



The Science of Safety

CNSC Research Report
2017-18



The Science of Safety: CNSC Research Report 2017–18

© Canadian Nuclear Safety Commission (CNSC) 2019
Cat. No. CC171-24E-PDF
ISSN 2369-4351

Extracts from this document may be reproduced for individual use without permission provided the source is fully acknowledged. However, reproduction in whole or in part for purposes of resale or redistribution requires prior written permission from the Canadian Nuclear Safety Commission.

Également publié en français sous le titre : La science de la sûreté : Rapport de recherche de la CCSN 2017-2018

Document availability

This document can be viewed on the [CNSC website](#). To request a copy of the document in English or French, please contact:

Canadian Nuclear Safety Commission
280 Slater Street
P.O. Box 1046, Station B
Ottawa, Ontario K1P 5S9
Canada

Tel.: 613-995-5894 or 1-800-668-5284 (in Canada only)

Fax: 613-995-5086

Email: cnscccsn@canada.ca

Website: nuclearsafety.gc.ca

Facebook: [facebook.com/CanadianNuclearSafetyCommission](https://www.facebook.com/CanadianNuclearSafetyCommission)

YouTube: <http://www.youtube.com/cnscccsn>

Twitter: [@CNSC_CCSN](https://twitter.com/CNSC_CCSN)

LinkedIn: [linkedin.com/company/cnsc-ccsn](https://www.linkedin.com/company/cnsc-ccsn)

Publishing history

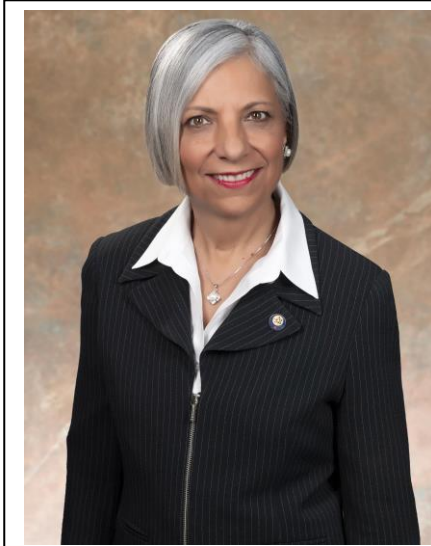
August 2019

Edition 1.0

Table of contents

Message from the President	1
Message from the CNSC’s Chief Science Officer	2
Introduction.....	3
Ensuring the safety of nuclear power plants	5
Protecting workers	8
Protecting the environment	11
Spotlight on CNSC staff	21
Advancing regulatory perspectives on new technology.....	22
International commitments	25
The next generation.....	31
Future research at the CNSC.....	35
Glossary of terms	36
Annex: CNSC technical papers, presentations and articles	37

Message from the President



Ms. Rumina Velshi, President and Chief Executive Officer

I am pleased to share the Canadian Nuclear Safety Commission's (CNSC's) fifth annual Science of Safety research report.

The Science of Safety report summarizes the research projects and initiatives that the CNSC supported during the 2017–18 fiscal year. This report and the regulatory research it outlines play an essential role in our continued fulfillment of our mission, which is to protect health, safety, security and the environment; to implement Canada's international commitments on the peaceful use of nuclear energy; and to disseminate objective scientific, technical and regulatory information to the public.

The CNSC has the important role of maintaining Canada's regulatory requirements while being responsive to emerging technologies. Regulatory research is essential in supporting regulatory activities, as it provides the necessary objective scientific information that forms the basis for regulatory decisions. Regulatory research also allows the CNSC to remain agile and able to respond to the regulatory challenges that the nuclear industry faces by helping technical experts understand new emerging technologies. Finally, it fulfills our mandate of

disseminating objective scientific, technical and regulatory information to the public through publications and participation at conferences and outreach events. The variety and diversity of achievements of the Research and Support Program allow us to maintain scientific integrity in all our operations. All regulatory activities, actions, recommendations and decisions are based on scientific information.

The aim of this report is to provide accessible information to the public so they can understand what we are doing to better serve as Canada's nuclear regulator. Reporting clearly to the public about our research program's important work allows the CNSC to maintain transparency while demonstrating the program's achievements. My hope is that it will reach a wide range of audiences, of all ages, genders and expertise, to give information about the work that the CNSC carries out to ensure that the safety of Canadians and the environment is never compromised. Many of the research projects and activities highlighted in this report have associated publications which are publicly available on our website and are posted in the form originally submitted by the authors. I invite you to read through the contents of this report and to explore the more detailed papers which the contents link to.

I'd also like to introduce the role of Chief Science Officer (CSO). This role was introduced to provide advice in support of the organization's regulatory activities to ensure that scientific information is always considered when it comes to making regulatory decisions.

Scientific information will always be the foundation of regulatory activities, actions, recommendations and decisions when it comes to protecting the health and safety of Canadians and the environment. That's the science of safety.

Rumina Velshi

President and Chief Executive Officer
Canadian Nuclear Safety Commission

Message from the CNSC’s Chief Science Officer



Mr. Peter Elder, Vice-President,
Technical Support Branch, and
Chief Science Officer

Science is the basis of the nuclear regulatory recommendations to the Commission. As the Vice-President, Technical Support Branch, and Chief Science Officer (CSO), my role is to provide technical services and advice in support of the organization’s regulatory activities. This includes the implementation and oversight of scientific integrity, which provides a framework to ensure that scientific information is always considered.

Scientific integrity is held in the highest regard by CNSC staff. This integrity is to be maintained by using science as a basis for all regulatory activities, actions, recommendations and decisions. The CNSC’s scientific expertise is drawn from experts in a wide range of fields, from physics and biology to human performance and cyber security. Experts within these fields apply their knowledge to support all CNSC regulatory activities. This knowledge is also used to help the CNSC disseminate objective scientific, technical and regulatory information to the public.

My vision is to make it transparent how science plays its role in the CNSC’s regulatory decisions. Regulatory research plays an important role at the CNSC, as knowledge and information is generated in support of the CNSC’s regulatory mission. Research conducted over the past fiscal year supplemented staff assessment capabilities and helped reduce uncertainties about health, safety, security and environmental issues.

The annual publication of this Science of Safety report further helps in the dissemination of information. In addition to the results obtained from original and collaborative projects, this report includes the knowledge shared by CNSC staff. The CNSC experts contribute their knowledge and research findings through publishing in peer-reviewed journals, participating in public information sessions, and contributing to public summaries of regulatory science on the CNSC’s website. This research report and its associated research projects have helped the CNSC become and remain a source of credible scientific, technical, and regulatory information.

Refer to the CNSC website for CSO presentations: [CNSC’s Chief Science Officer and the role of science](#).

Peter Elder

Vice-President, Technical Support Branch and Chief Science Officer
Canadian Nuclear Safety Commission

Introduction

Purpose of this report

A significant portion of the CNSC's mandate focuses on disseminating objective scientific, technical and regulatory information to the public. While information on the CNSC's research and research-related projects is publicly available online, the research documents contain technical and scientific language. *The Science of Safety: CNSC Research Report 2017–18* (Science of Safety Report) aims to summarize the research supported throughout the last year and present it to the public in order to make the results more accessible to a general audience. Terms that are underlined throughout the report are linked to their respective definition in the report's glossary.

Regulatory research

Knowledge gained from regulatory research can be applied to support regulatory decisions, identify unforeseen hazards, and to develop tools and procedures to address those emerging issues. These tools and procedures ensure that the health, safety and security of Canadians are protected. They are also used to create effective safety standards both domestically and internationally.

