economics of Thorium-Based Fuel Research Team** were awarded the **John S. Hewitt Team Achievement Award.** The **Bruce B Cobalt Harvest team** was recognized for its achievements in safely and efficiently implementing a new radionuclide harvesting process at the Bruce Power nuclear power plant, using High Specific Activity Cobalt Rods. The team, consisting of mechanics, radiation-safety technicians, station-control maintenance personnel, fuel handling operations personnel and crane crews, demonstrated strong technical and operational skills, exemplary teamwork and commitment to safety. Included in the team's list of successes was a reduction in Personal Contamination Events during the 2017 harvesting campaign from 20 to 0 events per year, and a decrease in total harvest time by 30% (from 10 days to 7 days). Their accomplishments help ensure a safe and secure supply of cobalt to the medical community, supporting the health and safety of Canadians and the world.

The **CNL Physics and Economics of Thorium-Based Fuel Research Team** was recognized for its scientific and technical achievement in closing several identified gaps in our understanding of reactor-physics behaviour, reactor physics modelling, fuel-cycle characteristics, long-term radiological characteristics and economic characteristics of various advanced fuels, including uranium-based fuels augmented by small amounts of thorium, and thorium-based fuels. Their studies have identified several technically viable and economically competitive options for using advanced thorium-based fuels in heavy-water reactors, which would help contribute to long-term energy security and safety for Canada and the international community.

Three **Education and Communication Awards** were presented this year. The first award went to **Ms. Jo-Ann Facella**, who is currently the Director of Community Well-Being, Assessment and Dialogue at the Nuclear Waste Management Organization (NWMO). Over the past 20 years, Ms. Facella's work has been focused on public involvement in policy making, and in particular, societal needs and expectations concerning the long-term management of used nuclear fuel. She has been a key contributor to NWMO's development and implementation of the Adaptive Phase Management plan for the long-term management of Canadian spent nuclear fuel. Throughout her career, Ms. Facella has demonstrated a strong commitment to public engagement and community well-being, and a deep understanding of societal issues. Furthermore, through her achievements she has shown that she can repeatedly find innovative and collaborative solutions to complex societal and engagement issues.

The second **Education and Communication Award** was presented to **Dr. Neil Alexander.** Dr. Alexander has broad experience in the renewable energy and nuclear industries, including biomass power, nuclear power, radionuclide production and management of radioactive waste. Dr. Alexander has for a long time been an active promoter of the benefits of nuclear power as a sustainable approach to managing some of the world's most significant environmental challenges. He has been a public speaker on nuclear science and technology topics at various national events and has also delivered talks at various provincial events in Saskatchewan. As an advocate for the industry, Dr. Alexander has made significant contributions to raising public awareness of the role nuclear power can play as a sustainable, low-carbon energy source, and the potential benefits of small modular reactors.

The third recipient of the Education and Communication Award is **Mr. Matthew Dalzell**. Mr. Dalzell is currently working as a Communications Officer at Western Economic Diversification Canada. He has over 12 years of experience in public, government and media relations as a strategic science communicator and planner. Mr. Dalzell has been a tireless supporter and advocate for the nuclear industry, promoting a better awareness of Canadian nuclear science, medicine and technology. He has been a driving force behind numerous outreach initiatives in Saskatchewan, including Nuclear Science Week, the NuclearFacts nuclear research annual symposium and the Canadian Radiation Dose Calculator, a user-friendly online tool which allows an individual to calculate and understand his/her annual radiation exposure dose from various naturally occurring sources. For the past 10 years, Mr. Dalzell has also been an active player in the Canadian Nuclear Society, both at the Branch level and at the national level.

The final presentation was for **Fellows of the Canadian Nuclear Society.** This year, two individuals have been designated as Fellows of the CNS: **Dr. Blair Bromley** and **Dr. Mohamed Younis**. **Dr. Blair Bromley** has worked as a Reactor Physicist at Canadian Nuclear Laboratories since 2003. Dr. Bromley is a respected researcher in the Canadian and international Reactor-Physics community, having contributed significantly to the general understanding of advanced fuel cycles in heavy-water reactors and thorium-based fuels in particular. Throughout his career, Dr. Bromley has been a strong supporter and volunteer for the Canadian Nuclear Society (CNS), both at the local and national levels, serving as Branch chair, and a member of various Conference Organizing Committees and CNS Council. He single-handedly spearheaded the CNS' Fusion Science and Technology Division for many years, providing its members with updates on the current state of fusion energy, and organizing various technical meetings and symposia on the topic.

Dr. Mohamed Younis has made numerous contributions to the nuclear industry as a scientist, engineer and in management. His career spans more than three decades in the Reactor Physics field, having worked at AECL, OPG and Amec Foster Wheeler. Dr. Younis has been an active member of the CNS and has performed exceptional services for the Society. His past and present activities and roles include: CNS Treasurer and Executive Committee member for over five years, CNS Council member for over 10 years, and Chair of numerous CNS Committees. He also served the Society with dedication and enthusiasm as part of various CNS Conferences and Courses Organizing Committees.

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 2019 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! If you have any questions, please contact me at awards@cns-snc.ca.

The 2018 CNS Annual Conference organizing committee

Back row (left to right): Neil Alexander, Daniel Gammage, Dave Delano, Tim Dalpee, Hugh MacDiarmid
Middle row (left to right): John Barrett, David Cox, Alberto Mendoza, Jovica Riznic, Neil Mantifel, Paul Nugent, Matthew Dalzell
Front row (left to right): Adnan Husain, Sulman Husain, Jo-Ann Facella, Joanne Ball, Mohamed Younis, Engin Özberk

John Cockcroft at the Montreal Laboratory

by JAMES E. ARSENAULT, P.Eng.

1. Introduction

Canada has a long and distinguished history of progress in nuclear science and technology, beginning with the work of Ernest Rutherford at McGill in 1898 to 1907. Since that era there have been a few other notable personalities who left their mark on the Canadian nuclear landscape. John Cockcroft certainly qualifies as one of these, arriving in wartime Canada at a critical time, to direct the construction of the country's first operating nuclear reactors.

2. Early Life

John Douglas Cockcroft was born in Todmorden, Yorkshire, England, on 27 May 1897, the eldest of five brothers. His early formal education began at the Church of England school in Walsden (1901–08) and continued at Todmorden Elementary School (1908-09) and Todmorden Secondary School (1909–14). In 1914, he won a scholarship to the Victoria University of Manchester, where he studied mathematics and completed the first year. In 1915 he joined the British Army, Royal Field Artillery where he trained as a signaller and was posted to the Western Front. There he was involved in some of the epic battles of World War One, including Passchendale, before he applied for a commission and was sent to Brighton in 1918 for gunnery training, and became an officer later that year. Shortly thereafter the war ended, and Cockcroft was released early in 1919 [1].

He then studied electrical engineering at Manchester College of Technology, where he received credit for the first year and graduated with a B.Sc. in 1920. He was persuaded to take up an apprenticeship with Metropolitan-Vickers, obtained an 1851 Exhibition Scholarship, and submitted an M.Sc. thesis in 1922 on "Harmonic analysis for alternating currents" [1].

Cockcroft then sat for a scholarship to Cambridge and was successful. He was allowed to skip the first year of the Tripos and in 1924 sat the Tripos and was awarded a B.A. degree. (Note: At Cambridge the Tripos is a set of undergraduate examinations that qualifies an undergraduate for a bachelor degree.) Ernest Rutherford, who was by then at Cambridge, accepted Cockcroft as a research student and he enrolled for a Ph.D. He wrote his doctoral thesis "On phenomena occurring in the condensation of molecular streams on surfaces" and was awarded his doctorate in 1925. In the following years he became very busy under Rutherford as an outstanding laboratory administrator. In 1928 Cockcroft was elected a Fellow of St. John's College [1,2].

In the same year, Rutherford, always searching for new fields to conquer, realized from his earlier studies using alpha particles from natural radiation, that further progress in nuclear research would require high-energy particle accelerators and set Cockcroft on that path, with the assistance of Thomas Allebone, Mark Oliphant and Ernest Walton [3,4].

3. The 1932 Experiment

3.1 The accelerator

While at Manchester in 1919, Rutherford introduced the notion of using elementary particles to bombard matter, in the hope of observing reactions that would reveal the inner workings of the atom. In this he was successful when he used alpha particles (the nuclei of the helium atom) to transform nitrogen into oxygen. The nitrogen, atomic weight 14, absorbed an alpha, weight 4, which then spat out a proton, weight 1, to make oxygen isotope, weight 17, thus establishing the existence of the proton as a constituent of atomic nuclei. In one of the associated papers he speculated that should particles with higher energy become available, more atomic secrets would be revealed. Thus began the drive to create effective particle accelerators and the teams assembled by Rutherford at Cambridge took up the challenge, in particular the Cockcroft and Walton team [5].

Quantum mechanics had been developing steadily and Cockcroft, with his mathematical ability, was able to use the tunneling theory of George Gamow, also at Cambridge, to work out that the nucleus might be penetrated by accelerated protons at around 300 kV DC [3]. After much effort over several years, in 1932 Cockcroft and Walton built an accelerator that used protons to target lithium, weight 7, which occasionally captured a proton and then broke up into two alpha particles with the release of considerable energy. This team was the first to bring about artificial fission and the press hailed the achievement as “splitting the atom” [6].

The Cockcroft-Walton accelerator can be considered to be a charge pump built from capacitors and diodes, to form a voltage multiplier network, transforming low-voltage AC to high-voltage DC. The voltage multiplier had been invented in 1919 by the Swiss physicist Heinreich Grenacher and Figure 1 shows the electrical schematic. Note that all the capacitors eventually become charged to twice the input voltage, except that C1 was charged only to the input voltage [4]. Voltage doublers are used in many contemporary applications wherever high voltage is required, including laptop backlighting, air ionizers, copy machines, bug zappers, and so on.

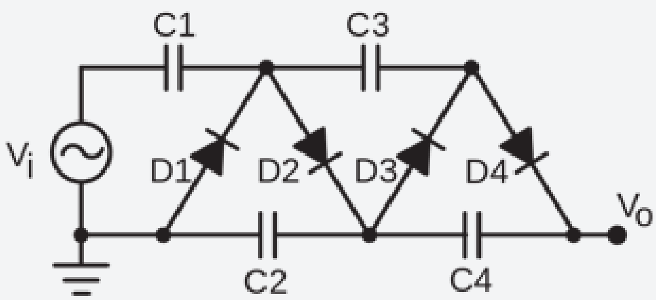


Figure 1: Voltage Doubler Network

The experimental arrangement began with an input AC voltage source, consisting of a motor-generator set, followed by a step-up transformer. The capacitors and diodes then rectify and boost the input voltage to DC. The high DC voltage was applied to an experimental tube to accelerate the protons, injected by a hydrogen source, toward targets within the tube. The diode array and experimental tubes were kept evacuated with vacuum pumps, and the joints were sealed with plasticine in the penny-pinching style of Rutherford. The detector was comprised of the customary zinc oxide screen, which produced the flashes of light caused by the alpha particles, so familiar to workers in the Cambridge laboratory [7].

Cockcroft and Walton were aiming for extremely high voltages (up to 800 kV DC) which required very large physical components. The tubular diode array alone was 12-ft high and 14-in in diameter; the similarly constructed experimental tube was 6-ft high and the capacitors were of comparable scale. The cost of the entire apparatus was on the order of 500 pounds sterling [8,3].

3.2 The results

When a single reaction takes place, the combined mass of the lithium atom plus the proton is 8.0263 and the mass of the two alpha particles is 8.0078 and, therefore, the difference of 0.0185 mass units is converted into energy [9]. Einstein’s famous equation can be applied readily to the situation. As one mass unit is 1.6603 x exp(-24) grams the mass difference is 3.072 x exp(-26) grams. The speed of light squared is 9.0 x exp(20) cm/sec and the energy liberated is thus 27.648 x exp(-6) ergs. As one erg is 6.24 x exp(5) Mev, 17.25 Mev of energy was liberated [10]. This result was about what was observed by Cockcroft and Walton in the experiment, by measuring the resultant alpha particle range in air, and was the first laboratory confirmation of the conversion of mass into energy.

Assuming the protons were accelerated across a potential of 300,000 V DC they would hit the lithium target at 0.3 Mev, for a gain of 17.25/0.3 = 57.5. At this point, Rutherford thought that the practical release of atomic energy was “moonshine” because the reaction was so infrequent. Years would pass before further research led to sustained nuclear reactions for weapons and power applications [11].

4. The Road to Montreal

4.1 Getting ready

After 1932 Cockcroft became widely known in the world of physics and in 1933, during a North American tour, he came to Canada and visited McGill where Rutherford had taught and “There he gazed with appropriate reverence on the rooms where Rutherford made his reputation 25 years or so ago” [2].

In 1935 Rutherford appointed Cockcroft to be Director of Research at the Mond Laboratory at Cambridge University, where he supervised low-temperature research and installation of new cryogenic equipment. In 1936 he was elected a Fellow of the Royal Society. By this time, Ernest O. Lawrence had developed a new kind of accelerator called the cyclotron in the US, and Cockcroft pressed Rutherford for one to be built at the Cavendish. Rutherford balked at the expense but a gift moved the project along and the cyclotron was completed by Cockcroft in 1939. In the same year he was elected Jacksonian Professor of Natural Philosophy [1].

At the outbreak of the Second World War (WW II) in 1939, Cockcroft took up the post of Assistant Director of Scientific Research in the Ministry of Supply and became very active in the development of radar. In 1940 he became a member of the Committee for the Scientific Study of Air Warfare, formed to handle issues arising from memoranda prepared by Otto Frisch and Rudolf Peierls at Birmingham University. The memoranda laid out, for the first time, detailed calculations showing that an atomic bomb was theoretically possible. In the same year this Committee was superseded by the MAUD Committee, on which Cockcroft served, which directed all nuclear research in the UK [12,13].

Whereas the UK was at war already, it was appreciated that the US would be drawn into the conflict eventually and, therefore, it was in everyone's interest to bring the US up to speed with war-related technologies developed in the UK since 1939. In the summer of 1940 the Tizard Mission was organized to accomplish this and Cockcroft was on the team sent to the US. Tizard was chair of the committee for the Scientific Survey of Air Defence that had launched the UK radar effort. Perhaps the most important of the technologies revealed were those associated with the magnetron, proximity fuze, jet engine and underwater detection. In particular the magnetron, which provided high power at very short wavelengths for use in aircraft, illustrated how far behind the US was in radar [14].

Canada was also at war as part of the British Commonwealth effort, and was slated to produce radar sets and this was a concern of the Tizard Mission. As a result, late in October 1940 Cockcroft visited Ottawa and became acquainted with C.J. Mackenzie, acting head of the National Research Council (NRC) and the war work that the Council was pursuing. He had to return to the US for further discussions on radar for the three weeks of his stay before making a final visit to Canada. Thus he became familiar with the work of George C. Laurence at the NRC in Ottawa, who was experimenting with a uranium oxide-carbon pile he had designed. Cockcroft and Laurence had overlapped at the Cavendish, as recorded in a 1928 photo of the research staff [15]. Laurence was briefed on the nuclear research in the UK by Cockcroft and on work which the Tizard team had just seen in the US. As a result, Laurence visited Columbia University where he became familiar with the research there and received copies of the earliest reports on the subject of pile design. In response to Cockcroft's suggestion when he returned to the UK, the NRC received a gift of $5,000 from Imperial Chemical Industries (ICI) in support of the Laurence pile experiment [16].

4.2 The MAUD Report

By the end of July 1941, the MAUD Committee had finished its Report, which described in some detail the industrial processes required for producing the materials necessary for use in weapons (Part 1) and power generation (Part 2). The latter activity was predicated on work by Hans Halban and Lew Kowarski at Cambridge who were exploring heavy-water reactors. Part 2, Appendix VII contains the following statement:

> *(5) If it be decided that the large scale development should take place in the United States or Canada, we believe that I.C.I. in collaboration with nuclear physicists in this country should continue to work on the problem so as to be ready to exploit any successes in the national interest."* [12].

This consideration was based on the fact that all available resources in the UK were tied up in the war effort, and at the time it was under a real threat of invasion. In October 1941 it was decided to place the work of the MAUD Committee in the hands of ICI under the company's research director Wallace Acres, and it was renamed Tube Alloys [17] .

The MAUD Report shows how far ahead the UK had progressed compared to the US, which had only a tentative program underway in atomic research. However, that changed when the Report arrived in the US in the fall of 1941 and the scientists there saw the grave possibility of a German atomic weapon, so the US program was given a kick-start. After the attack on Pearl Harbor, Hawaii, in December, the US was at war. Thereafter, things moved quickly and in September 1942 all nuclear work was organized under the US Army (which created the Manhattan Engineering District led by Leslie Groves) to develop an atomic weapon. Thereafter, the UK could see the rapid progress being achieved by the US and subsequently decided that collaboration offered it the best possible long-range position available and negotiations began. In this regard, things did not go well for the UK because of mutual mistrust concerning security, availability of materials, and commercial interests.

4.3 Nascent laboratory in Canada

As a result, C.J. Mackenzie at the NRC was approached to explore the transfer of certain UK scientists to continue their research in Canada [18]. In particular, the work was to be led by Hans Halban who, as already noted, had been doing research on the use of heavy water in reactors. Mackenzie recognized the situation as an opportunity for the development of science and industry in Canada. After some discussion he was successful in gaining an understanding with the US with respect to supplying experimental materials (uranium and heavy water) and exchanging information. With the approval of C.D. Howe, Minister of Munitions and Supply, an agreement was reached in September. In late 1942, UK scientists and equipment started to arrive in Montreal and the work of the Montreal Laboratory (ML) began in an old McGill residence at 3470 Simpson Street, and later moved to larger facilities at the University of Montreal [16].