The three main objectives of the CNSC's research program are to:

- seek independent advice to support regulatory decisions
- develop the tools needed to address health, safety, security or environmental issues
- develop nuclear safety standards

These objectives can be further defined into 10 research goals:

- to strengthen the CNSC's licensing, compliance and regulatory framework in preparation for long-term/post-refurbishment operation of Canadian nuclear power plants
- to enhance the CNSC's capability to independently assess hazards and to analyze/respond to severe reactor accidents
- to support CNSC staff in preparing and conducting vendor design reviews
- to enhance the CNSC's understanding of the environmental transport and behaviour of hazardous/nuclear substances and associated environmental exposures
- to inform the CNSC's radiation protection knowledge base to reflect the best available science with respect to the protection of workers and the public
- to support CNSC staff in evaluating licensing applications or other submissions related to waste repositories
- to further the CNSC's understanding of the long-term behaviour of uranium mining and milling waste
- to support Canada's safeguards commitments and international safeguards efforts to strengthen Canada's nuclear forensics capability
- to support development of standards for nuclear safety and security
- to support capacity building, outreach and safety promotion

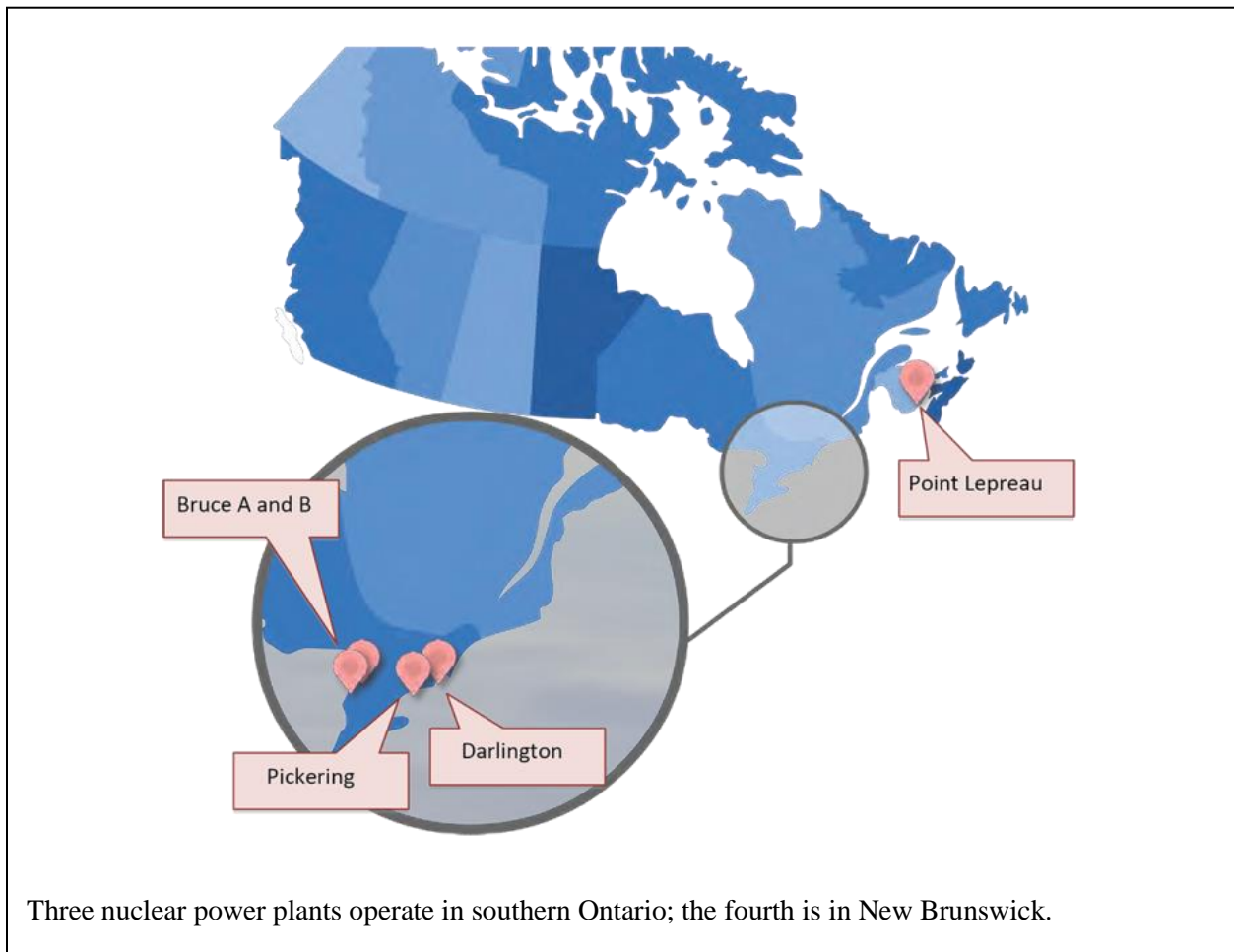
In addition to these research goals, the research is also linked to the CNSC's Safety and Control Area Framework. The safety and control areas are used to evaluate how well licensees meet regulatory requirements and safety performance standards. More information about this framework can be found on the CNSC website.

Each chapter of this report summarizes all the research projects and similar work completed by the CNSC from April 1, 2017 to March 31, 2018. You can find links to these summaries and the previous Science of Safety reports on the CNSC's [Scientific and technical information](#) web page.

Ensuring the safety of nuclear power plants

The CNSC's Research and Support Program plays an important role in supporting nuclear power plant regulation. The following research summaries describe projects undertaken or further developed this past fiscal year to make sure the four operating plants – and their structures, systems and components – in Canada (Figure 1) continue to operate safely throughout their lifetime.

Figure 1: Locations of the four nuclear power plants in Canada



Analysis of degradation mechanisms of cable insulation due to aging in a decommissioned nuclear power plant

Electrical cables in nuclear power plants deteriorate with time because of their surrounding environmental conditions. Temperature and radiation dose are two main factors that contribute to this degradation. This CNSC project explored the aging (including the environmental qualification¹) of cable insulating materials occurring under both laboratory and operational conditions.

The conclusions of this report elaborate on the condition of cables, predict remaining [service life](#), and validate assumptions made during the initial environment qualification process. Hydro-Québec's Gentilly-2 Nuclear Facilities² provided the electrical cable samples needed for this study. Samples at a greater distance from high-radiation spots show less damage and degradation versus those closer to terminals, high-radiation zones and splices. Polyvinyl chloride insulation used for cables has shown signs of greater deterioration at terminals of instrumentation equipment. Depending on cable insulation materials and environmental conditions, some cables have been found to be at or past the end-of-service life, while other cables still have additional service life. The majority of cables indicated that the extent of the damage was in agreement with initial assumptions. However, cables in environmental conditions that were harsher than initially expected showed signs of high degradation. This helps to determine the remaining cable service life and evaluate assumptions made per environmental qualification process.

This study provides a basis for engineering assumptions and for monitoring, testing and maintenance activities related to cables. Cable analysis can be used to improve the use and replacement of electrical cables to ensure the safe functioning of nuclear power plant equipment.

The final publication will be available on the CNSC website later this year.



Removal of cable samples from the Gentilly-2 Facilities to be used for verifying initial assumptions. This is one of the locations within the site where samples have been extracted for this study.

¹ An environmental qualification program tests different required structures, systems and components – such as cables – to make sure they are capable of performing their designated safety functions in a postulated harsh environment resulting from an accident.

² Formerly called Gentilly-2 Nuclear Generating Station, the facility is now permanently shut down.

Analysis of packages used to identify and rank severe irradiated fuel bay accidents

Once safely removed from a nuclear reactor, used fuel is stored in an irradiated fuel bay. The pool water in the fuel bay keeps the used fuel cool and acts as a shield from the radiation (see “Did you know?”). The Fukushima Daiichi accident prompted the CNSC to review its own capabilities to independently model accident scenarios that would apply to a CANDU irradiated fuel bay.

The research aims to ultimately develop improved computer codes for better understanding of the existing safety margins. The CNSC sponsored this research project because better understanding of the safety margins required for maintaining safe storage of used fuel means that better models can be developed for preventing or mitigating a hypothetical irradiated fuel bay severe accident.

To achieve this understanding, all relevant data must first be gathered on fuel bays and their associated progression in a severe loss-of-coolant accident. This data package is known as phenomena and key parameter identification and ranking tables. Once the data is gathered, technical experts analyze the accident phenomena and rank them based on importance and knowledge of them. They then evaluate all the data for those phenomena that are ranked as most important to see if more research is needed in the areas. A great deal of information for high-importance phenomena is desirable for creating a highly accurate and detailed computer model. Lower-ranked phenomena need less as they have a smaller impact on the results.

The final report contains a breakdown of the 86 phenomena studied and shows how they were ranked in terms of importance and amount of data available. Of this total, 37 were ranked high in at least one phase and 21 ranked as medium. This analysis helps to show which phenomena are complex and need more attention, and also illustrates to the industry which areas lack information and will need further research. New, accurate codes are needed for further understanding the existing safety margins, and results from this analysis will also help development of these codes. International and domestic partners have also expressed interest in the data from this research project, as it can form part of the reference material needed for future code development.

Refer to the CNSC website for the final report: [RSP-602.2, Phenomena Identification and Ranking Table for a Severe Accident in a CANDU Irradiated Fuel Bay](#).

Did you know? After being removed from a reactor, used fuel bundles are stored in the fuel bay. The bays are typically six to eight metres deep, three metres deeper than Olympic swimming pools. The amount of water covering the fuel shields workers from the radiation dose they could otherwise receive.



A typical Canadian irradiated fuel bay.

Protecting workers

Canada's laws on the use of nuclear energy, together with the CNSC's strict oversight of licensed facilities and activities, are designed to ensure that nuclear industry workers are protected from work-related hazards. These include traditional hazards such as electrical, fire and tripping, as well as radiation hazards, which are related to the amount of radiation an exposed worker may receive.

Research provides evidence-based opinions that keep industry up to date on information and technological developments that may affect workplace safety procedures and equipment. Through amendments to policies and procedures as new developments arise in workplace safety, the risk associated with workplace hazards can be minimized.

The summaries in this section highlight two projects completed during the last fiscal year that show how the CNSC supports safe workplaces.



In coordination with its licensees and federal and provincial emergency and health partners, the CNSC participates in simulated incidents to evaluate and improve emergency response capabilities. Regular drills are conducted to evaluate licensee response actions, give technical advice, and grant regulatory approval when required. Experience from the drills can highlight new elements to incorporate into the emergency response plan, ensuring that industry workers are informed of the latest developments in safety procedures and equipment. Above, members of a fire response team conduct a fire drill exercise at Point Lepreau Nuclear Generating Station.

State of policies and practices on substance use in safety-sensitive industries in Canada

An effective fitness-for-duty program is an important aspect of maintaining nuclear safety and security. The CNSC's REGDOC-2.2.4, *Fitness for Duty, Volume II: Managing Alcohol and Drug Use*, provides requirements and guidance for managing a fitness-for-duty program specifically relating to alcohol and drug use and abuse. REGDOC-2.2.4 includes provisions for alcohol and drug testing under a range of circumstances, such as preplacement and random testing. Based on feedback on the draft of this document, CNSC staff requested the assistance of the Canadian Centre on Substance Use and Addiction (CCSA) to enhance staff's understanding of best practices in substance abuse evaluation, the qualifications required for an individual to be considered a substance abuse expert, and the prevalence of substance abuse in communities where a nuclear facility is located. CNSC staff established a memorandum of understanding with the CCSA to further understand the concerns about the potential effect that cannabis legalization could have on safety in Canadian workplaces.

The CCSA based its analyses on a 20-question custom-developed survey that was sent to several hundred Canadian organizations in various safety-sensitive industries. These industries included aviation, construction, law enforcement, marine, oil and gas, and rail. In total, 87 respondents completed the survey and 12 key informant interviews were conducted. The CCSA also analyzed existing survey data from provincial and federal agencies (such as the Canadian Tobacco, Alcohol and Drugs Survey and the Centre for Addiction and Mental Health Monitor) to understand the prevalence of alcohol and drug use in communities surrounding nuclear facilities.

The CCSA also conducted a legal analysis to determine the qualifications required for an individual to be accepted as a substance abuse expert by Canadian courts and adjudicators. The report noted that employers generally rely on the expertise of physicians, psychiatrists, counsellors or other professionals for conducting substance abuse evaluations. However, it advised that employers "use what adjudicators would consider an 'expert', namely a physician or psychiatrist with a specialization in addiction medicine and ideally occupational medicine" to perform substance abuse evaluations.

The researchers also examined potential effects of the legalization of cannabis based on data from the U.S. states of Colorado and Washington, where the substance was recently legalized. The effectiveness of substance testing on the workplace was examined to understand potential impacts on workers.

Through this research, the CNSC gained a better understanding of best practices in substance abuse evaluations. The CCSA's report provided CNSC staff with the necessary insight on policies and procedures across safety-sensitive industries, which will strengthen the Canadian regulatory framework. The report will be used to improve fitness-for-duty programs through the implementation of REGDOC-2.2.4 and will inform the CNSC's compliance oversight strategy.

Refer to the CNSC website for the final report: [RSP-673.1, *State of Policies and Practices on Substance Use in Safety-Sensitive Industries in Canada*](#).

UNSCEAR 64 support

The CNSC provided travel support to the Canadian delegation participating in the 64th session of the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), specifically for Dr. Paul Demers of Cancer Care Ontario. Dr. Demers is an expert in epidemiological studies associated with cancer and radiation exposure. This funding activity demonstrates the CNSC’s commitment to support international scientific committees on radiation and its health effects.

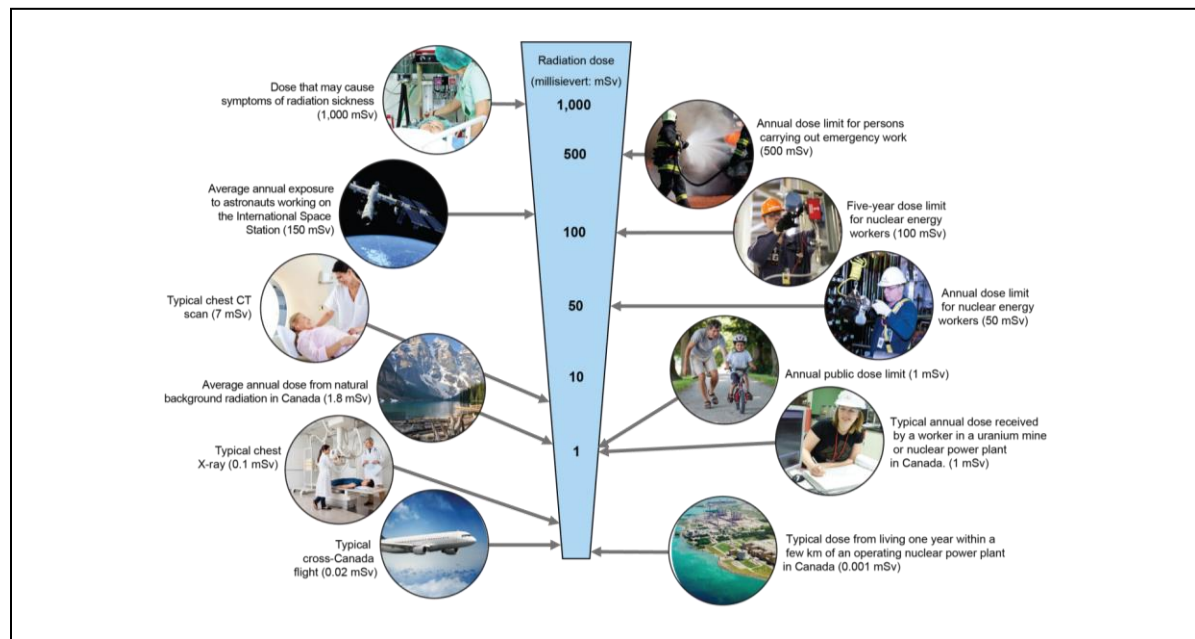
UNSCEAR publishes reports that are used globally as a scientific basis for evaluating radiation risk. Its scientific committees review developments in radiation and health sciences so that their reports and publications reflect the latest international consensus on the state of the science. The CNSC uses this information to improve its regulation of nuclear activities in Canada.

Dr. Demers participated in, and contributed expertise to, the session on the risk of cancer due to low-dose-rate radiation from environmental sources. He completed reviews on this topic and on quality criteria for epidemiological studies, and provided them to the Canadian delegation lead before the meeting; the studies are in the scientific annexes of the final report. Dr. Demers also supported the Canadian delegation during the plenary sessions and associated discussions. In these discussions, delegates addressed the above documents, updates to the level and effects of radiation exposure due to the nuclear accident in Japan in 2011, and the evaluation of thyroid cancer data in regions affected by the 1986 nuclear accident in Chernobyl.