Activity at the Laboratory proved to be slow as the US nuclear program was now under the firm control of the Army and extreme secrecy and security became the order of the day. US suspicion of many of the foreign-born UK scientists led to the restriction of information and, eventually, lack of materials from the US. Mismanagement by Halban put the existence of the Laboratory in question and Mackenzie was tempted to shut it down, even though good progress had been made in many technical areas [19]. However, the Laboratory was spared and given new life with the signing of the Quebec Agreement by Prime Minister Winston Churchill and President Theodore Roosevelt in August 1943. The Agreement provided for a Combined Policy Committee (CPC), on which Canada was represented by C.D. Howe. A Subcommittee was set up to direct the ML, consisting of James Chadwick (head of the UK Atomic Mission in Washington, and discoverer of the neutron in 1932), Howe and Groves [20].

In November 1943 Cockcroft was back in the US as part of a mission led by Robert Watson-Watt, the father of radar, to avoid duplication in the production of mobile radar sets. The mission also travelled to Canada and Cockcroft joined it there on 16 December, where they visited defence laboratories in Toronto and Ottawa. On 18 December on his return journey to the UK, he talked with British, Canadian and Free French scientists at the ML but it is unlikely that he mentioned that he might return as its Director. In fact, Chadwick had already discussed this possibility and encouraged Cockcroft to visit the Laboratory and see it for himself but he was doubtful he would be released from his radar work [2].

The ML hardly seemed to have a viable situation to the US, as it now had a clear path to a weapon. It appeared that once again the ML was going to be abandoned but Chadwick proposed the construction of a 10,000-kW heavy-water pilot plant in Canada to investigate whether it would be a more efficient way to produce plutonium. He promised that the plant would be completed quickly. The proposal was approved in April 1944 and the ML Subcommittee generally agreed that a new Director was necessary for the project to progress with the full support of all concerned, and the name of Cockcroft rose to the top among the Subcommittee members. Cockcroft agreed but it took some time until the bureaucratic channels approved his release to take up the position as Director of the ML [21,22].

5. The Montreal Laboratory

5.1 Arrival

By the time Cockcroft arrived at the ML in April 1944, his role was to drive the design, construction and operation of a high neutron flux, natural uranium–heavy water reactor, to produce plutonium before war's end, because it was speculated that this would result in a more efficient process than the reactors under construction at Hanford, WA. It became known as National Research Experimental (NRX) reactor.

At this point in his career he was an experienced administrator, scientist, engineer and was familiar with the atomic programs of the UK, US, and Canada, and was trusted by their governments. He arrived in Montreal on 25 April 1944 and the next day went to the Laboratory to announce that he was taking over as Director, and that Halban would continue on, in charge of the Theoretical Division [2]. Cockcroft then set about organizing the Laboratory.

5.2 Organization

Cockcroft established a divisional structure with clear lines of responsibility including a Programme and Coordination Committee, with Information Meetings designed to control the flow of information among those with a need to know. He recorded the structure he was aiming for in a memo (format slightly edited):

> *"The Director of the Montreal Laboratory is responsible to the Sub-Committee of the Combined Policy Committee. He reports to Dean Mackenzie for all matters of Administration.*
>
> *The Director will be assisted by a Liaison Director approved by the U.S. In the absence of the Director, Dr. Steacie will act as Deputy.*
>
> *The Laboratory will be divided into the following Divisions: 1) Administration. In charge of Mr. Jackson. 2)Chemistry 1. …Prof. Paneth. Chemistry 2. …Dr. Steacie. 3) Theoretical Physics. …Dr. Placzek. … 4) Nuclear Physics 1. …Dr. Halban. Nuclear Physics 2. …Dr. Laurence. … 5) Engineering. …Mr. Newell. … 1. Design group. 2. Pilot Plant group. … 3. Instrument Group. … 4. Experimental Engineering and Technical Physics Group. This group may be split from Engineering … if a suitable leader is found.*
>
> *Information will be passed to D.I.L. [Defence Industries Limited] through the Head of the Engineering Division. Administrative and policy matters will be discussed and decided at Divisional leaders meetings. The Director or his Deputy will fill the chair … A Coordination and Programme Committee will be appointed … to discuss and decide on the experimental programme of the Laboratory and advise the Director on assigning priorities. The Committee will appoint special design groups to study special problems.*
>
> *The Director will be Chairman of this Committee with Dr. Halban as Deputy.*
>
> *An Information Meeting will be regularly convened, with a function similar to the Chicago Information Meeting. Dr. Halban will act as Chairman and will prepare Agenda and speakers."* [23].

Defence Industries Limited (DIL) was engaged to do the engineering design of the reactor, the laboratories, the services, and the town site where the employees would reside [16]. The appointment of Steacie as

Table 1: Build-up of Divisional Staff

Report Period	Admin.	Nuc. Phys.	Theor. Phys.	Tech. Phys	Chem.	Eng.	Extra-mural	Health	Can.	UK	Total
Jul. 1944		7		14	10	1			9	23	32
Aug. 1944	38	20	16	43	39	29	13				198
Sep. 1944	44	21	16	48	45	32	13				219
Oct. 1944	49	22	16	50	45	36	17				235
Nov. 1944	59	26	18	52	47	37	28	6			273
Dec. 1944											282
Jan. 1945	69	30	19	54	55	39	36	6	217	91	308
Feb. 1945	74	30	19	56	56	41	36	6	227	91	318
Mar. 1945	74	28	19	56	50	42	44	8	231	90	321
Apr. 1945									242	90	332
May. 1945	76	41	15	59	51	46	48	11	253	94	347
Jun. 1945	87	43	15	67	55	48	48	14	276	101	377
Jul. 1945	89	49	16	70	62	48	52	15	296	105	401
Aug. 1945	96	54	18	71	63	52	48	15	305	112	417
Oct. 1945	81	48	15	68	52	43	56	14	268	109	377
Dec. 1945	84	49	15	74	54	43	56	12	278	109	387

Note: Values for Jul. 1944 are additions to the Staff complement only

deputy meant that Cockcroft could focus on the bigger decisions that had to made, such as site selection for the pilot plant (Chalk River) and the associated town (Deep River), information exchange with the Chicago group (who had built CP-3, a small natural uranium, heavy-water reactor), negotiating with the US for the required heavy water and uranium, aligning ML activity with the direction of the CPC Sub-Committee, and overseeing recruitment.

After three months on the job as Director, Cockcroft began a series of Monthly Reports that reveal, in some detail, the progress and setbacks he experienced while managing a very large project at the cutting edge of science and technology, and under the pressure of war [24]. Cockcroft's Reports are based on the Divisional Reports provided by the Division leaders which had started in June. There are 16 reports in all, totaling 69 pages, covering the period from July 1944 to November/December 1945. They range in length from two to nine pages, with most consisting of four pages. The Reports were typically distributed to Mackenzie, Chadwick, Groves, Akers, Steacie, Jackson, and Boulton of Munitions and Supply. A transcription of his first report can be found in the Appendix. The reports had a wide coverage of issues but perhaps most interestingly they dwell on issues of staffing, schedule, cost, and so on, i.e., the elements that today we would commonly associate with Project Management.

5.3 Staffing

As could be expected, obtaining staff for the ML was an ongoing problem for Cockcroft, because there was heavy competition for technical talent between the government, military and industrial sectors. Nevertheless, the staff built up slowly and comprised a combination of personnel supplied from the UK and from Canada, including a considerable number of foreign nationals assigned by the UK. The Monthly Reports provide a staff breakdown for the various Divisions, including Administration, Nuclear Physics, Theoretical Physics, Technical Physics, Chemistry, Engineering, Extramural and Health, as shown in Table 1. Some of these Divisions were created as needed, as the pilot plant development progressed. The Extramural Division included work performed outside the ML but closely associated with it and took place at the University of Toronto, McMaster University, and the Department of Mines and Resources [16].

Table 1 shows how the staff complement increased steadily, and more than doubled between August 1944 (198) and August 1945 (417). Note the substantial decrease reported in September/October 1945, after the war had ended and staff migrated back to civilian life elsewhere.

5.4 Schedule

The pilot plant project was promoted by Chadwick to the CPC, on the basis of completion before the end of the war but this proved to be impossible because of its complexity and personnel and material shortages. The project was rescheduled numerous times by DIL, and Cockcroft was in the middle of the problem–making adjustments as the plant took shape, as best he could.

> *"The first completion date set, February 1945, proved to be utterly unattainable. The completion date was set forward to January 1946, and finally to March 1947... As of 31 December 1946, however, the design and construction were very nearly completed and the start-up of operation appeared definitely in sight."* [22].

To ensure that the pilot plant design would be optimal, a small 1-W Zero Energy Experimental Pile (ZEEP) was proposed. It was approved by the CPC Sub-Committee near the end of July 1944, with the proviso that work on it not interfere with the building of the pilot plant. Cockcroft took some time getting things underway and wanted to build the reactor at the NRC in Ottawa. However, Laurence insisted that all the nuclear activity be centralized at Chalk River, and that is what happened [25,26]. Lew Kowarski, who had split with Halban and remained in the UK, was recruited by Cockcroft to design the small reactor and he arrived in August 1944 [27].

The schedules in the Monthly Reports reflect the kinds of delays that any large research and development project typically experiences. However, the pacing items were always identified, highlighted, and managed with finesse by Cockcroft.

5.5 Cost

In his November/December 1945 Report, Cockcroft refers to an estimate by DIL that was an "appreciable increase" over that of February 1945. The estimate given was $18,219,800, exclusive of the plutonium extraction plant but it included the cost for the development of the town of Deep River.

Originally Mackenzie, writing to Howe in April 1944, provided a capital cost estimate of $8M and an operating cost of $1.5M, exclusive of the town. He also assumed some cost-sharing between the three governments, with the UK paying the salaries of their personnel, the US supplying the heavy water and uranium, and Canada being responsible for the remainder [28].

> *"... Dr. Hufmann expressed his personal opinion (as of 1 December 1945) that the total construction cost, exclusive of the cost of the heavy water which has been loaned by the United States, would reach $22,000,000...".* [22].

This figure was considered valid until the end of September 1946 but it was noted that the final cost could be even higher [MDH, 1946]. At the end of the war the project was recognized as the most expensive ever undertaken by Canada, and was more expensive than all the other Canadian research projects combined [29].

5.6 Construction

The actual construction was subcontracted out by DIL to Fraser Brace Limited, including the design of the townsite. Construction started to build up slowly in June 1944, accelerated thereafter, and the first bottleneck noted by Cockcroft was a lack of draughtsmen to prepare the necessary drawings. This problem was appealed as far up the chain as Howe. Construction labourers were always in short supply, even though there were large numbers added on a monthly basis, often in the hundreds. The peak payroll was 2900 at the end of November/December 1945, including 250 prisoners of war working at the town site. The plant site called for the construction of 49 buildings, and six water tanks. Many new houses in the town were built but DIL also brought in 120 wartime houses from another site near Parry Sound [30]. Construction, however slow, enabled the research programs and staff of the ML to move to Chalk River in July 1946 [29].

As for the reactor, Cockcroft noted the usual materials issues inherent in a large research-and-development project involving an extensive supply chain, and problems associated with detailed reactor design, specification, integration and testing. As the DIL engineers had little familiarity with nuclear technology, they were given a series of 43 lectures by the Laboratory staff, The Montreal Lectures, from 2 August to 2 October 1945, in Montreal.

5.7 Espionage

On 10 September 1945, the RCMP (complete with a secure phone) visited Cockcroft at his Montreal home, and he was quite shaken up [2]. He was summoned to Ottawa, and informed of a spy-ring operating out of the Russian Embassy that had been exposed by Igor Gouzenko, a cipher clerk at the Embassy. Alan Nunn May, who worked at the ML, had been tasked to obtain top-secret nuclear data and samples from the University of Chicago Metallurgical Laboratory operated for the Manhattan Project. He delivered in both cases. It was decided to initiate a full-scale investigation and May was allowed to continue working normally at the ML, under surveillance. May returned to the UK, was arrested, tried, convicted, and sentenced to 10 years in prison in March 1946. Whether May's activities contributed significantly to the Russian atomic program still seems to be an open question [31].

5.8 Family matters

In 1925 Cockcroft married Elizabeth Crabtree from his home town of Todmorden. They had four daughters, and in 1942, prior to coming to Canada, Cockcroft and his wife had their last child, a son, who was born into an already strong family unit. In August 1944 Elizabeth and the children arrived and took up residence in a large house at 709 Upper Roslyn, in the Montreal suburb of Westmount. After just over a year there, in the first week of October 1945 the Cockcrofts moved into 17 Beach Avenue, Deep River, another large house which had a spectacular view of the Ottawa River. Throughout their stay there they enjoyed winter sports. Cockcroft took up skiing for exercise and encouraged the children in skiing, skating and outdoor life. He described the whole situation as "an idyllic place" [2].

6. Call from Home

6.1 Moving on

Cockcroft had formed a Future Systems Group in December 1944, to examine possible reactor designs, eventually including designs of particular interest to the UK. By the time the war ended, Cockcroft had been shuttleing back and forth between Canada and the UK, discussing, among other things, the future of atomic energy [26].

In July 1945, just before the war ended, the Churchill government was swept from office and postwar nuclear planning began in earnest. In August 1945 WW II ended with the surrender of Japan to the allies, and the world was introduced to the power of the atom. On 13 August, Cockcroft participated in a press conference in Howe's office in Ottawa which provided a complete picture of the NRX project, including the names of the staff of the ML [32].

Eventually it became clear that the UK wanted to create a nuclear research and development program of its own along the lines of Chalk River, and they offered the Director's position to Cockcroft. Mackenzie also had offered Cockcroft the position of Vice President of the NRC but Cockcroft, feeling a deep affinity for his own country, decided to return home despite the attraction of staying on at Chalk River.

Mackenzie began a search for a Canadian replacement. At first he was not successful, although several qualified candidates were identified. After some declines by prospective Canadian candidates, in late July Mackenzie secured the services of W.B. Lewis. He was then Chief Superintendent of the Telecommunications Research Establishment (TRE), located in the Malvern Hills of central England. He was a long-standing friend of Cockcroft, indeed they had coauthored papers in 1936 when continuing the work begun by Cockcroft and Walton in 1932 [33]. Lewis arrived in Canada on 7 September 1946; Cockcroft departed Chalk River on 30 September.

Cockcroft took charge of the Atomic Energy Research Establishment (AERE) at Harwell, a few kilometers south of Oxford. By the time of his departure, the ML Future Systems Group had begun design of an air-cooled, graphite experimental reactor to be built at Harwell. It became known as Graphite Low Energy Experimental Pile (GLEEP), the first to operate in the UK [34]. Many of the UK scientists at Chalk River left to join Cockcroft. However, collaboration continued between the two laboratories and both benefited from mutual data and personnel exchange, particularly with respect to a plutonium extraction plant. It was to be operated in conjunction with the large air-cooled, graphite production reactors at Windscale (later named Stellafield, on the Cambrian coast) [35] .

6.2 Later life

At Harwell, Cockcroft became fully engaged in the UK's post-war research efforts to develop weapons and power plants based on nuclear science. For this body of work he was knighted in 1948. In 1951 he and Walton received the Nobel Prize in Physics for their 1932 experiment. The citation states, in part:

> *"... It has been of decisive importance for the achievement of new insight into the properties of atomic nuclei, which could not have been dremt [sic] of before. Your work thus stands out as a landmark in the history of science."* [3].

In 1952 he was the driving force behind the UK's decision to support the establishment of the Conseil European pour le Recherche Nucleaire (CERN) [17]. He was appointed Master of Churchill College, Cambridge, in January 1959 and moved there from Harwell in October. The College was officially opened in June 1964 [2]. The total number of honours, awards and medals Cockcroft received for his contribution to science, education and world peace, comprise a very long list indeed [1].

Cockcroft died at his home at Churchill College on 18 September 1967, at the age of 70. His collected papers are located in the Churchill College Archives. Elizabeth Cockcroft outlived her husband by two decades, and died in 1989 at age 90.

7. Conclusion

When John Cockcroft arrived in wartime Canada he quickly set to work applying his extensive experience as an engineer, scientist and administrator, and laid the groundwork for the nuclear landscape we see today. His impact can be measured by reviewing the history of the evolution of the ZEEP and NRX reactors. His memory is commemorated today by Cockcroft Crescent in Deep River. It is surprising that he made such an impressive and lasting contribution in the short time–just two and a half years–that he spent in Canada.

8. Acknowledgements

Tom Lukowski M.S., P.Eng. made valuable contributions to the accuracy and readability of the text, and I would like to thank Lyn Arsenault for editing this article through multiple iterations.

9. Appendix

N.R.X. PROJECT – PROGRESS REPORT FOR JULY, 1944

1. SITE

A site for the pilot plant has been selected on the Upper Ottawa River, four miles from the Chalk River Station of the C.P.R. The Main highway, No. 17, passes through Chalk River. This is kept open throughout the winter.

The site has a direct rail and road connection with Ottawa and Montreal and rail times are 3 and 5 1/2 hours respectively.

The site is well isolated by wooded, sparsely farmed country. It adjoins the Petawawa Military Reservation on the south. The terrain by the river is almost ideal. The river flow is ample to meet the needs of pilot and full scale plants. Water purity is better than Georgian Bay and dissolved solids are small.

Official action was taken on 20/7/44 to expropriate an adequate area round the site.

It will be necessary to build a village for plant workers. A survey of three sites has been made by a Town Planning Expert whose report is now under consideration. Two good sites are available 4 and 6 miles up the Ottawa River from the plant.

2. SITE BUILDINGS

It is now planned to build the laboratories on the site for 100 - 150 scientists and assistant staff from the Montreal Laboratory leaving the main Laboratory in Montreal.

This will require about 40,000 sq.ft. of laboratory building at the site and housing accommodation for the staff.

D.I.L. will require to build administration offices, plant maintenance workshops, cafeteria and pile building, power station, etc.

Plans of the laboratories and pile building are well advanced and should go to D.I.L. within a few days. D.I.L. standard designs for housing will be used.

3. CONTRACTOR

Messrs. Fraser Brace have been appointed contractors and have visited the site. It is hoped to start work immediately.

4. PILE DESIGN

After a month spent on investigating the relative merits of:

i. A pile using metal rods sheathed with stainless steel;

ii. A pile using alumimium sheathed rods with close spacing to give stability against loss of cooling water.

iii. A conventional pile using aluminium sheathed rods and light water cooling; it has been decided to proceed with the third type. This decision was made largely because adequate polymer deliveries could not be guaranteed for the first or second designs. Aluminium sheathing 1/8” thickness will be used to minimise troubles of corrosion and pin holes in welds.