The CNSC’s continued support of UNSCEAR plays an important role in ensuring that regulation of nuclear activities in Canada is based on the latest accepted science with respect to radiation and its health effects on workers and the public. The CNSC infographic on radiation and related dose limits (Figure 2) shows just one way that the CNSC keeps Canadians informed about the results of this research.

Refer to the UNSCEAR website for the final report, including the annexes: [Sources, Effects and Risks of Ionizing Radiation: UNSCEAR 2017](#).

Figure 2: Examples of radiation and radiation-related dose limits in Canada



Protecting the environment

The CNSC monitors every facility that it licenses to ensure that the licensees uphold their commitment to the environment. Protection of the environment is a key part of the CNSC's mission, and licensees must demonstrate that they are not harming the environment while carrying out licensed activities. While licensees must implement their own environmental monitoring program, the CNSC independently monitors the environmental impacts of the same licensed activities. This continuous monitoring reduces the risk of harming the environment.

The projects in this section were supported by the CNSC to further develop environmental science and waste management techniques to ensure that the safety of the environment is not compromised by nuclear activities.



A CNSC employee takes a soil sample near Point Lepreau for the CNSC's [Independent Environmental Monitoring Program](#).

Establishing environmental recovery baselines at the Elliot Lake historical mine sites

The CNSC expects state-of-the-art decommissioning of uranium mining and milling facilities, based on stringent decommissioning objectives set out in the *Nuclear Safety and Control Act*, regulations made under the Act, and licence conditions established with the site owners. These licensees are also required to monitor recovery of the environment downstream to confirm the success of the decommissioning. An environmental recovery is considered successful when the level of contaminant in the receiving environment is similar to levels stated in the decommissioning objectives. In most cases, the overall objective is to reduce concentrations of radionuclides and metals to levels that are comparable to natural conditions that existed before activities began.

Where mining operations – such as those at Elliot Lake – started over 50 years ago, it is difficult to determine what the natural concentrations of contaminants were at that time. However, they can be closely estimated.

For a contaminated water course, specialists can estimate natural concentrations by measuring metal and radionuclide concentrations in water from an adjacent, uncontaminated environment. For this study, specialists took their water samples from the uncontaminated Mississagi River watershed to estimate the natural content of metals and radionuclides that were likely encountered in the surface water of the Serpent River watershed before contamination from the Elliot Lake operations.

As for estimating the natural concentrations of contaminants in sediments, it is known that contaminated sediments accumulate on top of uncontaminated ones during mining operations. Specialists gathered sediment core samples to see what insight they could offer on changes to environmental contamination due to mining operations. By examining concentrations of metals and radionuclides in deep sediment layers, the specialists were able to estimate the natural concentrations of metals and radionuclides in sediments prior to mining activities.

These combined approaches helped in estimating the pre-mining concentrations – the baseline – of metals and radionuclides in both water and sediments in Elliot Lake. The baselines estimated by this study will guide the CNSC in evaluating environmental recovery in the Serpent River Watershed.

Refer to the CNSC website for the final report: [RSP-692.1, *Environmental Recovery at the Elliot Lake Historical Mine Sites*](#).

Modelling thermal, hydraulic, mechanical and chemical processes in rock and clay seals

Deep geological repositories are being considered as a long-term solution for the disposal of radioactive waste. Such a facility would rely on a [multiple-barrier system](#) for the long-term containment and isolation of the waste. The host rock formations and clay seals are important components of this multiple-barrier system. The CNSC undertook this research to support its independent reviews of repository proposals like Ontario Power Generation’s deep geologic repository for low- and intermediate-level waste.

In this research, specialists conducted comprehensive investigations on the different changes that might occur in the rock and seals, that is, the thermal, hydraulic, mechanical and chemical (THMC) processes that might influence the short- and long-term performance of these barriers. The study focused on the stability of the waste placement rooms, as well as the vertical shafts that are viewed as the potential route for the upward migration of waste gases and pollutants.

Mathematical models of coupled THMC processes were developed using experimental data from research laboratories. This work included studies of effects on shale samples and Cobourg limestone; swelling tests on MX-80 bentonite seal materials infiltrated with brine (see “Did you know?”); and a heater experiment involving THMC processes in both bentonite seals and [argillaceous](#) rock.

Using the knowledge gained from the above experiments, researchers performed scoping analyses of coupled hydraulic and mechanical processes for the proposed deep geologic repository site. The assessment shows that the rock formations around the repository would retain their effectiveness in containing radionuclides, both in the short and long terms, despite the disturbances created by excavation, gas generation and a future glacial cycle.

This project provided CNSC staff with an enhanced understanding of THMC processes in bentonite seals and rocks to assess the long-term safety of geological repositories.

Refer to the CNSC website for the final report: [RSP-413.7, *Modelling Thermal-Hydraulic-Mechanical-Chemical Processes in Rock and Seals for Deep Geological Disposal*](#).

Did you know? MX-80 is a commercial product of Wyoming bentonite marketed by the American Colloid Company. It is a blend of several natural sodium [bentonite horizons](#) that is mined, dried and milled to millimetre-sized grains and has high [smectite](#) content. It has a high ability to swell in water and gives good [colloidal](#), plastic, bonding and low [permeability](#) properties. MX-80 can be used as buffers and seals in the geological disposal of radioactive wastes to limit radionuclide migration, and as a base liner for landfills to contain water, [leachates](#), or other liquids and gases.



CNSC and International Atomic Energy Agency (IAEA) representatives visit Cantley Quarry to look at the effects of glacial erosion. Cantley is located in Quebec, Canada, where the effects of glaciers are showcased well with this image showing [glacial striations](#) caused by moving glaciers. Studies into past glacial movement may offer insights into how a future glacier could impact the safety of a deep geological repository for long-term storage of radioactive waste.

Upgrading safety assessment codes for nuclear waste disposal facilities

The CNSC has developed a computer code, DOC-WMF, which can be applied to improve dose calculations for various types of waste repositories. High precision is desired in these calculations to ensure that the facilities are safe for workers, the public and the environment.

DOC-WMF builds upon the U.S. Nuclear Regulatory Commission's dose calculation code SOAR, by expanding the list of radionuclides and increasing the exposure pathways. Specialists have verified the code's reliability by comparing the dose estimates from DOC-WMF with those from other models in two case studies, one a hypothetical deep disposal facility and the second a near surface disposal facility. Comparisons between DOC-WMF and other models found similar doses in both cases.

Licensees who submit applications for such facilities will require verification and validation of the information given in support of their application. CNSC staff can use this code to support their evaluation of licensees' dose calculations for waste repositories.

Refer to the CNSC website for the final report: [RSP-613.6, Safety Assessment Code Development and Application.](#)

Implications of the effect of microbes in the management of radioactive waste

Deep geological repositories have long been studied as an option for the disposal of low- and intermediate-level waste. Figure 3, found on the next page, shows a representation of a proposed deep geologic repository. Before regulatory approval of such disposal methods can be granted, the licence applicant must develop conservative models that show they will ensure the long-term safety of people and the environment.

But it's not "just" rocks that scientists need to examine. Did you know that the study of the effects of microbes plays a significant role in evaluating the safety of a deep geologic repository? The CNSC funded this project to learn more about how microbial activity can affect the long-term containment and isolation of radionuclides within low- and intermediate-level waste in such repositories, particularly the effects of this activity on shaft seals and host rock.