The pile will have a safe output of 8000 kilowatts. If heat flow were not limited by dirt films the maximum output would be about 18,000 kilowatts.

Arrangements will be made to produce 23 substituting thorium rods in place of some of the metal rods or by inserting thorium rods in the reflector. In the latter case an output of about 60 grams per month of 23 should be obtainable.

5. METALLURGICAL PROGRAMME

The canning of the metal rods is likely to be a bottleneck in the programme.

Dr. Farnham of the Canadian Bureau of Mines Laboratory has undertaken an experimental programme on the drawing of long aluminium tubes over a number of short meal slugs and over a single long bar.

Contact has been established with the Aluminium Laboratories of Canada on problems of aluminium corrosion.

A programme of work on canning with stainless steel is to proceed with a view to substituting for aluminium at a later stage.

6. WATER TREATMENT, HEAT TRANSFER and CORROSION.

An experimental investigation has been undertaken by the Chemical Engineering Department, National Research Council and experiments should start at the pilot plant site in about six weeks using Ottawa River water.

Advice on corrosion has been sought from the Non-Ferrous Metals Research Association of U.K.

7. CHEMISTRY PROGRAMME

Highest priority is at present given to separation of 23.6 milligrams have been separated from irradiated samples of thorium carbonate from the X pile. This has been delivered to Chicago.

A number of irradiated uranium slugs have been received from X and a first separation made.

8. NUCLEAR PHYSICS PROGRAMME

Highest priority is given to the "exponential experiment" to check the theoretical design figures for the pilot plant. Chicago are providing 3 tons of polymer and the requisite metal.

A substantial amount of the time of senior staff has been devoted to the design problems of the pilot plant.

Consideration is being given to the building of a very low power polymer pile to be used as an experimental tool for nuclear physics. The building of such a pile would not have to interfere in any way with the pilot plant programme.

9. HEALTH PROGRAMME

Surgeon Commander Carleton B. Peirce of the Royal Victoria Hospital has taken charge of health of laboratory staff. Routine checks of dosage are established and periodical blood tests and clinical examinations are being made. It is hoped to recruit Dr. J.S. Mitchell from U.K. to work full time on the scientific aspects of health problems.

10. LABORATORY STAFF

The following additions to the laboratory staff have been or are being arranged, since 1/6/44.

	From U.K.	From Canada
Nuclear Physics	6	1
Chemistry	7	3
Technical Physics	9	5
Engineering	1	–

11. LABORATORY BUILDINGS

An additional 6000 sq. ft. of floor space has been leased from the University of Montreal for a period of 9 months.

12. STAFF REQUIREMENTS

The limiting factor in the progress of the whole project is likely to be draughtsmen. It is estimated that 40-50 draughtsmen will be required by D.I.L. At present 15 are in view.

Montreal, 29th July, 1944. J.D. Cockcroft

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CNSC Public Hearings for Pickering NGS are Complete

In August 2017, OPG submitted its licence renewal application to the Canadian Nuclear Safety Commission (CNSC). This requested 10 year licence term will cover the period between Sept. 1, 2018 and Aug. 31, 2028.

The current plan is to operate the Pickering station until the end of 2024. The licence term between 2024 and 2028 will allow for safe storage activities such as removal of fuel and water.

The two-part hearing for the renewal of Pickering Nuclear's operating licence was completed on June 29. Over the course of the six-day hearing, OPG presented the safety case for Pickering's continued operations to the CNSC. The CNSC's decision on OPG's request for a 10-year licence is expected in August.

Public interventions are an important part of the licensing process. There were several intervention presentations, including the CNS and several other organizations and private individuals. They can all be found at http://www.nuclearsafety.gc.ca/eng/the-commission/hearings/cmd/index.cfm

Saskatchewan Centre for Cyclotron Sciences: A Multi-User Research and Production Facility

by D. SCHICK-MARTIN[1], J. CAWTHRAY[1], J. MACKENZIE[1], D. FRATTINGER[1], JOHN ROOT[1]

[Ed. Note: The following paper was presented at 38th Annual Conference of the Canadian Nuclear Society and 42nd Annual CNS/CNA Student Conference, Sheraton Cavalier Hotel, Saskatoon, SK, Canada, 2018 June 3-6.]

Abstract

The Sylvia Fedoruk Canadian Centre for Nuclear Innovation Inc. (Fedoruk Centre), established in 2011, is committed to placing Saskatchewan among global leaders in nuclear research, development and training. The Fedoruk Centre operates the Saskatchewan Centre for Cyclotron Sciences (SCCS), a multi-user $25 million research and radioisotope production facility supporting innovative radiopharmaceutical research and development, located at 120 Maintenance Rd. on the campus of the University of Saskatchewan. The SCCS supports an interdisciplinary program to develop and produce radioisotopes and probes for pre-clinical and clinical nuclear imaging. The facility is outfitted with state-of-the-art cGMP production clean rooms, QC laboratories, packaging rooms, and research hot labs. The facility's Innovation Wing is equipped with a pre-clinical nuclear imaging scanner (SPECT/PET/CT) and animal housing facilities. Canada's first nuclear plant imaging facility, the 'PhytoSuite', is under development with nuclear imaging techniques dedicated to plant and soil studies. The Fedoruk Centre looks forward to supporting cutting-edge research and innovation in radiopharmaceuticals and nuclear imaging.

1. Introduction

Saskatchewan has a strong history of leadership in nuclear research and development. Recent investments in nuclear sciences and molecular imaging build on this legacy. On March 2, 2011, the province announced a commitment of $30 million over seven years to establish a "new centre for research in nuclear medicine and materials science at the UofS" [1]. This led to establishment of the Canadian Centre for Nuclear Innovation in December 2011 with the purpose of placing Saskatchewan among global leaders in nuclear research, development and training through investment in partnerships with academia and industry for maximum societal and economic benefit. In October 2012, the Centre was renamed as the Sylvia Fedoruk Canadian Centre for Nuclear Innovation (Fedoruk Centre) to honour the memory of one of Saskatchewan's nuclear pioneers.

In March 2011, $20 million in funding from both provincial and federal governments was also announced for a cyclotron and PET/CT scanner. The latter was installed in the Royal University Hospital (RUH) located on the U of S campus, and scanning of patients began in 2013. In the meantime, the Fedoruk Centre focused on bringing into operation the Saskatchewan Centre for Cyclotron Sciences (SCCS) and creating a framework from which a successful, world leading nuclear imaging program for research and innovation can grow. Substantial renovation and transformation of a former animal husbandry facility on the U of S campus into the 24-MeV cyclotron nuclear facility was completed by the end of 2014. The license to operate the cyclotron as a Class II Nuclear Facility was issued by the Canadian Nuclear Safety Commission in April 2016. The following month Health Canada approved the Clinical Trial Application for 2-[^{18}F] fluoro-2-deoxy-D-glucose ([^{18}F]FDG) production. A Drug Establishment Licence was issued by Health Canada in October 2016 followed by a Notice of Compliance in December 2016 indicating the facility was a manufacturer of [^{18}F]FDG and meets all regulatory requirements for the safety, efficacy and quality of the product. The total cost for renovating, commissioning, and bringing the facility into operation was $25 million, with funding from Western Economic Diversification Canada, an agency of the federal government, Innovation Saskatchewan (IS), a provincial agency, and the Fedoruk Centre.

2. The Fedoruk Centre and Saskatchewan Centre for Cyclotron Sciences

The Sylvia Fedoruk Canadian Centre for Nuclear Innovation Inc (Fedoruk Centre) was established December 2011 as part of a commitment by the province of Saskatchewan to establish a "new centre for research in nuclear medicine and materials science at the University of Saskatchewan" [1]. The Fedoruk Centre, incorporated under the Canada Not-For-Profit Corporations Act, is a wholly owned subsidiary of the

1 Sylvia Fedoruk Canadian Centre for Nuclear Innovation Inc. Saskatoon, Canada

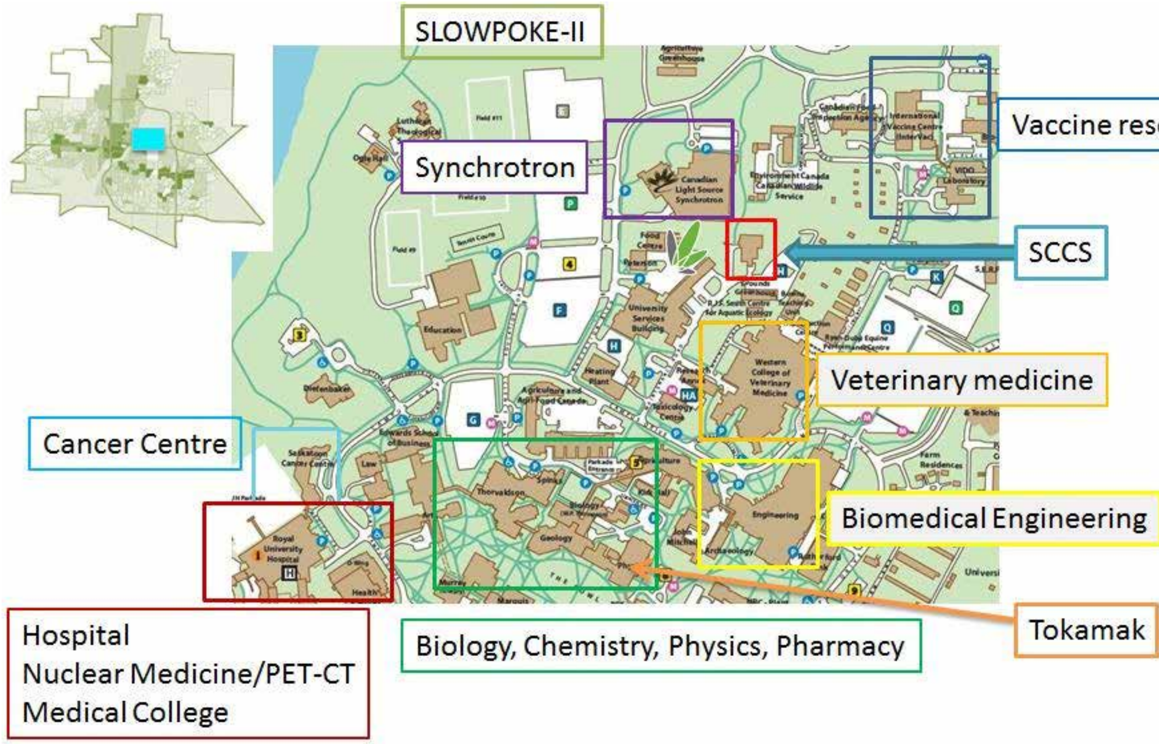

Figure 1: SCCS location and the nearby cluster of unique grouping of expertise, resources, and facilities.

University of Saskatchewan with funding through Innovation Saskatchewan (Agreement 2012 – 2019). Oversight of the Fedoruk Centre's programs and activities is managed by a board of directors who represent key stakeholders from academia, industry and government. The purpose of the Fedoruk Centre is "To place Saskatchewan among global leaders of nuclear research, development and training through investment in partnerships with academia and industry for maximum societal and economic benefit [2]."

The Saskatchewan Centre for Cyclotron Sciences (SCCS), Saskatchewan's first cyclotron and radioisotope facility, is operated and managed by the Fedoruk Centre. While the SCCS is situated on the University of Saskatchewan campus and uses many of its services, its mandate is to serve all of Saskatchewan. It builds upon the province's pioneering research in nuclear medicine and advances research in the expanding fields of molecular imaging, nuclear medicine and other areas of science that make use of radioisotopes. With funding from the Government of Saskatchewan and Western Economic Diversification Canada, the facility strives to be a world-class centre for research, training and innovation in nuclear medicine - including radiochemistry, physics and development of new radiopharmaceuticals for medical imaging.

Life Sciences are thriving and diverse at the U of S, and offer the SCCS an amazing concentration of resources on one campus allowing for advancing basic, translational and clinical research and commercialization of new drugs via collaborative work. Additionally, SCCS activities benefit from the on-campus presence of different centres as seen in Figure 1. This includes RUH, which serves as a leader in providing acute-care services for the province, with over 455 beds, 42,000 adult emergency visits and 5,500 adult surgeries per year; the Veterinary Medical Centre, a state-of-the-art animal health facility part of the Western College of Veterinary Medicine, currently providing medical imaging services, and one of only four Canadian locations to offer advanced radiation therapy for animals with a linear accelerator; and other noteworthy facilities such as the CLS, where complementary imaging experiments can be carried out. In addition to human and animal health facilities, the UofS is a one of the largest hubs of agriculture-related research in Canada, anchored by the College of Agriculture and Bioresources including facilities such as the Crop Development Centre and the Controlled Environment Facility (Phytotron) to sustain global leadership in plant growth and productivity and provide tangible benefits to Canadians through improved crops and agricultural practices. In summary, a strong and diverse research capacity is already established to leverage contributions from SCCS facilities and expertise. This truly unique combination of scientists, clinicians and facilities combined with the SCCS provides an opportunity for Saskatchewan researchers to become world leaders in nuclear medicine research, plant PET imaging, as well as the development of radiopharmaceuticals for animals and humans with a strong connection from research to impacts in life sciences and technologies.

3. MainFacility

As can be seen in Figure 2, the SCCS consists of 2000 m² incorporating the Main Facility (solid line) and the Innovation Wing (dotted line). Within the Main Facility, the SCCS houses a high-current TR-24 model (Figure 3) with expanded injection and RF systems from Advanced Cyclotron System Inc. (ACSI). Beam current of H- accelerated ions up to 500 µA can be reached after beam extraction at energies variable between 16 and 24 MeV. Beam current of up to 120 µA is typically used at the moment. The 2 splits of the Y-shaped split beamline on the right hand side of the cyclotron enclosed within separate concrete walls for optimal target shielding. There is room for a second Y-shaped split beamline to be added on the left hand side of the accelerator in the future, with separate concrete walls for target shielding already in place. A 3-port target selector is directly fixed to the exit flange of the cyclotron instead of the second split beamline. A second 3-port target selector terminates one split of the existing beamline. The other split is terminated by a solid target station. Dual bombardment is possible but not currently used. Figure 4 shows the cyclotron and part of the existing split beamline in the vault.

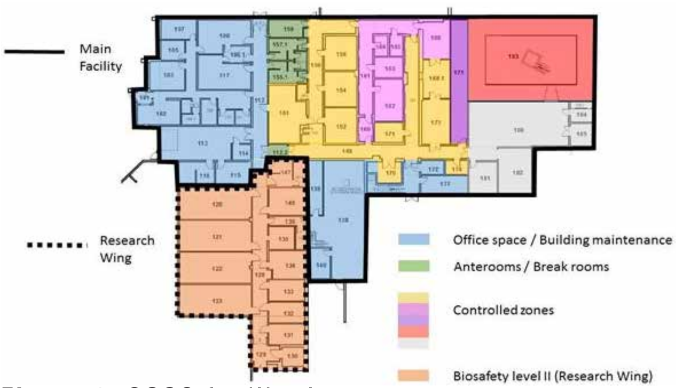

Figure 2: SCCS facility layout.

The available targetry is listed in Table I. The ACSI ^{18}F water targets can stand up to 120 µA and are used for GMP grade [^{18}F]FDG production. Two targets are mounted on the cyclotron: one on the beamline for daily productions; and the other held as spare on a port on the left hand side of the cyclotron, ready to be used. The third water target is stored for decay and maintenance. These water targets may also be used for ^{13}N production in limited capacity. The ACSI ^{11}C gas target can stand up to 40 µA and is mounted on the second port of the beamline. The ACSI 90° solid target (coin) holder has been delivered and installed. This coin-type target holder can operate up to 70 µA, although some coin targets may have a lower maximum depending on material. The ACSI high-current solid target station mounted on the second split of the beamline is operated at an angle of 7° and can be irradiated with a beam current up to 500 µA depending on material. It is complete with an automated pneumatic transfer system to a processing hot cell. This dedicated solid target station allows high current bombardment and automated transfer to maximize production yields.

Current isotope and radiotracer production include ^{18}F, FDG and ^{13}N (nitrate mixture) with production of ^{89}Zr in commissioning phase.. Currently planned isotope and tracer development (expected within 3-6 months) include, ^{18}F-NaF and ^{11}C-CO_2. Further expansion of isotope production will be prioritized by emerging persistent demand with the following currently under consideration: ^{68}Ga, ^{64}Cu, ^{13}N-NH_3, ^{13}N-N_2, Tc-99m, ^{11}C-CH_4, ^{18}F-(F-MISO), ^{18}F-FLT, ^{18}F-(F-DOPA).

Figure 3: ACSI high-current TR-24 cyclotron.

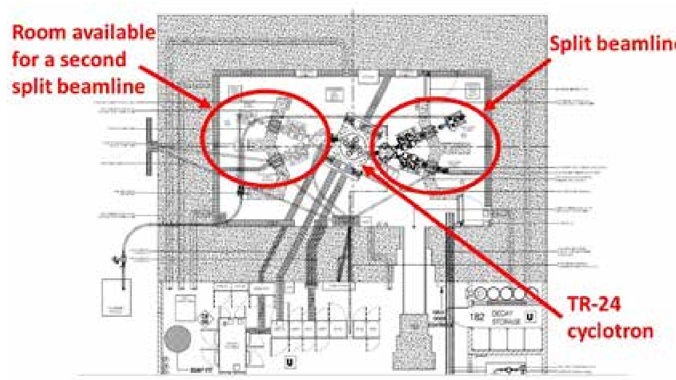

Figure 4: Layout of the cyclotron vault.

As a production facility for approved radiopharmaceuticals, the SCCS is outfitted with state-of-the-art production clean rooms conforming to good manufacturing practice (GMP) regulations, quality control (QC) laboratories, and packaging rooms. The facility is GMP compliant with Health Canada with respect

Table I: Available targetry

Target type	Quantity
ACSI 18F water target	3
ACSI 11C gas target	1
ACSI 90° solid target (coin) holder	1
ACSI high-current solid target station	1

Table 1: Radioisotope production at SCCS March 2017-April 2018

Number of Operating Days	Number of Outages (unplanned)	Number of Production Runs			Total isotope produced
		RUH	MB	AB	
216	4	214	7	16	F18 (FDG) 5460GBq (approx.)

to its laboratories, equipment, procedures, QC, and batch release of drugs for human use. The facility has successfully provided a daily supply of [^{18}F]FDG to the Saskatoon Health Region since June 2016 and has also been a back-up supplier for facilities in Alberta and Manitoba. ^{18}F produced using the cyclotron and water target loaded with 4 ml ^{18}O-enriched water is transferred to the hot lab where [^{18}F]FDG is synthesized in a GE FASTlab^{tm} automated synthesis unit (ASU) in a Grade A hot cell and dispensed aseptically into sterile vials there also.

Trained production technologists perform quality control (QC) test of the [^{18}F]FDG prior to its release for patient healthcare. The facility houses QC Instrument lab, QC wet lab and packing room dedicated to these purposes. These QC tests include: appearance; radiochemical/radionuclidic identification; chemical purity, physical tests (pH); radiochemical/radionuclide purity; and microbiological tests (bacterial endotoxins and sterility). All tests are done at SCCS except for retrospective testing such as sterility and radionuclidic purity testing which are currently outsourced to a qualified third party.

In addition to GMP and QC space, the main facility also contains a Radiochemistry Lab and Research Hot Lab. The Research Hot Lab is equipped with 6 hot cells (Comecer) for the safe handling, dispensing and processing of radioisotopes. A Trasis mini AIO synthesizer, situated in one of the hot cells, is used by researchers for processing of radioisotopes and chemical synthesis of new radiotracers. The Radiochemistry Lab is equipped with fumehoods, a UHPLC, and a rapid-solvent evaporation system (Biotage V-10).

By producing short-lived nuclear imaging agent FDG, the SCCS has reduced wait times to one week for patients in the province requiring PET-CT scans. This information was announced by Premier Brad Wall in July 2017 at the cyclotron in Saskatoon. "Our government has re-established significant support for nuclear research and development as part of our growth plan, including a $19.4 million capital commitment to build the Saskatchewan Centre for Cyclotron Sciences," Wall said. "That investment is not only advancing the cause of innovation and science, it is bringing about real improvements in quality of life in Saskatchewan. With a secure supply of locally-produced medical isotopes in place, wait times for PET-CT scans have been reduced significantly. Critically ill patients are getting the care they need faster. The Cyclotron is helping to make life better in Saskatchewan [3]."

3.1 Innovation Wing

The commissioning of the Innovation Wing was completed in November 2016 and is still currently under development. In its current form, the Innovation Wing houses a Pre-Clinical Nuclear Imaging Suite, Animal Housing Room, Radiochemistry Lab and Tissue Culture Facility. The Pre-clinical Nuclear Imaging Suite is equipped with a MILabs VECTor^{4}CT scanner. The Vector system is modular in nature, allowing PET, SPECT or CT functionality alone or in combination. It has a wide energy range (200-600keV) with PET resolution of <0.75mm and SPECT <0.25mm with the ability for dynamic scanning and co-injection and imaging of PET and SPECT radioisotopes. Data acquisition, image reconstruction, and data analysis is performed in the adjoining Computer/Control Room. The Radiochemistry Lab is equipped for compound radiolabeling and sample analysis including HPLC, gamma counter and alpha particle camera. A Cell Culture Room has recently been completed and includes an automated live cell analysis system (IncuCyte S3).

Further development of the Innovation Wing is currently underway with plans to renovate and equip the remaining 3 large rooms and 2 small rooms. This includes establishing a plant nuclear imaging suite, the Phytosuite, equipped with plant growth chamber, state-of-the-art plant imaging equipment (plant PET scanner with integrated CT – the PhytoPET, and its companion nuclear detector technologies, the BioProspector and PhytoCount) necessary for establishing a strong plant imaging research program in partnership with academia and industry. The other rooms will include an Analytical Lab and a second Radiochemistry Lab in addition to a Necropsy Suite and Animal Support Room.

3.2 Projects at SCCS

The SCCS facility currently supports access and

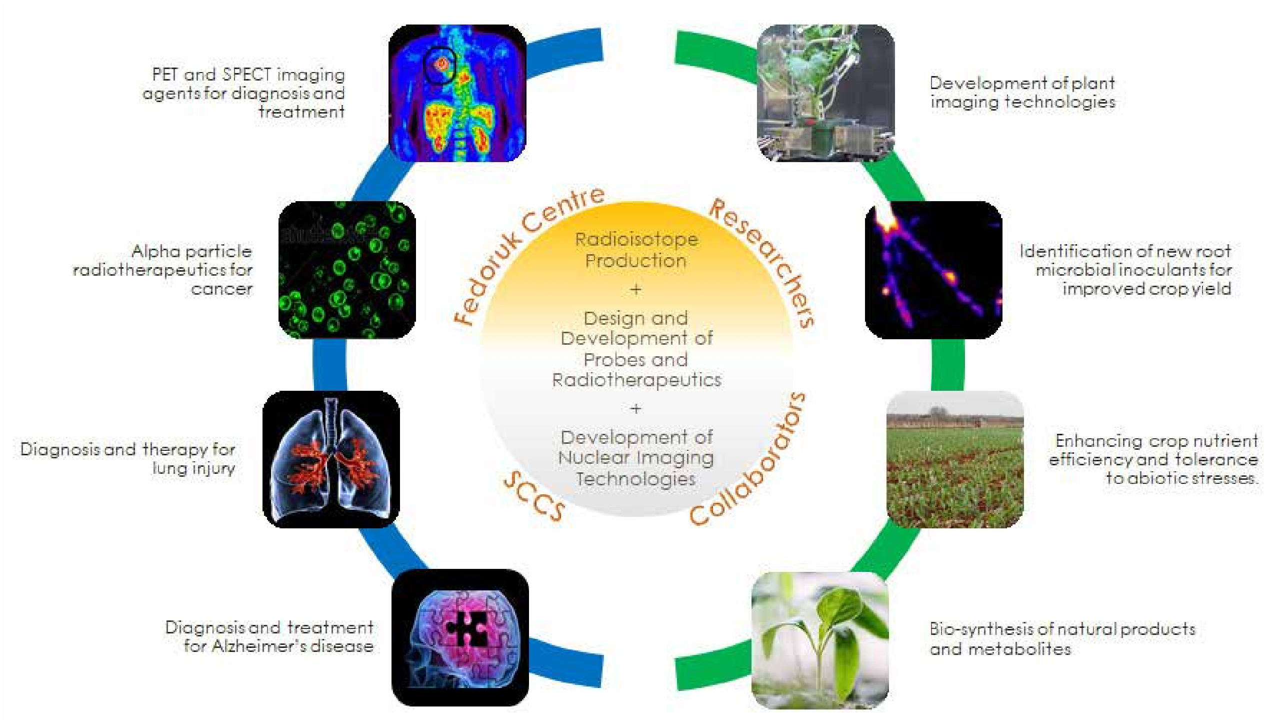

Figure 5: Focus areas of the Fedoruk Centre's Nuclear Imaging Program.

research by more than 45 users and affiliated scientists ranging from principal investigators, trainees, research officers and industry partners. In order to fully realize the opportunity of the SCCS, a program for research and education in nuclear imaging was approved through an agreement of the University of Saskatchewan (U of S), the University of Regina (U of R) and the Sylvia Fedoruk Canadian Centre for Nuclear Innovation Inc (Fedoruk Centre), effective May 7, 2015. Together the Fedourk Centre, the U of S and the U of R have recruited a team of world-class scientists with expertise in nuclear physics, radiochemistry, radiopharmacy, human/animal imaging and plant imaging to leverage and catalyze Saskatchewan's Canadian-leading momentum in nuclear imaging research, development, and training. The interdisciplinary team includes three Fedoruk Centre for Nuclear Innovation Chairs established in Radiopharmacy, Nuclear Imaging Technologies and Nuclear Physics (Detection Technologies) and Animal Imaging at Saskatchewan universities. A Nuclear Imaging Program was established with the Vision to advance nuclear imaging tools and techniques at the SCCS for applications in life sciences. The Nuclear Imaging Program integrates and accelerates research in four critical areas: (i) Design and Development of Probes and Radiotherapeutics, (ii) Enhancing Human and Animal Health, (iii) Development of Nuclear Imaging Technologies and (iv) Plant, Soil and Microbiome Interactions as illustrated in Figure 5.

The SCCS is able to support research in plant, human and animal health through new isotope production in response to emerging requirements of its users. The cyclotron with its dedicated solid target station and remote pneumatic delivery system will provide researchers with access to a portfolio of cyclotron produced radioisotopes for use across all key research themes and also in clinical trials. For example, Dr. Fonge (Assistant Professor Medical Imaging), in collaboration with Advanced Cyclotron Systems Inc. (ACSI, BC) has commenced research on the cyclotron production and processing of ^{89}Zr at SCCS to be used with new radioprobes developed by Drs. Fonge and Geyer (Professor Pathology, UofS) in clinical trials at RUH.

With substantial infrastructure dedicated to the study of human and animal health, Saskatchewan is well-po-

Figure 6: MILabs VECTor^{4}CT in the nuclear imagine suite at SCCS.

Figure 7: PhytoPET at SCCS.

sitioned to propel the development of advanced imaging tools for humans and animals. Such infrastructure includes a new large animal PET/CT imaging system currently being installed at the Western College of Veterinary Medicine (WCVM). Researchers are developing the next wave of imaging probes and radiotherapeutics for human and animal diseases with a focus on cancer, inflammation and infection. With radiochemistry laboratories, human PET, microPET, large animal PET, and GMP-manufacturing facilities, researchers are accelerating probe development through access to bench-to-bedside research and innovation path from preclinical imaging in animals through to clinical trials in humans facilitated by collaboration with WCVM and the Royal University Hospital on the UofS campus. Testing these new probes heavily utilizes the SCCS infrastructure, including the pre-clinical nuclear imaging suite, animal housing facilities and radiochemistry laboratories. Researchers, working with the Clinical Trials Coordinator, are currently seeking regulatory approval from Health Canada for a number of clinical trials of novel imaging and therapeutic agents in Saskatoon (RUH) and Canada employing the GMP facilities and SCCS resources for manufacturing. Current clinical trials planned include ^{68}Ga-DOTATOC for neuroendocrine tumor imaging; ^{68}Ga-PSMA for prostate cancer imaging and ^{89}Zr-nimotuzumab for imaging EGFR.

The Province of Saskatchewan, which has over 40% of Canada's arable land, is striving to strengthen its agricultural leadership. Nuclear imaging represents an exciting opportunity to pioneer new imaging tools in fundamental areas that include: adaptation to environmental stresses, disease, efficient nutrient and water use, and seed quality. Direct visualization of nutrient uptake through plant roots will enable the development of improved fertilizers and microbial inoculants. Nuclear imaging of plants will provide new insights for plant breeders, which will accelerate improvements in productivity of Canadian crops. Nuclear biotechnologies underpinned by cyclotron produced radioisotopes can provide insight into spatio-temporal movement of plant resources (e.g. sugars and amino acids) and of key signal molecules (e.g. plant hormones, peptides) across various scales of the whole plant enabling researchers in plant science to carry out unprecedented analyses of plant metabolism and its regulation.

Within the scope of research activities undertaken under the umbrella of the SCCS and in partnership with the University of Regina supported by the Fedoruk Centre, Canada's first plant dedicated PET imaging system, PhytoPET, was successfully tested in June of 2017 (Figure 7 and Figure 8). A state-of-the-art nuclear scanner for plants, the PhytoPET, was developed at the University of Regina (U of R) by a team led by Aram Teymurazyan (Fedoruk Chair in Nuclear Imaging Technologies) & Zisis Papandreou

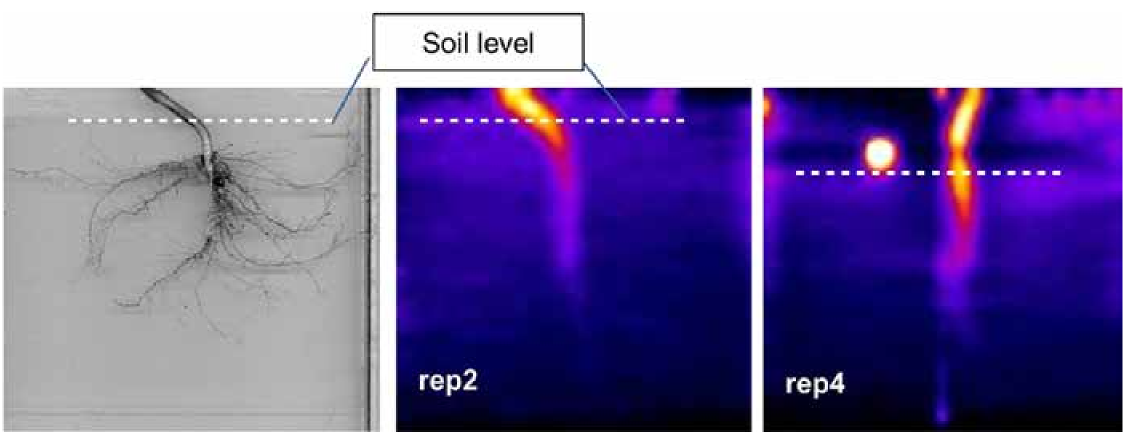

Figure 8: Glucose (^{18}F(FDG) allocation in canola roots.

in collaboration with the Fedoruk Centre, University of Saskatchewan and Virginia's Thomas Jefferson National Accelerator Facility. Pilot studies were performed by Steve Siciliano's research team (UofS Agriculture and Bioresources) working closely with the UofR team and SCCS staff identified differences in root structure of several crop species important in Saskatchewan such as canola, wheat and lentils as well as monitoring the transport of the glucose analogue, (^{18}F)FDG. In order to support these studies, similar studies were performed at the Royal University Hospital (RUH) using the PET/CT instrument in the nuclear imaging department. Working with Scott Mildenberger (RUH PET/CT), researchers were able to validate studies performed on the PhytoPET. Following on from this, in another Canadian first, the PhytoPET was used to image the soil microbiome using F-18 and FDG, radioisotopes produced at the SCCS, in intact field cores from a hydrocarbon-contaminated site.

Quantitative image analysis techniques for plant PET images are in infant stages and the development of these is of paramount importance and is a top priority of the Nuclear Imaging Detector Development Laboratory (NIDDL) at the UofR. Work is currently underway by Drs. Teymurazyan and Papandreou in collaboration with Jefferson Lab and Duke University to enhance the existing PhytoPET system including increasing the field of view by a factor of 80. Such state-of-the art plant imaging technology will further galvanize the Nuclear Imaging Program's goal as a world leader driving research and innovation in this field. The addition of microCT (computed tomography) capability to the PhytoPET at SCCS, currently underway by Drs. Teymurazyan and Papandreou, will allow detailed 3D root topography and seed anatomy visualization, and, importantly, the option to co-register the dynamic functional images afforded by the PET onto the structural features of the plants.

4. Acknowledgments

The Fedoruk Centre is grateful to Innovation Saskatchewan, an agency of the Canadian Province of Saskatchewan, and Western Economic Diversification Canada, an agency of the Government of Canada, for grants to construct the Saskatchewan Centre for Cyclotron Sciences. Innovation Saskatchewan also contributes baseline support to operate the SCCS through a grant to the Fedoruk Centre.

5. Conclusion

Well-equipped and strategically situated, the SCCS is a unique user facility that supports research and innovation across the life sciences in the areas of design and development of new radioprobes, pre-clinical testing through to clinical trials of new radiopharmaceuticals for nuclear and molecular imaging and therapy. The production capacities of the facility allow for daily and reliable supply of [^{18}F]FDG to the local hospital and back-up supply to regional imaging centres. Both its production, research and innovation activities are important for human and animal healthcare, and also beneficial to the agri-food industry.

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Present and Future Prospects of Radiation Therapy Using α-Emitting Nuclides

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[Ed. Note: The following paper, submitted by the Author (J. Cuttler) was first published in Dose Response: An International Journal, January-March 2018. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5784465/ .]

Abstract

Therapy with α-radiation has issues associated with internal exposure; its clinical use has been avoided. However, phase III clinical tests of the α-emitting nuclide ^{223}Ra on patients with cancer have been conducted, and results were reported in 2011 to 2012. Since then, research has being carried out on targeted internal therapy by introducing a-emitting nuclides directly into the cancers. For many decades, nontargeted radon therapy has been carried out and is controversial because its mechanism of action is stimulation. The low-level radiation sends powerful signals to upregulate many biological protection systems, which protect against the effects of radiogenic and nonradiogenic toxins. These vital systems prevent, repair, and remove DNA and other biomolecular damage being produced endogenously at a very high rate by the very abundant reactive oxygen species associated with aerobic metabolism. Stimulation of protection systems results in beneficial effects, including a lower risk of cancer. This article reports the results of treatments on 4 patients with cancer and reviews the clinical use of α-radiation from ^{223}Ra and radon. It discusses the prospect of using the novel ^{225}Ac-prostate-specific membrane antigen ligand-617 ligand as a therapeutic agent for prostate cancer. It presents a new treatment system that we developed, α-Radiorespiro-*Rn*, which seems to be extremely effective in treating cancer.

Keywords

α-emitting nuclides, radon, ^{223}Ra, ^{225}Ac-PSMA ligand, α-Radiorespiro-*Rn*

Introduction

Therapy with α-radiation has issues associated with internal exposure; its clinical use has been avoided. This article describes fundamental and clinical knowledge of cancer treat-ments using targeted $^{223}RaCl_2$ and ^{225}Ac-prostate-specific membrane antigen ligand-617 (^{225}Ac-PSMA-617) and nontar-geted ^{222}Rn gas. Alpha rays are released from radionuclides having an atomic number of 82 or higher, and more than 400 of them exist. Those whose half-life is not too long or too short are suitable, and Table 1 lists the main a-emitters that can be clinically used.