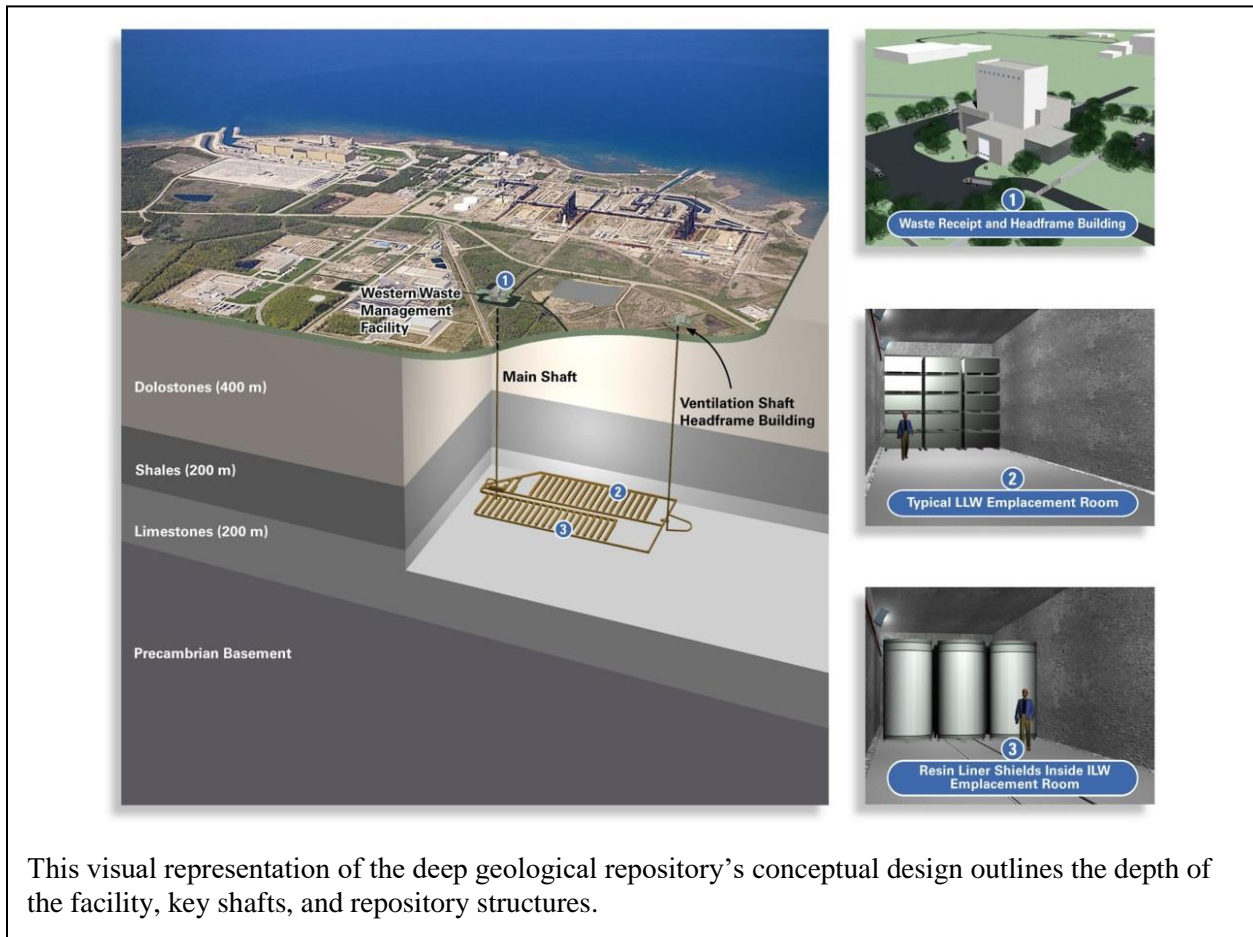
The study indicates that the breakdown of organic materials by microbes produces gases and acids. Pressure buildup in repository caverns by gases decreases the rate at which water infills the rock caverns that host the waste. The delay in water flooding of the rock caverns lengthens the isolation and containment time of water-soluble radionuclides. This is a desirable condition, as the time required for radionuclide transport through the rock will increase.

Microbial breakdown of organic material contained in waste also produces acids that could deteriorate host bedrock and shaft seals meant to isolate and contain radioactive waste. The study suggests further analysis of microbes in actual storage containers may help gauge the long-term impact of gases within a deep geologic repository.

Models used to predict shaft seal and host rock scenarios can be updated with the information on the effects of microbial activity gained by this project to help create an adequate margin of safety for the repositories' lifetime.

Refer to the CNSC website for the final report: [RSP-613.2, Gas Generation From Organic Waste Over a Seven-Year Period: Implication for the Management of Low- and Intermediate-Level Radioactive Waste.](#)

Figure 3: Visual representation of proposed deep geological repository



This visual representation of the deep geological repository’s conceptual design outlines the depth of the facility, key shafts, and repository structures.

Support for the Sustainable Network for Independent Technical Expertise (SITEX) for radioactive waste disposal – 2nd phase complete

The Sustainable Network of Independent Technical Expertise for radioactive waste disposal (SITEX) (2012–13) and SITEX II (2015–17) are European Union–supported projects aimed at addressing the safety issues for the long-term management of high-level radioactive waste that is faced by the nuclear industry globally.

The second phase of the SITEX project was completed this past fiscal year. The goal of SITEX II was to build on the success of SITEX I and develop an expertise network aimed at harmonizing activities related to independent technical expertise of safety for deep geological repositories. SITEX II included representatives from 18 organizations, including regulatory authorities, technical support organizations, research organizations and [civil society organizations](#). Here’s a snapshot of achievements made during SITEX II:

- A strategic research agenda was developed to implement research on radioactive waste disposal to enhance knowledge and expertise for safety case reviews.
- Participants prepared several regulatory position papers on optimization, site characterization, and waste acceptance criteria.
- They also developed several guidance documents on the technical review of safety cases, and developed training modules and tested them in a training workshop hosted by SITEX for general experts involved in the safety case review.
- Finally, workshops were organized that promoted interaction with civil society in the framework of geological disposal.

With the conclusion of SITEX II, project participants expressed interested in formalizing the SITEX Network. The network would continue international cooperation to develop high-quality expertise in the field through four main activities: research and development related to waste management safety; promotion of interaction with civil society organizations; activities related to safety case reviews; and development of professional capabilities through seminars and site visits, such as the Underground Research Laboratory.

Refer to the [SITEX II website](#) for the final report.

Did you know? The Nuclear Waste Management Organization (NWMO) is carrying out a site-selection process to look for potential host sites for a deep geological repository for Canada’s used nuclear fuel. Currently, five sites remain in the NWMO’s site selection process. Three are in the Canadian Shield and are made up of ancient Precambrian rock. The other two are located within Paleozoic-age sedimentary rocks. Factors affecting the long-term stability of the host rock – such as seismic hazards, future glaciation, permeability, and climate change – must be considered when choosing a site. Research conducted on Precambrian and Paleozoic rocks has indicated that they have ideal properties for long-term stability as host rock for a deep geological repository.

IAEA technical meeting on the *Roadmap for Developing a Geological Disposal Facility*

The IAEA Underground Research Facilities Network for Geological Disposal encourages the global development of safe, sustainable and effective geological disposal programs. As a member of this working group, the CNSC helped to create a draft document outlining the roadmap for developing a geological disposal repository for the long-term management of intermediate- and high-level radioactive wastes. The document will provide general guidance to IAEA Member States.

The CNSC hosted a technical meeting at its headquarters of working group representatives to continue work on the draft document, titled *Roadmap for Developing a Geological Disposal Facility*. The meeting collected and discussed Member States' valuable feedback on the document and the extent of the generic plan for a geological disposal program. Besides reviewing the draft document and holding group discussions, meeting participants spoke on the development and implementation of national geological disposal programs.

The working group used the feedback from Member States on the roadmap document to develop a better generic plan for the development and implementation of a geological disposal program. The roadmap document will support the CNSC in evaluating the development of geological disposal programs in Canada.



Participants of the IAEA working group working on the draft *Roadmap for Developing a Geological Disposal Facility*.

Validating international models against experiments - DECOVALEX

The CNSC is one of 11 member organizations participating in the DEvelopment of COupled models and their VALidation against Experiments (DECOVALEX) project. DECOVALEX is an international cooperative whose member organizations contribute funds and expertise to support improvement in the understanding of the long-term performance of engineered and geological barriers for deep geological repositories. This past fiscal year, the CNSC participated in the third meeting, held in Stockholm, and hosted the fourth meeting in Kingston, Ontario.

In both meetings, the CNSC provided updates on two tasks in which the CNSC is involved. The first task is to model the gas flow through low-[permeability](#) materials. The second is an experiment that models a fault slip due to water injection in an [argillaceous rock](#) formation. Preliminary results from both tasks and their associated models resulted in similar data when compared to those of experimental data.

The fourth meeting allowed the CNSC access to experimental data and comparisons of various models, and to a peer review of the CNSC's research results by international experts. Also presented was a summary of all the [CNSC's regulatory research activities related to the geological disposal of radioactive waste](#), available on the CNSC website.

The CNSC's participation in this cooperative effort will provide staff with the latest developments in this field. The studies have yielded the technical basis to assess submissions related to deep geological repositories.



Participants pause for a group photo at the DECOVALEX meeting in Kingston, Ontario.

Spotlight on CNSC staff

Quanmin Lei, PhD



Dr. Quanmin Lei, Technical Specialist in the CNSC's Technical Support Branch.

The knowledge and expertise of many individuals, including Dr. Quanmin Lei, are needed to support the CNSC's operational work. Dr. Lei is able to draw from a strong technical background through his BSc and MSc in agricultural engineering and his PhD in mechanical engineering. Over 28 years, his work in the CANDU nuclear industry and for the CNSC has equipped him with expert-level knowledge and capability to review and assess safety measures for preventing and mitigating accidents, including severe accidents in nuclear power plants. He has been a key resource with much understanding of severe accident phenomena, progression and consequences, and is capable of performing severe accident simulation, diagnosis and prognosis.

Dr. Lei's experience before joining the CNSC gave him strong industrial experience that has allowed him to excel in his regulatory contributions. He held various technical specialist and managerial positions at Atomic Energy of Canada Limited (AECL), OPG, and Nuclear Safety Solutions. During his term at AECL, Dr. Lei developed and applied his expertise in the areas of fuel, fuel channel, thermal-hydraulic safety analyses and severe

accident safety assessments. At OPG, he utilized his skills in code development and numerical methods to provide technical reviews and safety assessments of fuel and fuel channels for licensing and safety compliance. From Nuclear Safety Solutions, Dr. Lei gained experience with safety assessments for postulated scenarios of dry storage containers.

Dr. Lei joined the CNSC in 2012 as a Technical Specialist in the Reactor Behaviour Division. Drawing from his education and industrial expertise, he has performed technical reviews on licensees' submissions, contributed to developing regulatory documents, participated in international activities and projects, and directed severe accident R&D. Accident management is important to the CNSC because it helps its licensees implement necessary safety measures to prevent accidents, as well as mitigation measures in the event of an accident. Dr. Lei reviewed the post-Fukushima international requirements and practices related to accident management and took a lead role in developing the CNSC's REGDOC-2.3.2, *Accident Management*, which reinforced the CNSC's regulatory framework. His expertise was also called upon for international work through the Nuclear Energy Agency for the working group on analysis and management of accidents. He led an international task group to produce a state-of-the-art report on informing severe accident management guidance and actions through analytical simulation. Dr. Lei's contributions have helped the CNSC maintain its safety culture by ensuring that staff are informed of the latest developments in accident management.

By applying his experience with both industry and the CNSC, along with his knowledge of fundamental physics, engineering principles, accident phenomena, progression and simulation, Dr. Lei has greatly advanced the CNSC's nuclear safety standards to uphold the organization's mandate. His continual efforts have won him several CNSC awards, as well as international recognition for his efforts in the Working Group on Analysis and Management of Accidents, Nuclear Energy Agency, and Organisation for Economic Co-operation and Development.

Advancing regulatory perspectives on new technology

The CNSC maintains a strong regulatory framework by developing its perspective through R&D in science. The Research and Support Program promotes sharing of this knowledge with international partners so that regulators can implement the highest standards. Through international collaboration on advanced nuclear technologies and the insight gained into issues experienced internationally, the CNSC can continuously improve its regulatory framework based on scientific information. In doing so, the CNSC is always prepared to respond to the regulatory challenges that come with new technologies.

The projects outlined in this section support the maintenance of standards relating to advanced nuclear technologies.



The Sixth Technical Meeting on CANDU Probabilistic Safety Assessment (PSA) was organized by the IAEA and hosted by the CNSC in October 2017. The purpose of this meeting was to facilitate information exchange and harmonization of PSA practices among the seven member countries that operate CANDU-type reactors. The meeting included participants from the CNSC, Argentina, China, India, Korea, Pakistan, Romania.

Molten Salt Reactor Experiment design overview and operating experience

During the 2017–18 fiscal year, developers involved in modern molten salt reactor (MSR) technology showed increased interest in the CNSC’s pre-licensing vendor design review (VDR) process. In response to this interest, the CNSC contracted Oak Ridge National Laboratory (ORNL), an R&D facility of the U.S. Department of Energy, to develop and present an information session about its historic MSR program. That program ran from 1946 to 1969 and is now being revived through work between technology developers and the U.S. Government. A number of the new developers are using scientific information and experience from the ORNL prototype reactors, in particular the Molten Salt Reactor Experiment (MSRE), which operated throughout the 1960s as a fuel and materials test facility. The CNSC uses contracts such as this one to support ongoing technical readiness to license projects that may include new technologies such as MSR.

CNSC investigations into MSR technologies noted many possible plant configurations, all of which would use one or more types of molten salt to carry the heat away from the fission reactor for different uses, such as electricity production and process heat. All currently operating nuclear reactors need a coolant to control the heat produced by the fuel. One reason that developers choose this option is because molten salts have a significantly higher boiling point at atmospheric pressure than light or heavy water (the usual reactor coolant), which needs to be kept at a very high pressure to stay liquid at high temperatures. This means that, when used as a coolant, the molten salt would continue to effectively cool the reactor in a liquid state far above temperatures where water would have flashed to steam – thereby making a reactor more resilient against high-temperature accident events. In addition, experiments have shown that MSRs have varying degrees of [inherent](#) and [passive behaviours](#) that may make them more resistant to conditions that have contributed to accidents.

MSR designs being developed range from traditional solid fuel designs using a molten salt coolant to modern variants of the MSRE concept that would employ a molten salt coolant with fissile material in the salt (fissile salt) rather than using traditional solid pellet fuel.

New R&D work by developers and research institutions around the world are continuing the work started by ORNL, and developers and researchers have been participating in international efforts such as the Generation IV International Forum. As technology developers continue to engage with the CNSC in the [pre-licensing vendor design review process](#), the CNSC is also engaging with R&D organizations and new reactor technology forums to supplement knowledge on new technological developments and best practices for new technologies. This will ensure that the CNSC has the best knowledge for making informed decisions should developers apply for a licence that involves use of MSR technology.

Did you know? A molten salt reactor was the design basis for the United States Air Force’s Aircraft Reactor Experiment (ARE). ARE testing was done from 1954 to 1957 to see if nuclear power could be used to power an aircraft. Due to difficulties in assuring safety throughout the flight, the project was discontinued. However, the reactor was able to safely reach an impressive 860°C.

The plane was powered by jet and propeller engines, with 47 recorded flights made between 1955 and 1957. Throughout each flight, the reactor did not power the plane but was turned on to collect data to determine if a nuclear reactor was a feasible method for powering planes. In the end, safety and budget concerns led to discontinuation of the project, as it became impractical to use nuclear power as a propulsion method. Improvements in conventional aircraft and in engine design were another reason to stop the project.

Technical seminar on the American Society of Mechanical Engineers construction requirements for high-temperature reactors

In 2017–18, the CNSC participated in the American Society of Mechanical Engineers (ASME) Section III Division 5 High Temperature Reactor Technical Seminar.

The CNSC is reviewing [small modular reactor](#) designs, which operate at higher temperatures than water-cooled reactors such as the CANDU reactor. At these temperatures, failure modes and mechanisms will be different, and ASME Section III Division 5 is being used as a basis for the design phase. The CNSC participates in these technical seminars to further develop its expertise on important aspects of design and damage assessment of pre-licensing vendor design reviews of high-temperature reactors.