Targeted Internal Radiotherapy

Radiotherapy by intravenous or oral administration of a non-sealed radionuclide itself or in a medication is called internal radiotherapy. When the target tissue is cancer, it is internal radiotherapy for cancer. Radiations usable for this therapy include α-radiation, β-radiation, γ-radiation, X-rays, auger electrons, Compton electrons, internal conversion electrons, and the like. Among these, β-rays from nuclides such as ^{89}Sr, ^{90}Y, and ^{131}I have been widely used in clinical treatments for many decades. Because of their long tracks in tissues (up to 12 mm), β-rays also affect the healthy tissues that surround the targeted cancer cells. Incorporating an

Table 1. Clinically Available a-Emitting Nuclides.

Radionuclide	Half-Life	Eα, average (MeV)	Decay Series	Production
^{149}Tb	4.12 hours	3.97	Cyclotron	
^{211}At	7.21 hours	5.87	Actinium	Cyclotron
^{212}Bi	60.55 minutes	6.05	Thorium	Generator
^{213}Bi	45.59 minutes	5.85	Neptunium	Generator
^{222}Rn	3.82 days	5.49	Uranium	Uranium ore
^{223}Ra	11.43 days	5.67	Actinium	^{227}Ac source
^{225}Ac	9.92 days	5.79	Neptunium	^{229}Thsource

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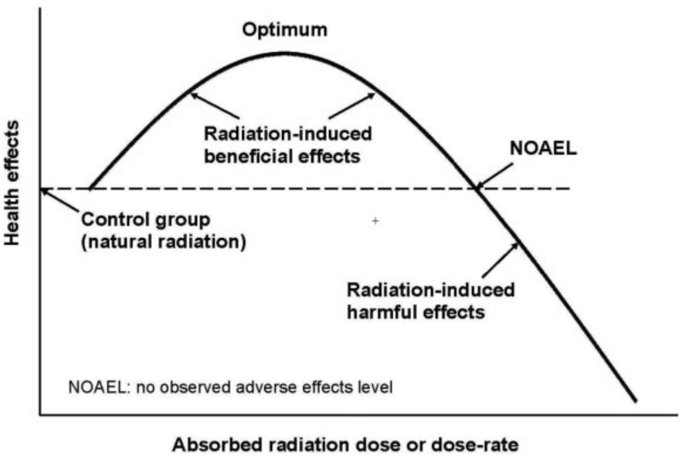


Figure 1: Dose-response for nontargeted radiotherapy.

α-emitter into cancer cells or other target cells (0.05-0.06 mm in diameter) is advantageous because a-tracks are much shorter, 0.03 to 0.1 mm. They inflict lethal damage only to cells that are very near the target cells. The energy lost by the α-ray per unit distance, its linear energy transfer (LET), is 80 keV/mm, increasing to 240 keV/mm at the end of its track. This is 400 to 1200 times the LET of the b-ray, 0.2 keV/mm. The α-ray is not scattered; it passes straight through cells, densely ionizing or exciting the nearby atoms, while losing energy and reaching maximum effectiveness just before stopping. The lethality of damage to DNA is proportional to LET, so α-rays kill cancer cells much better than β-rays. A prime target of internal therapy is the tissue of a disease that is highly sensitive to radiation, such as a cancer that has metastasized to bone marrow. Studies that exploit the superior capabilities of α-rays for cancer treatment have been reported since 1981. For example, ^{211}At was employed to suppress cancer growth in mice bearing malignant ascites.[1] Use of ^{212}Bi-labeled antibody has been reported to delay the deaths of mice with cancerous ascites.[2]

Nontargeted Radiotherapy

The mechanism for nontargeted radiation therapy is different from direct cell killing. Since about three quarters of human tissue is water, radiation-induced reactive oxygen species (ROS) is a very important effect. Reactive oxygen species and direct hits are a double-edged sword. They damage molecules but also send signals to stimulate or inhibit genes.[3] As shown in Figure 1, the response of the patient depends on the radiation dose or the dose rate. As dose (oxidative stress) is increased, a point is reached at which protective systems begin to induce beneficial effects. As dose is raised further, an optimum response is reached at which stimulation of protection is max-imal. As the dose is increased beyond the optimal point, inhibi-tion of protection intensifies and stimulation weakens until, at the threshold point, the health effect is the

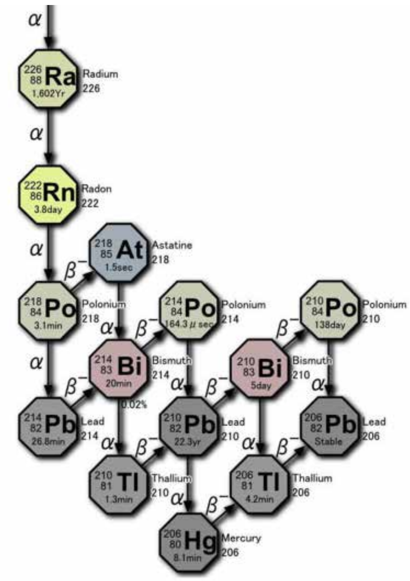


Figure 2: Decay chain of ^{238}U showing the production of ^{222}Rn and its α-emissions.

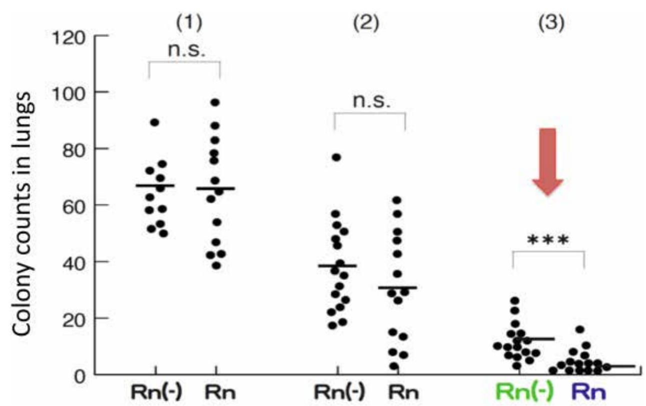


Figure 3: Effect of ingestion of ^{222}Rn-containing water (203 Bq/L) on the formation of metastatic lung colonies after intravenous injection of B16 melanoma cells via tail vein in 3 groups of C57 black 6 (C57BL/6) mice. Radon treatment was started 2 weeks before the injection of the melanoma cells and continued for 14 days. Rn (−) is tap water; Rn is radon hot spring water (203 Bq/L); (1) melanoma cells = 2 × 10^5; (2) melanoma cells = 1 × 10^5; (3) melanoma cells = 5 × 104. ***$\rho < .005$ (n = 7 each). NS indicates not significant.

same as for the unexposed patient. A dose or dose rate higher than this thresh-old produces net harmful effects. Therefore, the dose or dose rate administered is controlled to be in the range for high sti-mulation of the patient's protection systems.

Reactive oxygen species are produced abundantly and con-stantly by the patient's aerobic metabolism. The rate of DNA damage caused by endogenously produced ROS far exceeds the rate of DNA damage caused by low-dose hits and the ROS that they produced.[4] Studies on experimental living systems and on humans have shown that low doses of radiation upre-gulate biological protective mechanisms, which also operate against nonradiogenic toxins and produce beneficial effects, including a lower risk of cancer.[5] The degree of stimulation and inhibition depends on the individual genome. These biolo-gical effects are caused by the direct hits and by the burst of ROS that they produce. Although they damage cells, they send powerful signals also to activate many genes (>150) at the same time that they stimulate various biological protective functions originally provided to the cells. These vital protection systems prevent, repair, and remove DNA damage and other biomole-cuar damage being produced endogenously at a very high rate by the abundant ROS associated with aerobic metabolism. Upregulation of protection systems by a small amount of oxi-dative stress results in significant beneficial effects.

A recent analysis of 2 studies on dogs that received lifelong low-dose rates of ionizing radiation, one study with γ-rays and the other with α-rays, provided evidence of increased lifespan and well-defined dose-rate thresholds for the onset of reduced longevity.[6] Short-lived dogs received a greater relative benefit than the 50% mortality dogs. The study on dogs that inhaled $^{239}PuO_2$ aerosols (α-emitter) demonstrated very strong signaling to the protection systems of the entire animal, by local α-particle hits in the group of dogs with the lowest initial lung burden.6 An analysis of another study on dogs that inhaled $^{239}PuO_2$ aerosols demonstrated a threshold dose rate for lung cancer mortality. Two groups of dogs had lung cancer mortalities below that of the control dogs. The group with the lowest plutonium intake had no lung cancers.

Nontargeted Radon Therapy

As shown in Figure 2, ^{222}Rn gas is released from the radium present in uranium ore (pitchblende). Deposits of high-grade ore are found in countries, such as Kazakhstan, Canada, and Aus-tralia. In hot radium spring facilities, radon is absorbed mainly by inhalation. Most is exhaled, but a small amount of gas and decay products (progeny) adhere to the mucosa of the trachea and the lung surface. Some are taken up by alveolar epithelial cells and transferred into the blood together with oxygen. After 2 weeks, the gas (3.8-day half-life) almost disappears. There is no evidence of adverse health effects from these treatments and no significant long-term accumulation in any specific tissue. Radon is also absorbed into the bloodstream through the skin when the patient is immersed in warm radium bathwater. A third way is by drinking hot spring water (drinking therapy). In this case, dissolved radon is swallowed and transferred from the stomach to the blood. The subsequent kinetics in the body is the same as radon transferred from the lung to the blood. During the transit of radon, α-particles hit cells, imparting a dose of about 0.5 to 1 Gy to each. Water molecules are ionized and various ROS, mainly hydroxyl radicals, are formed. They damage biomolecules including DNA molecules.

For many decades, radon has been employed to treat various diseases, such as low-back pain, high blood pressure, and can-cer at radium hot springs in Misasa and in Tamagawa Onsen, Japan. Clinical trials have been carried out at the Misasa Med-ical Center in Okayama University Hospital, where patients are treated by inhalation of radon volatilized from radon-containing water. Patients inhale radon at a concentration of about 2000 Bq/m³ (54 pCi/L) for 40 minutes, every 2 days in a room that is maintained at 42°C and 90% relative humidity. Diseases that are treated with radon therapy are those related to ROS or oxidative stress, such as arteriosclerosis, osteoarthritis, and bronchial asthma. The effective absorbed radiation dose of each radon treatment is estimated to be 50 to 67 μSv. Nontar-geted therapies with X-rays, γ-rays, and radon are performed in clinics in Japan that have an established radon room.[7–11] Three patients were treated several years ago. Two had wide-spread bone metastasis of prostate cancer, diagnosed to be inoperable, and one had ulcerative colitis. Their diseases are now in remission, as described in a recent article about these 3 case reports.[12]

Radon therapy has been practiced in Central Europe and in Russia for many years.[13] The pain relieving treatment of rheu-matic disease by radon was reviewed in 2005.[14] This report states that "to bathe in about 0.3 to 3 kBq/L of radon water for about 20 minutes for therapeutic purposes" or "to stay in caverns or galleries of about 30 to 160 kBq/m³ for about 1 hour" made it possible to obtain a statistically significant pain relieving effect. Unfortunately, the US Environmental Protec-tion Agency (EPA) and many other organizations responsible for public safety use the linear no-threshold model to assess the risk of radiation-induced cancer. They do not consider any exposure to radon to be safe. The EPA action level for radon in homes is 4 pCi/L (150 Bq/m³). Therefore, radon therapy has not been accepted as an approved medical treatment in many countries; it remains in the category of an "alternative therapy."

Nontargeted Effect of Radon on Melanoma in Mice

In our laboratory, skin cancer B-16 melanoma cells (2×10^5, 1×10^5, and 5×10^4) were injected into the tail vein of 3 groups of C57 black 6 (C57BL/6) mice (male, 6 weeks old). They were given radon-containing water (203 Bq/L) every day to deter-mine the effect of radon on lung metastatic cancers.[15] The colo-nies formed were counted 14 days later. As shown in Figure

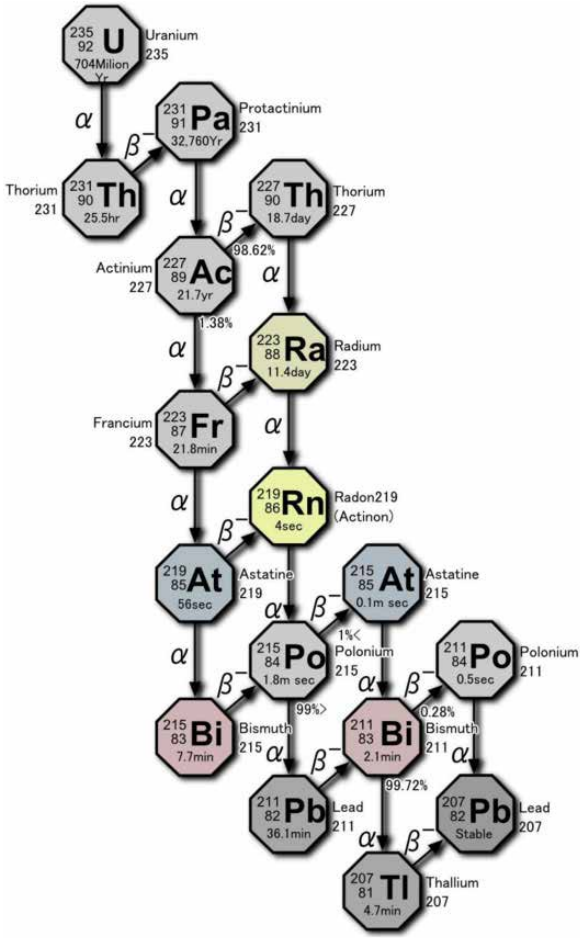


Figure 4: Decay chain of ^{235}U showing ^{223}Ra and its α-emissions.

3, metastasis was not significantlysuppressedinthe groupwith a large number of cancer cells, but significant inhibition ($P < .005$) was observed in the group with the smallest number of cells (5×10^4 cells). When the radon concentration in water was diluted twice, the inhibitory effect on cancer was not observed in the group in which metastasis had been sup-pressed. From these results, it is concluded that there is a threshold for radon concentration to suppress metastasis of the cancer to the lung, and the effect is not induced below that concentration.

Targeted $^{223}RaCl_2$ Therapy Against Bone Metastasis

Radiopharmaceuticals have been developed that can alleviate pain, but none have been able to extend survival. Bone-seeking ^{223}Ra was studied for alleviating the pain of metastasis; however, this therapy has been observed to prolong survival time.[16–18] In Europe and the United States, ^{223}Ra has become a focus of attention. Phase I/II tests are underway in Europe and the United States on other α-emitting nuclides.

As shown in Figure 4, ^{227}Ac transitions to ^{223}Ra. Four α-particles are emitted as ^{223}Ra transitions to ^{207}Pb, producing strong cell killing action. Irradiation of ^{226}Ra in a nuclear reactor produces ^{227}Ra, which β decays with a half-life of 42.2 minutes to ^{227}Ac. A reagent is added to a generator that con-tains 21.8-year ^{227}Ac to "milk" 11.4-day ^{223}Ra for use in bone cancer therapy.19 Comparing the efficacy of α-particles from ^{223}Ra with β-rays from ^{89}Sr, the radionuclide commonly used to treat metastatic bone tumors, it is noted that the α-particle energy is about 50 times larger than the β-ray energy, and the energy lost per micrometer of range is 400 times larger (80 keV vs 0.2 keV). ^{223}Ra inflicts irreparable damage to the DNA of the target cell. Furthermore, the cell killing effect is active also during the S phase, since the action of α particles does not depend on cell cycle.

Studies have been conducted worldwide on the use of $^{223}RaCl_2$ to inhibit bone metastases in castration-resistant pros-tate cancer (CRPC).[20–24] Phase III clinical trial reports issued in the United States and European countries from 2011 to 2012 state that this drug has a life-prolonging effect by relieving pain and delaying the occurrence of bone-related events such as fracture. It is said to be an excellent antitumor agent with fewer side effects than b-emitting treatments. In the phase III clinical study of $^{223}RaCl_2$ (Xofigo) that led to its Food and Drug Administration (FDA) approval in 2013, the

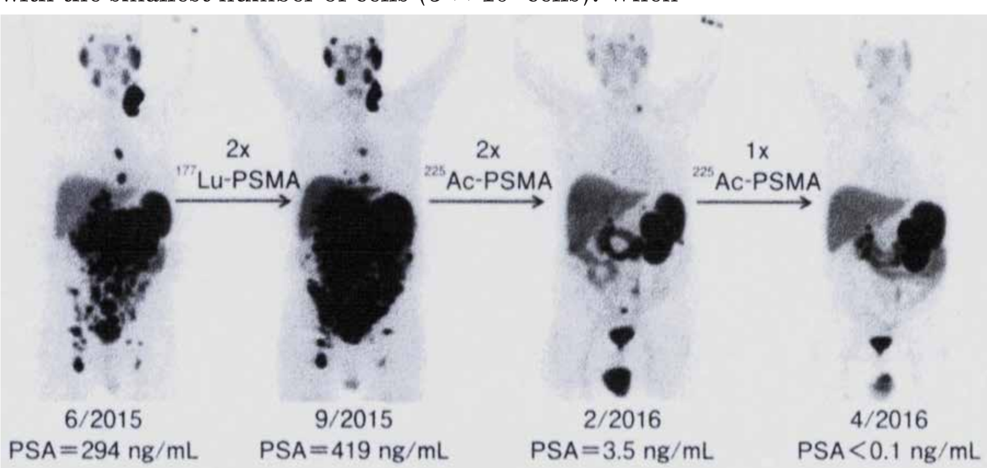
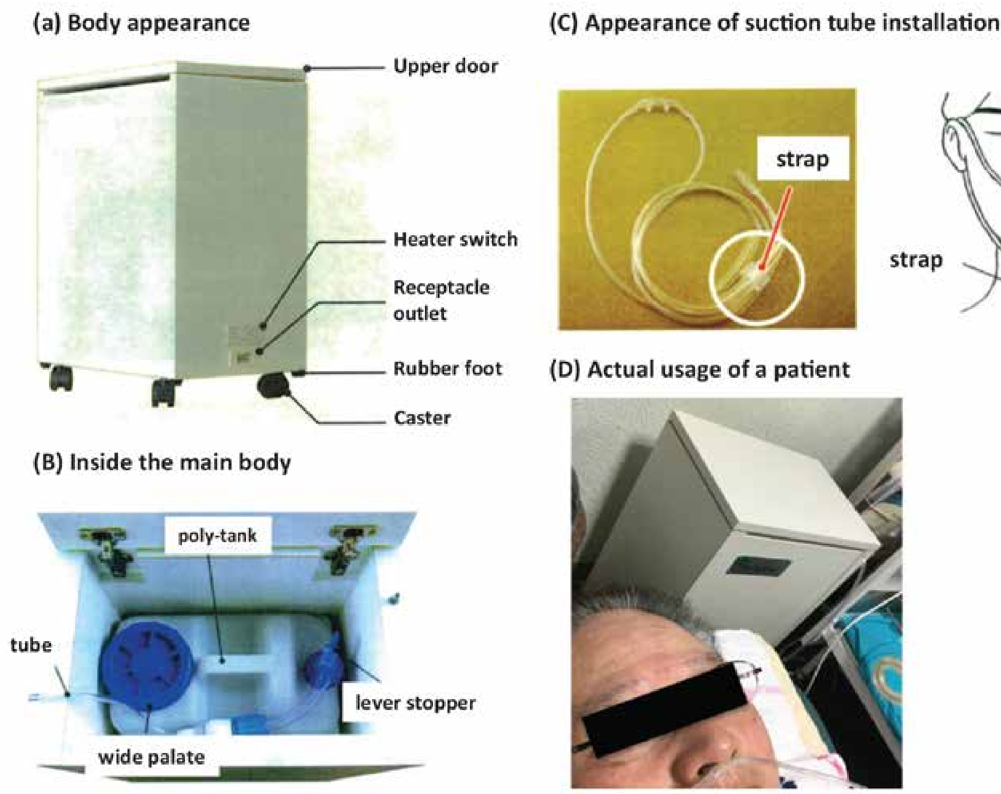


Figure 6: System of a-Respiro-*Rn* and its actual usage. Particles of uranium ore, about 4 mm in diameter, are spread evenly on the bottom of the 16-L polyethylene tank. About 2.5 L of distilled water is poured into the tank and maintained at a temperature of 35°C. Radon gas with a concentration of about 8 MBq/m^3 in air accumulates in the tank on the day before use. The patient inhales radon through the suction tube.



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mean survival time in the treated group was 14.9 months versus 11.3 in the placebo group, a 30% reduction in mortality risk. The average time to the onset of bone-related events was 15.6 months versus 9.8 months in the placebo group, a 34% reduction in risk. A drop in the alkaline phosphatase increase at the time of bone metastasis was shown. Improved quality of life was recog-nized. No significant difference in the incidence of adverse side effects was noted between the Xofigo group and the pla-cebo group. The rate of treat-ment dropout due to adverse side effects was lower, 16% versus 21% for the placebo group.[25]

In March 2016, $^{223}RaCl_2$ (Xofigo) was approved for clinical use in Japan for CRPC with bone metastasis. Its efficacy and safety for bone tumors, other than castration refractory prostate cancer, has not been confirmed. Further research will be needed. Because the drug price is high, about 700 000 yen (US$6300), multiple treatments would be a heavy economic burden on patients.

Targeted Treatment of 2 Patients With Metastatic Cancer Using ^{225}Ac-PSMA-617 Ligand

Prostate cancer is very common in elderly men in many west-ern countries.[26] Prostate-specific membrane antigen is a pro-mising target for prostate cancer, and the α-emitting PSMA ligand, ^{225}Ac-PSMA-617, has been successfully synthesized. Studies on the use of PSMA-617 have been carried out over the past few years.[27,28] We discuss here a recent case report about 2 patients who were treated successfully by ^{225}Ac-PSMA- 617 ther-apy.[28]

The first patient had peritoneal carcinomatosis and liver infiltration and was given an accepted treatment of β-emitting ^{177}Lu-PSMA-617 ligand (7.4 GBq per treatment). Referring to Figure 5A and B, the initial prostate-specific antigen (PSA) value was 294 ng/mL in June 2015, but after the second treat-ment with ^{177}Lu-PSMA ligand, the PSA value rose to 419 ng/mL in September 2015, and tumor progression was also seen with positron emission tomography (PET) diag-nosis. Therapy with α-emitting ^{225}Ac-PSMA-617 ligand was offered to rescue the patient. He was given 3 cycles of 6.4 MBq (100 kBq/kg body weight) at bimonthly intervals. No lesions were observed in the PET image after the second treatment, as shown in Figure 5C, and complete remission was achieved by 1 additional dose thereafter, Figure 5D. No related toxicity was observed, and the PSA value on the final day (in April 2016) was below the detection limit (<0.1 ng/mL).

The second patient was also treated with

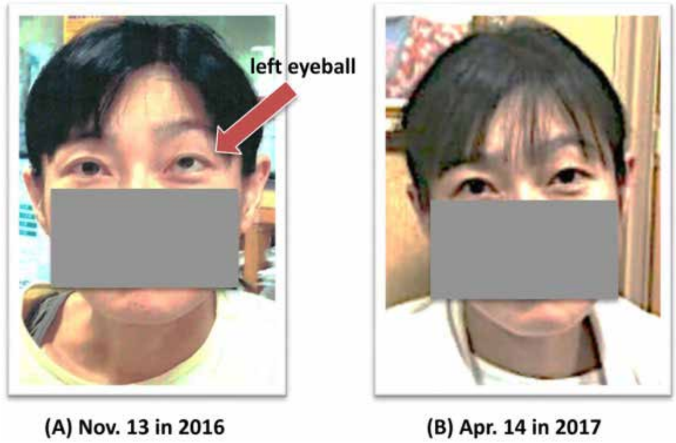

Figure 7: Eye of first patient with breast cancer before and after radon treatment using α-Respiro-*Rn* system.

^{225}Ac-PSMA-617 ligand (data not shown). In the PET images, diffuse red marrow invasion was observed. Treatment with β-emitting ^{177}Lu-PSMA ligand was considered contraindicated. Therefore, ^{225}Ac-PSMA-617 ligand (100 kBq/kg body weight) was intravenously administered to this patient 3 times at intervals of 2 months at doses of 9 to 10 MBq each. A target tumor was confirmed in a PET image scan immediately after treatment in December 2014. In the image after the third administration in July 2015, the PSMA positive lesion disappeared com-pletely. The PSA value decreased from 3000 ng/mL or more (in December 2014) to 0.26 ng/mL (in July 2015). In addition, 6MBqof ^{225}Ac-PSMA-617 ligand was administered to the patient as an integrated medical care, resulting in the image becoming much clearer and the PSA value decreasing to below 0.1 ng/mL.

Due to the short range of α-particles, ^{225}Ac-PSMA-617 needs to be taken into the cancer cell in order to destroy it. The uptake of this ligand into prostate cancer cells has been confirmed—54% and 75% of the ligand were incorporated into the cells after 1 and 3 hours, respectively.[29] The cases suggest that radioligand therapy using ^{225}Ac-PSMA-617 is an effective α-particle therapy targeting metastatic CRPC. This is important for patients who are in a clinically difficult stage, such as those showing resistance to diffuse red bone marrow infiltration and other treatments. A study should be carried out on a large cohort to confirm the effectiveness of this therapy; however, this will not happen soon because routine supply of this radio-nuclide has not been established.

Nontargeted Treatment of 2 Patients With Metastatic Cancer Using Radon

The α-Radiorespiro-*Rn* apparatus has been specially developed to deliver radon inhalation therapy. As

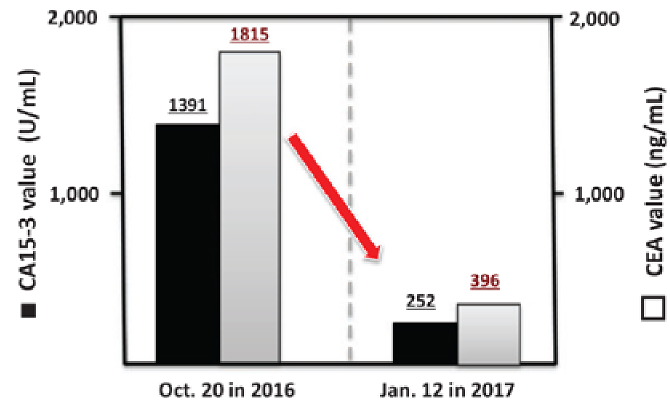

Figure 8: Breast cancer marker of first patient before and after treatment using a-Radiorespiro-Rn system. Cancer antigen 15-3 val-ues for October 20, 2016, and January 12, 2017, are 1391 and 252, respectively. CA15-3 indicates cancer antigen 15-3; CEA, carcinoem-bryonic antigen; ■, CA 15-3; ❑, CEA.

shown in Figure 6A and B, it is made from simple parts and stored in a wooden cabinet, 450 mm wide, 300 mm deep, and 600 mm high. Particles of high-grade uranium ore, averaging 4 mm in diameter, are spread evenly on the bottom of a 16 L polyethylene container. About 2.5 L of distilled water is poured into this tank and maintained at a temperature of 35°C. The amount of ore is adjusted to allow the radon gas to accumulate to a concentra-tion of about 8 MBq/m^3 (216 nCi/L) in the volume above the water. As

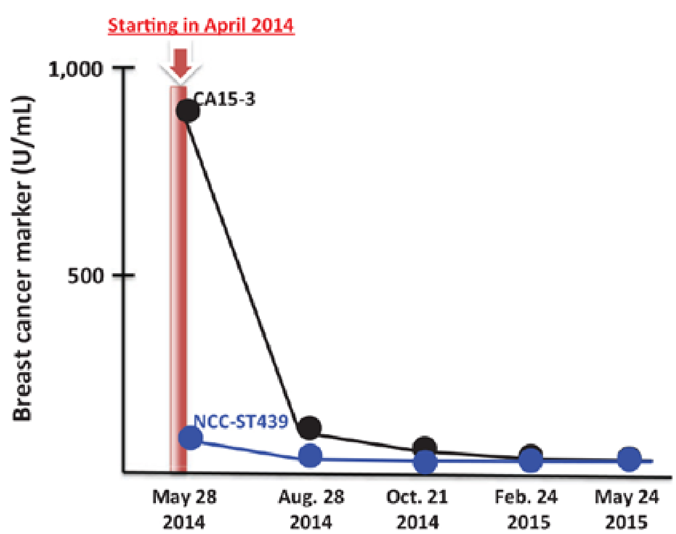

Figure 9: Changes in CA 15-3 and NCC-ST-439 of second patient with breast cancer with bone metastasis after hormesis room therapy. Hormesis room treatment: 40 minutes, twice daily, May 28, 2014, to May 24, 2015. Average radiation level and radon concentration in the room: 11 μSv/h and 9800 Bq/m^3. Temperature and relative humidity: 39°Cto40°C and 70%. CA15-3 indicates cancer antigen 15-3; NCC-ST-439, National Cancer Center-Stomach-439.

prescribed by the physician, the patient inhales radon through the suction tube into a special respirator, as shown in Figure 6C and D, for the time specified.

The first patient with breast cancer is a 42-year-old woman with metastasis to her brain. In 2013, she felt a sting on her left chest. The lump gradually enlarged to about 2 cm in diameter and was diagnosed to be breast cancer at a hospital. Only private therapy was carried out for 2 years, during which time the whole breast grew bigger and harder. Compression fracture in the lumbar vertebrae and inflammation throughout her chest were apparent in July 2016. In addition, the growth of the tumor in her brain pressed her left ocular nerve, affecting her field of vision; the image became blurred. There was bleeding from her breast, and she was taking analgesics to relieve the low-back pain.

On August 22, 2016, radon inhalation treatment was started using the α-Radiorespiro-*Rn* apparatus. Three days per week, she inhaled 0.5 to 1.0 MBq/m^3 of radon for 40 minutes, twice each day. In November 2016, the patient's condition was observed to improve. The rash on her breast started to disap-pear. A dramatic recovery was recorded in February of 2017. Her left eye ball, which had been rotated to the upper right side at the start of treatment, returned to almost normal position. Her visual acuity recovered to normal vision. Furthermore, she was able to walk normally without a cane and without back pain. Figure 7A is a photo of the patient on November 13, 2016, after 2.5 months of radon treatment, and Figure 7B is a photo on April 14, 2017, after 8 months of treatment. Breast cancer marker values, cancer antigen 15-3 (CA15-3, 1391) and carcinoembryonic antigen (CEA, 1815) on October 20, 2016, fell to 252 and 396, respectively, on January 12, 2017, as shown in Figure 8.

The hormesis room exposes the occupants to γ-radiation and radon gases from radiation sources in the walls, supplied by Lead & Company Co (Yokohama, Japan). The sources are natural mon-azite excavated from a mountainous area in Japan. The average γ-radiation level in the room is 11 μSv/h, and the average concentration of radon is 9800 Bq/m^3[3,12]. Temperature and humid-ity in the room are maintained at about 40°C and 70%, respectively.

The second patient with breast cancer is a 47-year-old woman with metastasis to her bones. She was diagnosed with breast cancer 5 years ago. She refused chemotherapy, opting instead for folk remedies such as hyperthermia. Her breast cancer gradually progressed to stage IV. Her treatment began on May 28, 2014. At the start, her body weight was only 38 kg and she wore a neck brace because of bone metastasis. Twice daily, she received radon therapy in the room for 40 minutes. No improvement was observed in the first week. She lost weight during the following week, but the secretion of pus from her chest stopped. This treatment continued into the following year. As shown in Figure 9, her breast cancer markers of CA15-3 and National Cancer Center-Stomach-439 returned to their normal values in August 28, 2014, and the patient returned to work. In May 2015, the tumor tissue became scab, and in June, she was walking 7 km every 2 weeks, an indication of good physical condition and improved quality of life. Subsequently, she went to Germany for 2 weeks of com-pany training. Her cancer markers are still at normal levels. The patient's weight, which was 38 kg at the start of treatment, increased to 51 kg.

Conclusions

Therapy with α-radiation has been regarded as having significant concerns associated with internal exposure, and its clinical use has been avoided. However, a phase III clinical trial of targeted therapy with $^{223}RaCl_2$ produced evidence of its effi-cacy for the treatment of metastatic bone tumors, and it was approved for clinical use by the US FDA in 2013. Since then, fundamental and applied research is underway on internal therapy with other α-emitting nuclides. The recent targeted treatment of metastatic prostate cancer by ^{225}Ac-PSMA-617 ligand therapy is one of the most promising results.

Clinical use of nontargeted α-radiation from radon gas on 2 of our patients with advanced breast cancer brought their dis-ease into remission. One patient received inhaled radon ema-nating from natural monazite ore in the walls of our hormesis treatment room. The other inhaled radon from uranium ore contained in a new treatment apparatus that we developed, the α-Radiorespiro-*Rn* system. Treatment with radon gas stimu-lated the patient's protection systems to produce their very remarkable recoveries from advanced breast cancer. Our α-Radiorespiro-*Rn* system is very convenient to use and very effective in reversing the progression of their illnesses. We expect it to be potent for other types of cancer and for other illnesses that would benefit from upregulation of inherent bio-logical protection. Further studies are recommended to opti-mize the treatment protocol for cancer and to identify other important applications.

This article reviewed the present and future prospects of treating cancer using α-emitting nuclides for internal radiation exposures. It examined the application of $^{223}RaCl_2$ and ^{225}Ac-PSMA ligand for targeted therapy and ^{222}Rn gas for nontargeted therapy. Employing α-emitters for treating cancer could be a very important method for curing many types of cancer and other illnesses.

Acknowledgments

The authors would like to thank our patients (MY and YO) for grant-ing permission to report their cases.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and or publication of this article.

Funding

The author(s) received no financial support for the research, author-ship, and/or publication of this article.

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Recovery From Rheumatoid Arthritis Following 15 Months of Therapy With Low Doses of Ionizing Radiation: A Case Report

by SHUJI KOJIMA[1], MITSUTOSHI THUKIMOTO[1], JERRY M. CUTTLER[2], KIYOMI INOGUCHI[3], TAKAHIRO OOTAKI[4], NORIKO SHIMURA[5], HIRONOBU KOGA[6], and AKIHISA MURATA[6]

[Ed. Note: This is a very recent follow-up report of the previous paper, submitted by the author, on the recovery of a patient who recovered from rheumatoid arthritis following treatment with low dose radiation therapy. It was published July 9 at http://journals.sagepub.com/doi/full/10.1177/1559325818784719.]

Abstract

Rheumatoid arthritis (RA) is an inflammatory autoimmune disease that occurs commonly in old people. Hot spring radon therapy is widely practiced in Central Europe and Japan for relief from the painful symptoms. The usual duration of a spa treatment is a week or two, and the relief is temporary. This article reports on the near-complete recovery of a patient who had been suffering from RA for 10 years. The patient received 15 months of low-dose radon and γ-radiation therapy in a room that reproduced the conditions of a radon spa. The daily 40-minute exposure in the therapy room was supplemented by ten 6-minute radio-nebulizer treatments. The inflammation markers C-reactive protein and matrix metalloproteinase 3 declined strongly to the normal level of 0.07 mg/dL and the near-normal level of 48.9 ng/mL, respectively. After the patient's return to good health, the frequency of the visits was reduced to twice each month. The patient's protection systems appear to have adapted to stimulated conditions, sufficiently to sustain the recovery from RA. Such a long-term course of treatments and follow-up maintenance could be carried out in any hospital that has these low-dose radiation therapy rooms. The therapy could be scheduled to suit patient availability.

Keywords rheumatoid arthritis, low-dose radiation, radon therapy room, hormesis, immune cells, Treg cells

Introduction

Radon therapy has been widely employed in Central Europe, Russia, and Japan.[1-8] Patients with age-related illnesses have been receiving traditional radon hot spring treatments for more than a century.9 In Europe, "bathing" in tunnels, mines, steam, inhalation, and so on, has been practiced. This therapy has included drinking radon water and inhaling radon gas. Falkenbach and colleagues have reviewed studies to analyze the effect of radon therapy on pain in rheumatic diseases.10 In a meta-analysis, the pooled data showed no difference immediately after treatment ($P < .13$). However, significant pain reduction was observed

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in the radon group compared to the control group at 3 months ($P < .02$) and 6 months ($P < .002$) after treatment.[10] The mechanism was not discussed.