The technical seminar presented CNSC staff with an overview of Division 5 requirements, differences in design principle and the technical basis for how the requirements relate to structural integrity of high-temperature reactors. The design requirements affect safety areas of interest, in particular material choice, fabrication and installation, testing, overpressure protection and quality assurance of components.

Over the two days, seminar participants presented relevant information that will assist CNSC staff in conducting pre-licensing vendor design reviews of small modular reactors.

Refer to the CNSC website for the seminar's presentations: [RSP-688.1, *Elevated Temperature Service, Graphite Materials \(1\), Graphite Materials \(2\), High Temperature Reactors, Materials.*](#)

International commitments

The benefits of the CNSC’s research often go well beyond the domestic scene. The organization also collaborates with international organizations such as UNSCEAR, the Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA) and the IAEA. This collaboration facilitates the exchange of information and, ultimately, the expansion of the knowledge base that participants use to inform and implement regulatory decisions.

This section describes the international initiatives in which the CNSC has been involved during the last fiscal year.



At the IAEA’s annual general conference, Member States discuss issues raised by the Board of Governors, Director General and Member States. The photo shows the Canadian delegation at the IAEA’s 61st General Conference in Vienna, Austria.

Organisation for Economic Co-operation and Development

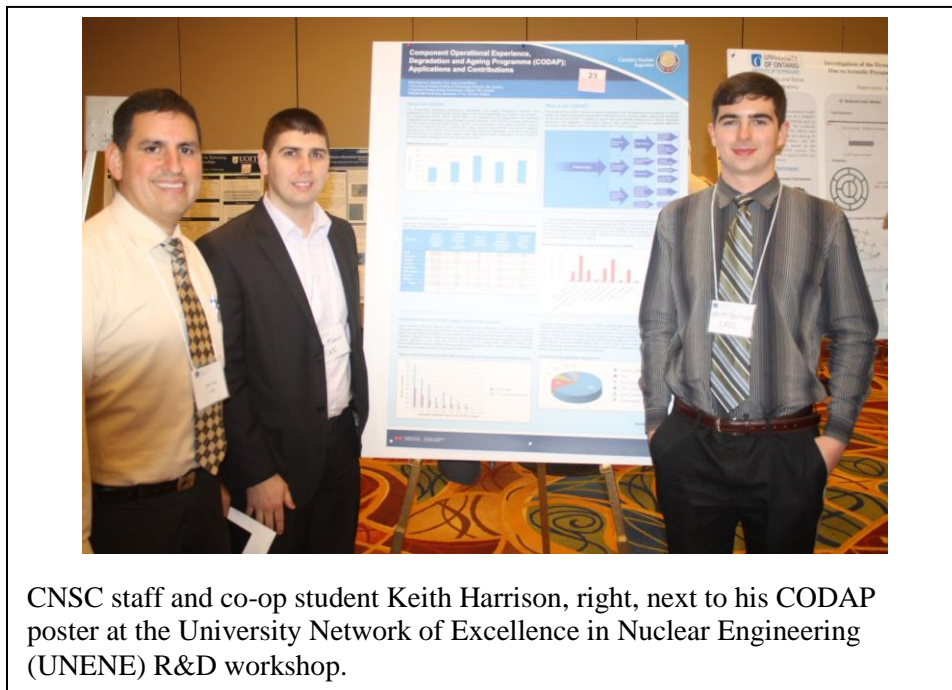
The OECD is an intergovernmental body that facilitates cooperation between member states to collaborate, share experiences and resolve problems. The CNSC has participated in the OECD through a number of joint projects with the NEA (a specialized agency within the OECD). The CNSC participated in several OECD projects over the past year, such as the Component Operational Experience, Degradation and Ageing Programme (CODAP) Phase II, Multinational Design Evaluation Programme (MDEP), and Cable Ageing Data and Knowledge (CADAK) Phase II research.

Involvement in OECD projects has helped the CNSC to disseminate objective scientific information, develop the scientific basis for regulatory policies and decisions, and maintain international relations with other industry organizations.

CODAP Phase II

The Nuclear Energy Agency created a unified project, CODAP, which combined two projects related to plant safety and operability: component experience, and the degradation and ageing program. The goal of CODAP is to develop a database that can be shared among regulatory agencies and other international organizations to provide feedback for reactor regulation, non-destructive examination, and in-service inspections.

The new phase improved on previous CODAP achievements, and participants shared best practices and discussed technical issues experienced by the regulatory agencies. CODAP provided licensees with benchmarks of operational experience and additional reports related to degradation mechanisms, and gave the CNSC access to a comprehensive, current database on piping failures, which CNSC staff use to review fitness-for-service submissions by licensees. Additionally, data collected on aging effects can help improve the CNSC's aging management by providing insight into areas of concern identified in the database.



CNSC staff and co-op student Keith Harrison, right, next to his CODAP poster at the University Network of Excellence in Nuclear Engineering (UNENE) R&D workshop.

OECD Multinational Design Evaluation Programme

MDEP is an international effort carried out by national regulatory authorities to help establish reference regulatory practices enhancing the safety of new reactor designs. Through its forums, MDEP facilitates information sharing among regulatory experts, with a range of expertise available to discuss issues informally. Developments to date have proven that MDEP is an excellent way to increase sharing of knowledge intended for regulatory design reviews.

The CNSC is involved in the policy group, steering technical committee, and the following working groups: AP1000, vendor inspection cooperation, codes and standards, and digital instrumentation and control. Participation took the form of meetings throughout the year where working groups discussed ways to further develop each aspect. A year-end report was published based on MDEP's accomplishments.

The CNSC continues to participate in MDEP to help further its international contributions and to apply lessons from international experience to reviews of potential new designs.

Cable Ageing Data and Knowledge Project Phase II

The CADAK project is a platform that the NEA participant countries use to exchange data and knowledge on cable aging phenomena for further advancements in the field. The CNSC participated in this project to help technical experts make decisions based on current scientific knowledge in cable aging management.

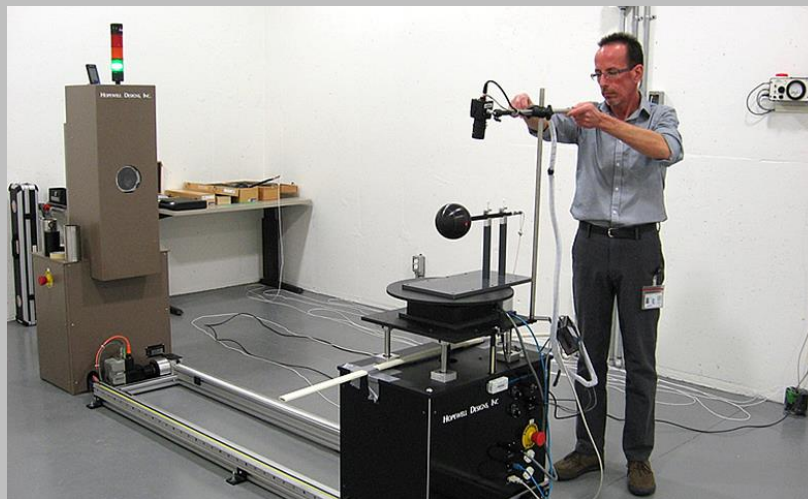
Phase II of CADAK built on previous efforts of Phase I, which was to increase knowledge related to the cable aging. Also included within the phase were discussions on international events that affect cables. The CNSC was able to share its knowledge and operating experience of cable ageing with its international counterparts. Furthermore, other regulators shared their experiences, contributing to developments in estimating the remaining lifetime of cables used in nuclear power plants.

Participant countries concluded that, overall, the project demonstrated that adequate cable performance and aging management in normal operation and post-accident services for periods beyond 60 years will be a demanding challenge. It appears that the approval of a nuclear power plant's lifetime beyond 60 years needs new representative test results and cable material research. This also requires more operational experience and analyses for recognizing critical subjects and targets for additional inspections, assessments and preventive maintenance.