An Italian research group conducted radon-enriched hot spring water therapy for asthma, upper nasal congestion, and allergic rhinitis.[11] Patients were treated for 12 to 28 days by inhalation of radon gas from high-concentration radon water. They were evaluated at baseline and after treatment. After 2 weeks of treatment, nasal resistance decreased, flow increased, mucociliary clearance enhanced, ciliated to muciparous cell ratio increased, and % forced expiratory volume (in 1 second) increased in patients with asthma. Inhalation therapy, rich in radon, improves objective indicators of nasal function in allergic rhinitis and chronic rhinosinusitis and causes alleviation of pulmonary obstruction in asthma.[11]

In Japan, radon treatment using radon volatilizing from radon-rich water is carried out at Misasa Medical Center (Okayama University Hospital) for patients with reactive oxygen species (ROS)-related diseases such as arteriosclerosis, osteoarthritis, and bronchial asthma. They are based on previous reports that low-dose radiation induces antioxidant capacity.[12-14]

Using a therapy room in Tokyo that was designed to reproduce the conditions of the Bad Gastein radon hot spa, we provided radon therapy successfully to 2 patients with advanced breast cancer and to a patient who suffered from severe inflammation.[15,16] In this article, we describe the case of a patient who had been suffering from rheumatoid arthritis (RA) for 10 years. Following 15 months of daily therapy using another therapy room in Osaka, she made a near-complete recovery. We also review and discuss the mechanism in relation to the results obtained from animal studies.

Treatment Facility and Equipment

Therapy Room

The therapy room is designed to reproduce the conditions of a health spa, that is, a warm, moist atmosphere of low-dose ionizing radiation, like those in the Bad Gastein radon hot spa. Because the duration of a visit to a health spa is usually limited from days to weeks, the benefit received is relatively small and short-lived. A therapy room located in a clinic in Osaka allows a patient, living nearby, to receive daily treatments, under carefully controlled conditions, for as long a time as needed to achieve a significant, long-lasting improvement. Furthermore, periodic 1-day treatments can be provided to maintain the improvement against aging-induced regression to the patient's previous condition.

The room, supplied by Lead & Company Co (Yokohama, Japan), has walls that contain natural monazite. This radioactive mineral, excavated from a mountainous area of Japan, contains phosphate of thorium and rare earth elements. The average γ-radiation dose rate in the room was 11 μGy per hour, and the average concentration of radon radioactivity was 200 000 Bq/m^3, as measured using Alpha-Scint-1 monitor (TRACERLAB, Koeln, Germany).

Radio-Nebulizer

Uranium ore (150 g) is placed into an 8-L stainless steel container. Then 4 L of water is added and left to stand for about 12 hours, as radon gas emanating from the ore dissolved in the water. Radon water of 15 mL is poured into the cup of an ultrasonic nebulizer. The patient inhales all of the vapor from the cup (about 6 minutes).

Case Report: Patient With RA Recovers After 15 Months of Radiation Therapy

The patient was 63 years of age when she was diagnosed with RA at a major hospital. During her treatments with bucillamine, loxoprofen, and methotrexate from September 2006 until January 2016—almost 10 years, she did not experience improvement as her condition deteriorated nor did she obtain significant relief from the increasingly painful symptoms. Water accumulated on her right knee; walking became excruciatingly painful and tiring; her whole body sagged. Removing the shoes from her swollen feet was a very difficult task. Eventually, she could not raise her arms above her shoulders, had painful swelling in both wrists, and could hardly do housework such as cooking.

In 2016, at age 73, she heard that low doses of (ionizing) radiation might help. She visited the Ootaki Clinic in Osaka and accepted the clinician's recommendation to try low-dose radiation treatments in a therapy room (hormesis room) followed by radio-nebulizer treatments. It was a major commitment on her part to continue receiving these treatments for an indefinitely long time, starting on February 8, 2016. For 40 minutes each day, 5 days every week, the patient occupied the small therapy room, where the temperature and relative humidity were maintained at about 40°C and 70%, respectively. Using The International Commission on Radiological Protection formula,[17] effective dose = 6.7×10^{-6} mSv per Bq·h·m^{-3}, the effective dose of each 40-minute exposure was calculated to be about 0.4 mSv. About 30 minutes after leaving the therapy room, the patient received 10 consecutive treatments with a radio-nebulizer. She received the

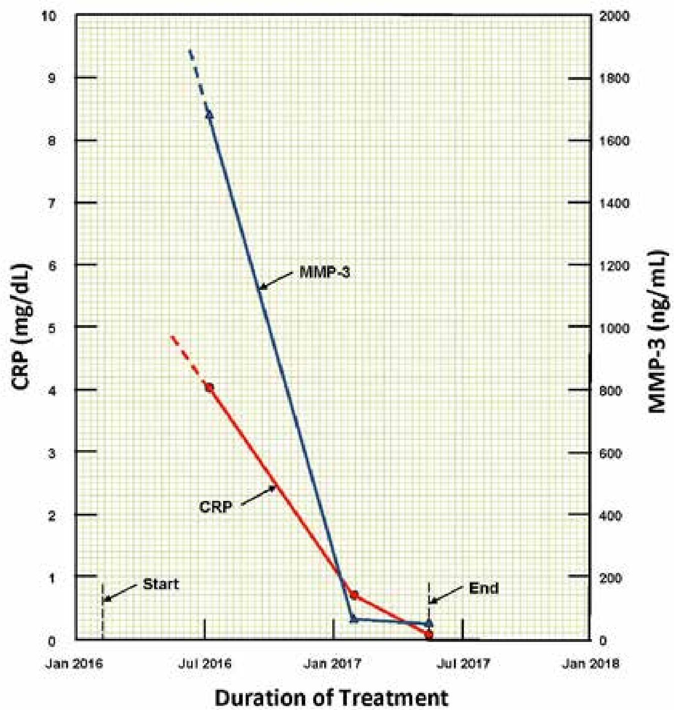

Figure 1. Changes in inflammatory rheumatoid markers, CRP and MMP-3, during the low-dose radiation treatments. The patient remained in the therapy room for 40 minutes a day, 5 days a week. She also inhaled radon-containing vapor from the radio-nebulizer, 10 times consecutively (6 minutes each time), 6 days a week. CRP indicates C-reactive protein; MMP, matrix metalloproteinase 3.

nebulizer treatments 6 days every week. She felt no symptomatic side effects from any of these treatments.

By July 2016, the inflammation had subsided and the pain throughout her body almost disappeared. The daily treatments ended on May 13, 2017. To prevent regression to her previous condition, she began to receive a treatment in the therapy room followed by 10 nebulizer treatments twice every month. By February 2018, at age 75, the patient's appetite had returned to normal; her muscular strength was restored, also to her legs and right knee. A happy smile appeared on her face.

The markers in Figure 1 clearly indicated a significant improvement. When the treatments started on February 8, 2016, the clinician did not measure the markers for RA because he did not anticipate the dramatic improvements that he began to observe later on. The inflammatory marker C-reactive protein (CRP), measured on July 7, 2016, was 4.03 mg/dL. It declined to 0.69 mg/dL on January 28, 2017, and to the normal value of 0.07 mg/dL on May 13, 2017. As for the RA blood marker matrix metalloproteinase 3 (MMP-3), its value was 1,680 ng/mL on July 7, 2016. It decreased to 61.8 ng/mL in January 28, 2017, and to the almost normal level of 48.9 ng/mL on May 13, 2017.

Discussion

Rheumatoid arthritis is one of the typical collagen diseases. It is an inflammatory autoimmune disease in which self-immunity mainly affects the joints of arms and legs, thereby causing joint pain and joint deformation. The effectiveness of radon hot spring treatment against the pain suffered by patients with RA was shown in the statistical analysis by Falkenbach et al.[10] In the Misasa Medical Center, patients stay in the high-concentration radon room without bathing. The room temperature is 42°C, and the radon concentration is about 2080 Bq/m^3 (100 times the average natural background radiation level). Every 2 days, steam from the hot spring is inhaled for 40 minutes under high humidity (90%) conditions. The effective dose is 50 to 67 µSv. The inhibitory effects of radon inhalation on ROS-related pathology have been reported[12-14]; human trials have demonstrated that radon treatment has anti-inflammatory and pain-reducing effects. These benefits were further confirmed in animal models of carrageenan-induced inflammatory paw edema and formalin-induced irritation pain.[17,18] However, it is regrettable that the descriptions of mechanisms that are related to pathological condition improvement are insufficient in these reports. In this case report, we write about our discovery of the very significant improvement in the health of a patient with severe RA following her long-term therapy in a room with conditions similar to the Bad Gastein radon hot spa. It can be expected from the changes in the pathological conditions and the rheumatism-related markers. MMP-3 inflammation occurs in the synovial cells covering the inside of various joints of the whole body of patients with RA, progressively spreading from the synovium to the cartilage and bone, eventually destroying the joint itself and causing joint deformation. Since MMP-3 is produced from proliferated synovial cells in RA, it is thought that this protein directly plays a major role in cartilage destruction. Therefore, if the serum MMP-3 concentration in a patient with RA shows a high value or rises, it is predicted that the progress of joint destruction will be fast. On the contrary, the value decreases when the disease state stabilizes due to the therapeutic effect. Although serum MMP-3 concentration does not increase in joint diseases such as osteoarthritis, gout, and many collagen diseases, it may be high even in systemic lupus erythematosus (SLE), glomerulonephritis, and the like, and the specificity in diagnosis of RA is not necessarily high. Therefore, it is usually combined with a CRP test, which can judge degree of inflammation, in clinical diagnosis of RA.[19] In doing so, clinicians obtain more accurate information of bone destruction, inflammation, and pathology of the patient. From the recovery of the inflammatory markers CRP and MMP-3 as described above, we can easily predict that other inflammatory cytokines tumor necrosis factor-α (TNF-α), interferon-γ (INF-γ), and interleukin-6 (IL-6) previously obtained from our animal experiments will change in a similar manner. Also, the decline of the markers after treatment correlated well with the relief experienced by the patient from the painful symptoms of RA and the happy expression on her face.

A mechanism of improvement of autoimmune disease of radiation including Đ-rays was surmised from our previous basic experiments in animal models. A reduction of IL-6 production may correct the balance that was inclined to Th17 cells to the Treg cell differentiation direction, and the scheme shown in Figure 2 can be evaluated.

this alternative form of treatment and perform proper clinical studies because it may lead to lasting cures for many important diseases.

The development of the special, low-dose radiation therapy room is very important. It allows long-term treatments to be carried out in hospitals or clinics located anywhere in the world. It makes this form of treatment accessible to all patients at an affordable cost.

Acknowledgments

The authors would like to thank their patient (H.H.) for granting us permission to report her case.

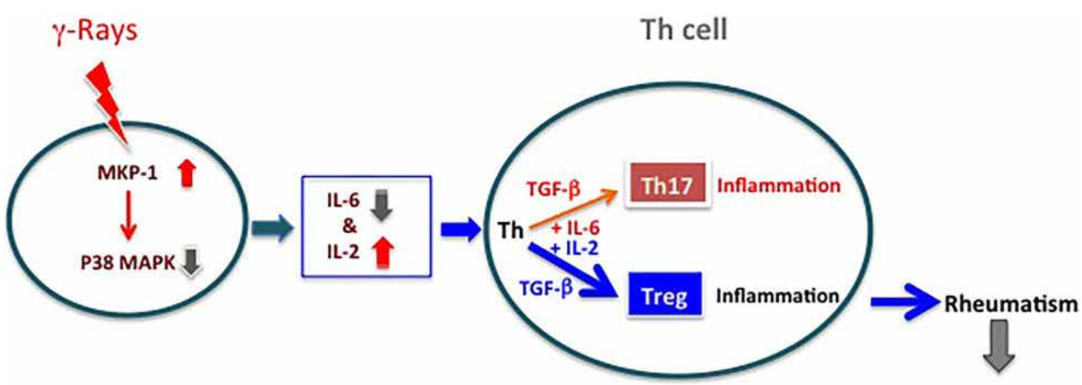

Figure 2. Surmised mechanism of attenuated autoimmune diseases by low-dose ionizing radiation. Whole-body ionizing irradiation against autoimmune diseases → increase in MKP-1 expression in macrophages → suppression of production of inflammatory cytokines (TNF-α, IL-6, etc) → Th17 decrease and Treg cells increase → inflammatory cytokines and autoantibody production reduction → attenuation of autoimmune pathology and inflammatory rheumatoid markers. MKP-1 indicates mitogen-activated protein kinase phosphatase 1.

Conclusions

Rheumatoid arthritis is a painful and debilitating disease that affects many old people. Some travel a great distance to visit a radon hot spring spa and receive a short-lived benefit. However, most patients are treated with various pharmaceutical remedies that relieve symptoms but do not change the illness.

This case report describes the achievement of a significant reversal of this disease. The daily exposure in the special therapy room and the supplementary radio-nebulizer treatments produced a major change after 15 months. Moreover, it appears possible to sustain the improvement by a periodic maintenance treatment, twice monthly.

This very important discovery should be confirmed by repeating the long-term therapy on other patients and measuring the inflammatory rheumatoid markers at frequent intervals, for example, monthly, starting from the beginning of the treatment. Health science centers around the world should begin to investigate

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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CNS news

News from Branches

Chalk River Branch

Renfrew County Science Fair (April 7, 2018): On Saturday April 7, members of the Chalk River Branch of the CNS were on hand in Petawawa to evaluate participants of the Renfrew County Science Fair. There were many excellent projects by aspiring young scientists and engineers. The branch proudly awarded the CNS Nuclear Research Award of Excellence to Alison Hyatt (Pine View), Sam Mills, and Nathan Nguyen.

Canadian Nuclear Society Award Winners (from left) Nathan Nguyen, Sam Mills and Alison Hyatt with CNS-Chalk River Branch Chair Andrew Morreale.

Members of the CNS Chalk River Branch Executive Pose with Speaker Kiza Sauve (middle left) and WIN Eastern Ontario Chapter President Larkin Kee (middle right).

CNS Chalk River Branch and Women In Nuclear (WIN) Joint talk (April 24, 2018): This joint talk with the local chapter of WIN was given by Kiza Sauvé of the Canadian Nuclear Safety Commission and focused on "Canada's Nuclear Regulator and her role in its Independent Environmental Monitoring Program". The talk was well attended and produced lively discussion, benefitting from the more personal tone which included a detailed chronical of her career and discussed the relationships built with licensees regarding the independent environmental monitoring program.

CNS Chalk River Branch Joint Lecture with the CNL ZED-2 Summer School (May 16, 2018): As part of an ongoing partnership between the CNS CRB and the CNL ZED-2 Summer School, a joint public lecture by Nicholas Woolstenhulme of Idaho National Laboratories was held on May 16. Nicholas gave a lecture entitled "Resumption of Transient Testing in the United States", which discussed the restart and upcoming testing plan of the previously closed TREAT facility. The Transient Reactor Test (TREAT) facility at the Idaho National Laboratory was constructed in 1958, and operated from 1959 until it was put into a safe shutdown state in 1994. An initiative to restart the TREAT facility and bring it operation again was conducted and the reactor was brought back online in late 2017. Transient testing is ramping up in the facility and returns a vital reactor testing capability to INL. This talk was very well attended by CNS members and students and faculty of the ZED-2 Summer School.

Upcoming news, events and talks to look out for:

- We are in the process of refurbishing and refinishing the information sign for the NPD reactor in Rolphton in order to keep up the record of NPD's tremendous contributions to the nuclear industry and inspire future generations of nuclear professionals.

Ottawa Branch/Ken Kirkhope

The Ottawa Branch was pleased to be a sponsor of the Ottawa Regional Science Fair, held April 6th and 7th, 2018.

On May 4th, the Ottawa Branch in collaboration with the CNSC Speaker Series co-hosted a presentation by Greg Hersak, of Canadian Nuclear Laboratories. Mr. Hersak gave a very successful presentation on "Additive Manufacturing in the Nuclear Industry". Additive manufacturing (more commonly referred to as 3D printing) is rapidly changing the landscape in the manufacturing

Greg Hersak (Canadian Nuclear Laboratories)

industry and is opening the doors wide open for new, innovative design. Components can be printed from an ever-growing array of materials and printed components are becoming more prominent in end-use applications as the enabling technology is improving. Greg provided an excellent overview of the technologies that are employed, the challenges that are encountered when printing and qualifying components, and provided a snapshot of how printed components are being employed in the nuclear industry and how this might change the baseline paradigm over the coming years. The event was well attended by CNS Ottawa branch members as well as approximately 50 CNSC staff, including CNSC President Michael Binder, and considered a success on many levels.

The Ottawa Branch is actively looking for new members to join the branch executive.

Sheridan Park Branch/Raj Jain

The Branch organized the following events during the reporting period:

1. A presentation by Stephen Yu, M.Sc., P. Eng., (CANDU Product Engineer Emeritus, Nuclear, SNC-Lavalin) was organized on May 24, 2018. The title of the presentation was "History of CANDU Reactor Product Developments".
2. A tour to McMaster Nuclear Reactor (MNR) and McMaster Manufacturing Research Institute (MMRI) was organized on May 31, 2018.

Toronto Branch/Moe Fadaee

In February we had a joint event with the mechanical engineering department at University of Toronto and take student to Darlington Energy Complex to visit the full-size mock-up CANDU nuclear reactor. We had a very good response rate but we only could take 24 due to limitations on the site. For this event CNS paid for the lunch ($250) and University of Toronto paid for transportation ($600).

The Branch organized a seminar on fast neutrons and their potential influence on the future of nuclear science development in March. The event was in the Physics department of University of Toronto.

A tour to McMaster Nuclear reactor and brand new post irradiation examination hot cell and electron microscopy facility (CANS) was organized on April 18th. The event received lots of attention and we had 30 participants.

This was a joint event with Physics Department at Ryerson University. CNS provided lunch ($200) and Ryerson University paid for the transportation ($800).

We are having another event in July and one in August. Our focus is to work more and more with universities and colleges and engage students and at the same time reduce our costs.

Durham Region Branch/Jacques Plourde and Nick Preston

A Lunch and Learn session was presented at the Darlington Energy Centre June 22nd on the subject of "Reactor Safety Gaurantees". About 20 participants attended the event, including 5 CANDU Energy staff via live webcast (using CNS' youtube channel). J. Plourde (CNS) and Mark Knutson (OPG's Chief Nuclear Engineer) also attended. There were questions about differences between the new GSSs approved or demonstrated at Darlington, as well as changes for U2 restart after Refurbishment. Feedback from participants was positive.

Further Lunch and Learn sessions are planned for Q3/4 this year.

Planning is underway for a Nuclear Job Fair held at UOIT to coincide with Nuclear Science Week this October.

Constantin Banica attended the AGM in Saskatoon June 3rd. He gave a summary presentation on behalf of the Durham Region Branch.

Western Branch/Matt Dalzell & David Malcolm

General

Several members of the Western Branch contributed to the CNS Annual Conference in Saskatoon, with Kurt Stoll and Matthew Dalzell serving on the Organizing Committee. Branch webmaster Arthur Situm ran the web-stream of the CNS AGM and Chary Rangacharyulu was elected to Council. It was great to welcome so many of our fellow CNS members to the Land of the Living Skies.

Outreach Activities

- Branch education coordinator Aaron Hinman represented the CNS at the Earth Science for Society Exhibition in Calgary March 18 to 20.

In May, Jason Donev made visits to a number of the potential NWMO host communities and First Nations in Northern Ontario including Hornepayne, Ignace and Manitouage, as well as Bruce County and Huron-Kinloss. Jason spoke at community meetings and almost every school in the towns where he visited.

Publications

The IAEA is pleased to announce the publications of:

Nuclear Power Plant Operating Experience

from the IAEA/NEA International Reporting System for Operating Experience 2012–2014

The International Reporting System for Operating Experience (IRS) is an essential element of the international operating experience feedback system for nuclear power plants. Its fundamental objective is to contribute to improving safety of commercial nuclear power plants which are operated worldwide. IRS reports contain information on events of safety significance with important lessons learned which assist in reducing recurrence of events at other plants. This sixth publication, covering the period 2012 – 2014, follows the structure of the previous editions It highlights important lessons based on a review of the approximately 240 event reports received from the participating countries over this period.

STI/PUB/1780, 53 pp.; 9 figs.; 2018; ISBN: 978-92-0-102417-6, English, 28.00 Euro

Electronic version can be found:

https://www-pub.iaea.org/books/IAEABooks/11154/Nuclear-Power-Plant-Operating-Experience

Medical Physics Staffing Needs in Diagnostic Imaging and Radionuclide Therapy: An Activity Based Approach

IAEA Human Health Reports No. 15

Over the last decades, the rapid technological development of diagnostic and interventional radiology and nuclear medicine has made them major tools of modern medicine. However, at the same time the involved risks, the growing number of procedures and the increasing complexity of the procedures require competent professional staff to ensure safe and effective patient diagnosis, treatment and management. Medical physicists (or clinically qualified medical physicists) have been recognized as vital health professionals with important and clear responsibilities related to quality and safety of applications of ionizing radiation in medicine. This publication describes an algorithm developed to determine the recommended staffing levels for clinical medical physics services in medical imaging and radionuclide therapy, based on current best practice, as described in international guidelines.

STI/PUB/1797, 23 pp.; 0 figs; 2018; ISBN: 978-92-0-107817-9, English, 20.00 Euro

Electronic version can be found:

https://www-pub.iaea.org/books/iaeabooks/12208/Medical-Physics-Staffing-Needs-in-Diagnostic-Imaging-and-Radionuclide-Therapy-An-Activity-Based-Approach

Physical Protection of Nuclear Material and Nuclear Facilities (Implementation of INFCIRC/225/Revision 5)

IAEA Nuclear Security Series No. 27-G

This publication is the lead Implementing Guide in a suite of guidance on implementing the Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13. It provides guidance and suggestions to assist States and their competent authorities in establishing, strengthening and sustaining their national physical protection regime and implementing the associated systems and measures, including operators' physical protection systems.

STI/PUB/1760, 120 pp.; 7 figs.; 2018; ISBN: 978-92-0-111516-4, English, 46.00 Euro

Electronic version can be found:

https://www-pub.iaea.org/books/IAEABooks/11092/Physical-Protection-of-Nuclear-Material-and-Nuclear-Facilities-Implementation-of-INFCIRC-225-Revision-5

GENERAL news

(Compiled by Colin Hunt from open sources)

Rumina Velshi Appointed New President and Chief Executive Officer for the Canadian Nuclear Safety Commission

The Canadian Nuclear Safety Commission (CNSC) announced on June 20 that Ms. Rumina Velshi has been appointed President and Chief Executive Officer (CEO) for a five-year term effective August 23, 2018.

Ms. Velshi replaces Dr. Michael Binder, who has served as President and CEO since January 2008.

Ms. Velshi brings to her new role extensive technical, regulatory and adjudication expertise in the area of energy. She has worked in various capacities at Ontario Hydro and Ontario Power Generation where, in her last role, she was Director, Planning and Control for the Darlington New Nuclear Project. Ms. Velshi currently also serves as a part-time Board member on the Ontario Energy Board, the economic regulator of the province of Ontario's electricity and natural gas sectors.

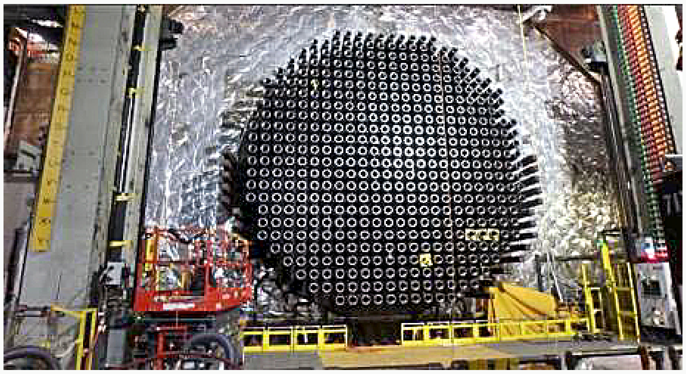
Ontario Power Generation Starts Rebuilding Darlington 2

Work has begun to reassemble Darlington unit 2, Ontario Power Generation announced yesterday. The 878 MWe Candu unit is the first of Darlington's four reactors to undergo refurbishment to enable it to operate for a further 30 years.

Refurbishment of Darlington 2 began in 2016 when the reactor was shut down and isolated from the operating station, after which it was defuelled. The reactor was then completely disassembled, with the last of the unit's 480 calandria tubes removed on 3 May.

Reassembly began with inspections of the calandria vessel - the tank which holds the reactor's core of nuclear fuel as well as the heavy water moderator - using a remotely controlled camera to allow viewing of key areas such as high stress welds, reactivity mechanisms and moderator nozzles to assess their integrity. These features of the calandria vessel can only be inspected when the fuel channels and other components have been removed.

Rebuilding of the reactor will begin with the installation of calandria tubes, fuel channel assemblies and lower feeders. In total, 58 connected systems will need to rebuilt in sequence, in a precision operation which will take about a year to complete.



The reactor face of Darlington 2 (Image: Ontario Power Generation)

The refurbishment project also includes the rehabilitation of steam generators, turbine generators and fuel handing equipment, as well as system improvements and plant upgrades to meet current regulatory requirements.

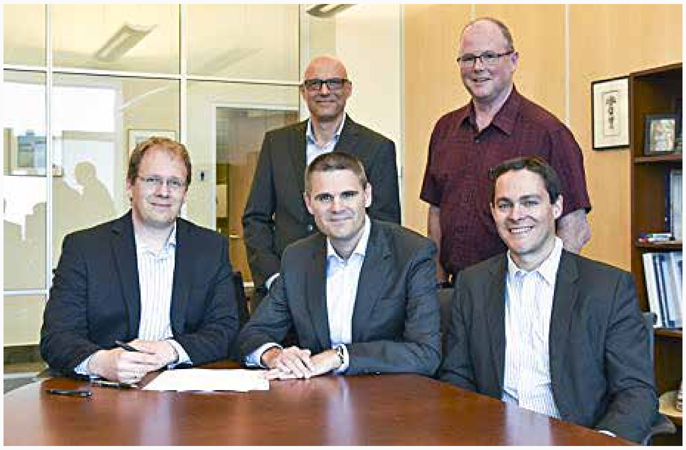
The CAD12.8 billion (USD9 billion) project to refurbish Darlington's reactors is scheduled for completion in 2026. Refurbishment of unit 3 is scheduled to begin after completion of work on unit 2 to allow the implementation of lessons learned.

Bruce Power and ITM to Supply Cancer Therapy Isotope

Bruce Power and ITG, a subsidiary of radiopharmaceutical technology company ITM Isotopen Technologien München (ITM), have launched a joint effort to explore the production of the medical radioisotope lutetium-177 (Lu-177) at Bruce Power's Candu reactors.

Lu-177 is used in targeted radionuclide therapy to treat cancers like neuroendocrine tumours and prostate cancer. The medical-grade radioisotope is used to destroy cancer cells while leaving healthy cells unaffected.

The companies yesterday announced the signature of a Memorandum of Understanding to explore the production of Lu-177 at Bruce, which they say has the ability to meet global supply needs until 2064. The



ITM's Mark Harfensteller, seated at left, signs the MoU with Bruce's James Scongack, front centre. Also shown are Bruce Power's Pat Dalzell at front right, with ITM's Ingo Russnak and Bruce Power's Kurt Wigle standing. (Image: Bruce Power)

partnership aims to meet the medical community's growing demand for the radioisotope. Development, processing, and global distribution of Lu-177 will be managed by ITG.

Bruce's CANDU units already produce cobalt-60, which is used for the sterilisation of medical equipment and in a specialised form of cancer treatment called the Gamma Knife. The company is part of the recently established Canadian Nuclear Isotope Council, which aims to develop collective solutions to maintain Canada's leadership position on the global isotope stage following the shut-down earlier this year of the National Research Universal reactor after over 60 years of operation.

Darlington to Supply Molybdenum-99

John McQuarrie, president of BWXT Canada, at the announcement of the collaboration (Image: BWXT)

Ontario Power Generation's (OPG) Darlington nuclear power plant is to produce molybdenum-99 (Mo-99) for use in new technetium-99m (Tc-99m) generators designed by BWX Technologies Inc. The Candu plant will be the first large-scale commercial nuclear power plant in the world to produce Mo-99, OPG said.

BWXT in May announced that it had developed an innovative process to produce Mo-99 for use in newly designed Tc-99m generators that are now in commercial development. A key element of the process includes the irradiation of molybdenum targets, for which BWXT requires a long-term, reliable and continuous supply. BWXT yesterday announced it had selected OPG subsidiary Canadian Nuclear Partners (CNP) to provide irradiation services and would now negotiate a definitive agreement.

Medical isotope targets can be inserted and removed from the Darlington reactors while they remain in operation, allowing for a continuous supply of the material. Use of Candu reactors - which use natural uranium fuel - also removes the proliferation risk associated with the conventional production of Mo-99 by the irradiation of enriched uranium targets.

Subject to regulatory approvals, production of Mo-99 is expected to begin at Darlington by the end of 2019.

Early Closure for Korea's Oldest Operating Reactor

Unit 1 of the Wolsong nuclear power plant will be retired prior to the expiration of its operating licence in 2022, Korea Hydro and Nuclear Power (KHNP) announced today as it also cancelled plans for four new reactors. The move is in line with the South Korean government's policy to phase out the use of nuclear energy.

State-owned KHNP said its board had made the

Wolsong unit 1 (Image: KHNP)

decision for the early closure of Wolsong 1 at a meeting today in Seoul. In a statement, the company said its decision was based on the "uncertain economic viability" of its continued operation and recent low operating performance. KHNP said it will "proceed with a follow-up process to acquire a licence under the Nuclear Safety Act to change [the unit's status] to permanent suspension of operation".

South Korean President Moon Jae-in was one of seven candidates in the May 2017 presidential election who signed an agreement in March for a "common policy" for phasing out the country's use of nuclear energy. At a ceremony last June to mark the permanent shutdown of Kori unit 1, he said plans for new power reactors will be cancelled and the operating periods of existing units will not be extended beyond their design life.

First AP1000 Unit Begins Generating Power

Unit 1 of the Sanmen nuclear power plant in China has been connected to the grid, becoming the world's first AP1000 to achieve grid connection and power generation. The milestone came just one day after Taishan 1, also in China, became the first EPR to reach the same milestone.

Sanmen units 1 and 2 (Image: CNNC)

Sanmen 1 was connected to the grid for the first time at 4.48pm on 30 June, Westinghouse and its Chinese customers China State Nuclear Power Technology Corporation and China National Nuclear Corporation have announced.

China's Taishan 1 Reactor Connected to Grid

China General Nuclear Power Group and EDF Group have today announced that unit 1 of the Taishan nuclear power plant has been connected to the grid, becoming the world's first EPR to achieve grid connection and power generation. It is expected to enter commercial operation later this year.

The Taishan project - 140 kilometres west of Hong Kong - is owned by the Guangdong Taishan Nuclear Power Joint Venture Company Limited, a joint venture between EDF (30%) and CGN. Unit 1 of the power plant started construction in 2009, followed by unit 2

A view inside Taishan 1, which is now connected to the grid (Image: CGNPC)

in 2010. These two units are the third and fourth EPR units under construction globally. The EPR design adopted in Taishan was developed by Framatome.

Zheng Dongshan, CEO of CGN UK, said: "Safe and efficient connection of the new Taishan 1 reactor to the grid is a major step forward in China, but is also important for the UK, where the same EPR technology will be used at Hinkley Point C and Sizewell C. The fact that an EPR power station has been linked to the electricity network for the first time reinforces our strong confidence in this reactor technology and in the HPC project as a whole."

Framatome said the unit had been connected to the grid at 5:59 pm local time.

Calendar

2018

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

CNS Speaking Tour in Britain

From Sunday June 10 to Saturday June 16, CNS Secretary Colin Hunt was the keynote speaker to the United Kingdom Nuclear Institute (UKNI). During the week, he gave presentations on the Canadian nuclear industry at five locations across the country.

Also included in the visit were several technical tours to Sellafield and the new nuclear reactor construction project at Hinkley Point C near Bristol. The tour also included two corporate sponsors: SNC-Lavalin Atkins and AECOM.

Shown below are some scenes from the tour.

The WAGR Boxstore, Sellafield. Colin Hunt, Alys Gardner and Sarah Beacock (left to right).

The world's first electric generation station, the control room of Calder Hall Unit 1, Sellafield. Left, Colin Hunt; Alys Gardner and Sarah Beacock, UKNI Chief Executive Officer, right.

Presentation at AECOM in Manchester on Friday, June 15. Colin Hunt (centre) and Alys Gardner (right).

Feasible Pathways to Better Nuclear Policy Outcomes

by NEIL ALEXANDER

When I moved to Saskatchewan to run the Sylvia Fedoruk Canadian Centre for Nuclear Innovation (Fedoruk Centre) I had to develop programs that would:

- Be sustainable whether or not Saskatchewan ever developed a nuclear power program
- Place Saskatchewan amongst global leaders in the nuclear field
- Offer value that might attract nuclear industry to Saskatchewan.

I am in no doubt that the expectation of both the supporters of the centre and the industry was that these objectives would be achieved through investment in equipment to support physical R&D in much the way that the University of Oregon became home to NuScale. But the circumstances in Saskatchewan were very different. It did not have a core nuclear capability (other than in fusion research) and there were no reactor developers lining up to settle in Saskatchewan unless it placed an order for a reactor.

So, it was that I went on the hunt for other capabilities that might meet all these objectives. As a fairly hardline physical scientist I held to the belief that social science was an oxy-moron and so was fairly slow to initiate contact with the Johnson-Shoyama Graduate School of Public Policy, hosted jointly by the Universities of Saskatchewan and Regina, despite its international reputation.

But when I did I quickly gained an understanding of just how important this science, that the nuclear industry seems to have largely ignored, could be to the future of our industry. I was pleased to be able to direct some of the Fedoruk funding to help set-up the Centre for the study of Science and Innovation Policy (CSIP). This centre is now looking at a range of diverse science policy issues, notably, Bioscience (including Genetically Modified Organisms), Digital Governance, Energy (with a specialism in nuclear) and Health and most importantly looking at the shared themes (of which there are many).

It was then, with some trepidation, that I attended this year's Canadian Nuclear Society conference where there were many keynote presentations from this centre's members. Would the rest of the industry recognise the value of this work? Would the centre be able to integrate with and become a permanent part of the Canadian Nuclear Industry? I should not have worried. Their new perceptions of our challenges and their application of existing knowledge about how policies develop enthralled.

All deserve a mention but it reached a zenith during Peter Philips' lunchtime address on the final day where he introduced us to the three faces of public policy;

- The consumer
- The citizen
- The Social animal

And more importantly he introduced us to the cognitive challenges of these groups with the warning that "education and evidence based advocacy is necessary but not sufficient, need to find ways to address the cognitive drivers of consumer choice".

One cognitive challenge that Peter drew our attention to is that while we might think risk is the product of hazard and exposure, societal risk has another multiplier; outrage. It is possible that I liked this because it was presented as an equation and like a visitor in a foreign country that had been enjoying the exotic food I had got to the point where I needed something I recognised. And I recognised the equation because it didn't seem to have people in it (except it did).

Outrage, he told us, is muted by things that are voluntary, familiar and predictable and is amplified by those that are involuntary, exotic or random. My interpretation of which is that we can tell people that nuclear is safe until we are blue in the face and it won't make a jot of difference because we score so highly on outrage.

The question is then how can we reduce the outrage? And that is a question that can't be answered by physical science or engineering. And it is the reason why we must welcome the social scientists into the camp.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