Did you know? The CNSC Laboratory was granted accreditation to ISO/IEC 17025 for calibration of its gamma survey instruments and electronic personal dosimeters. Issued by the Standards Council of Canada, this global standard is used to assess the competence of testing and calibration laboratories. The CNSC Laboratory is the first in Canada with an accreditation for calibration of working measurement standards and survey instruments for gamma measurement. The accreditation to ISO/IEC 17025 standard showcases the CNSC's commitment to achieving excellence in its operations, and to fostering public trust and confidence. To receive the accreditation, the CNSC Laboratory had to meet stringent requirements, including an assessment of the management system, manual documentation and an onsite evaluation of processes, staff, equipment and proficiency testing exercises. Achieving this accreditation makes the CNSC Laboratory a leader in calibration services that are necessary for nuclear regulation and its associated radiation measurements.



Certification awarded to the CNSC Laboratory for successfully meeting all requirements of ISO/IEC 17025.



CNSC Instrumentation Technologist Clifford Chouinor sets up a working standard for calibration at the CNSC Laboratory.

Canadian Safeguards Support Program Initiatives

The IAEA is responsible for providing assurance that nuclear material and facilities are used solely for peaceful purposes. It fulfills this responsibility through implementing verification measures known collectively as safeguards. The Canadian Safeguards Support Program (CSSP) was established in 1977 to assist the IAEA in developing the equipment and capability required for safeguards. Today, CSSP supports safeguards implementation through the development and advancement of safeguards technologies and equipment, IAEA inspector training, and the building and maintenance of safeguards capabilities. The following summaries highlight some of the contributions CSSP made during the 2017–18 fiscal year for the advancement of safeguards and [non-proliferation](#).

Canada celebrates 40 years of cooperative safeguards development with the IAEA

At the Member State Support Program Meeting in February 2018, the IAEA recognized the CSSP for 40 years of cooperative safeguards development, noting that the CSSP is the second-oldest established Member State safeguards support program. At the meeting, the CNSC highlighted 40 years of its own contributions, including the advancement of safeguards technology for CANDU reactors; the development of the Digital [Cerenkov](#) Viewing Device, which is widely used by the IAEA to verify spent nuclear fuel from light water reactors; training courses for IAEA inspectors; the application of remote sensing equipment for safeguards; and contributions to information management tools for state declarations to the IAEA.



David Moroz, Director of the CNSC's International Safeguards Division, accepting the IAEA's Certificate of Appreciation from Tero Varjoranta, Deputy Director General and Head of the Department of Safeguards at the IAEA.

Development of the IAEA's State Declarations Portal

IAEA Member States are required to submit nuclear material accounting reports that verify that they are meeting their obligations for [non-proliferation](#) efforts. The reports indicate a State's inventory of nuclear material that is in use, retained in waste, and in non-nuclear use. The State Declarations Portal will provide a more efficient method for States to share this information with the IAEA.

The State Declarations Portal is a web-based system recently introduced by the IAEA for transmission of safeguards information between an IAEA Member State and the IAEA. In particular, the IAEA's State Declarations Portal provides a secure two-way communication channel to facilitate the provision of state declarations. Canada's participation in the development of the State Declarations Portal through the CSSP complemented the IAEA's recent overhaul of its safeguards information systems as part of the multi-year, multi-million-dollar MOSAIC project.

Canada became the first country to make a submission to the State Declarations Portal. Over time, as more states make submissions this way, the IAEA will be able to reduce the number of paper-based processes for the exchange information, saving staff time for all parties, and reducing the overall time needed to process declarations. The State Declarations Portal also has the potential to increase the reliability and integrity of submitted data.

The next generation

The CNSC conducts and supports outreach initiatives for Canadian youth. Its aim is simple: to build and support an interest in working in scientific fields. These initiatives include in-school programs, university co-op programs and public outreach events. Through its participation in outreach events, the CNSC helps spread scientific, technical and regulatory information in ways that engage a variety of audiences and contribute to the next generation of scientists, engineers and technical experts who will become a strong and important part of the workforce.

The following summaries describe steps that the CNSC has taken this past fiscal year to encourage this interest.

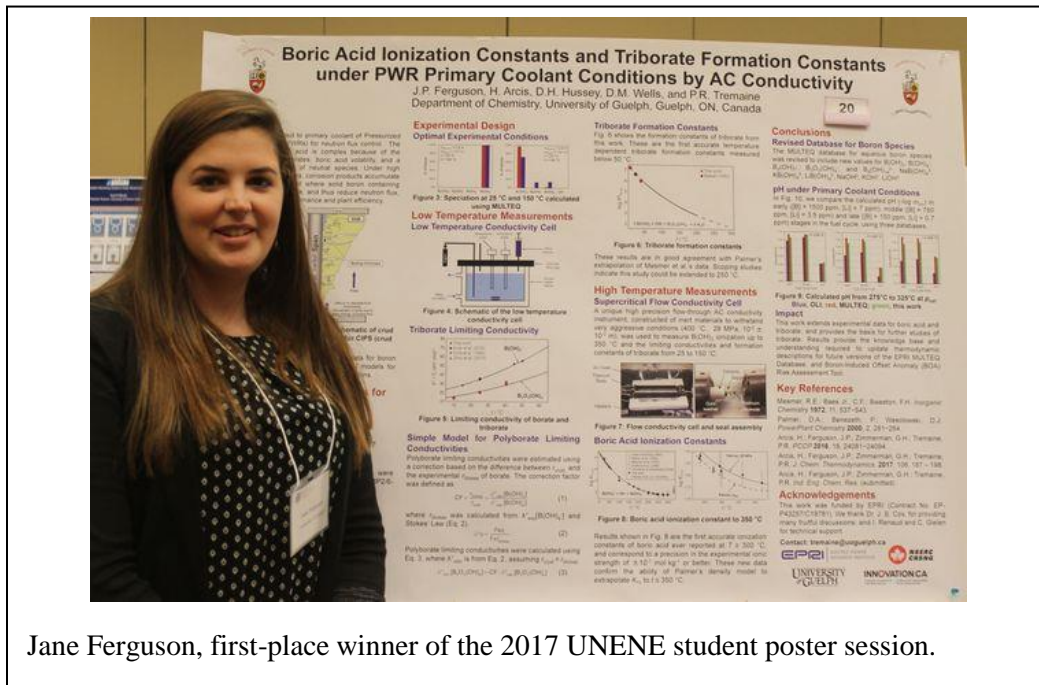


The CNSC participated in the 2017 Science Odyssey Funfest, where people visited the CNSC booth, met staff and learned more about nuclear science. Along with interactive CNSC online modules, experts demonstrated some everyday items that contain radiation. [Visit the Learning Portal.](#)

Annual UNENE student workshop poster session

UNENE was created in 2002 through a partnership of industry leaders and universities. The three main objectives of UNENE are to create a pool of scientific experts available for independent consultation by industry members, support nuclear research in universities through funding initiatives and provide training for qualified personnel to further develop their skills. UNENE also offers current industry workers the tools and resources to obtain a Master of Engineering degree while continuing their professional career.

UNENE holds an annual poster session that allows students conducting research to present their findings to its member organizations, which are made up of federal government, industry and university partners. The CNSC is one of two federal government members and grants some research funding to UNENE to help with its initiatives. The 2017 first-place winner was Jane Ferguson from Guelph University, whose research focused on thermodynamic properties of boric acids that are required for the accurate modelling of coolant chemistry in pressurized-water reactors.



Jane Ferguson, first-place winner of the 2017 UNENE student poster session.

Renewing the CNSC workforce

The CNSC is dedicated to strengthening the next generation of the workforce. Through the CNSC’s co-op program, graduate and undergraduate students can gain work experience in the nuclear sector. Students with backgrounds in several areas, including nuclear engineering, health science or other sciences, can obtain 4-month, 12-month, or 15-month co-op positions. Students in the two longer terms change their position every 4 months, so they can learn different aspects of the nuclear field.

The co-op program effectively prepares young employees for the workforce by providing hands-on experience and the opportunity to learn from a team of experts. Co-op students are also able to participate in extracurricular activities through the CNSC. Examples include charity events, conferences, industry training, and domestic and international travel. These events help co-op students to become more engaged and integrate into the CNSC’s working environment.

The skills they pick up through the program can help accelerate their careers in the nuclear industry once they have completed their studies, and their interest in the nuclear industry and appreciation of what they have learned from working with the regulator will support the CNSC in the future.



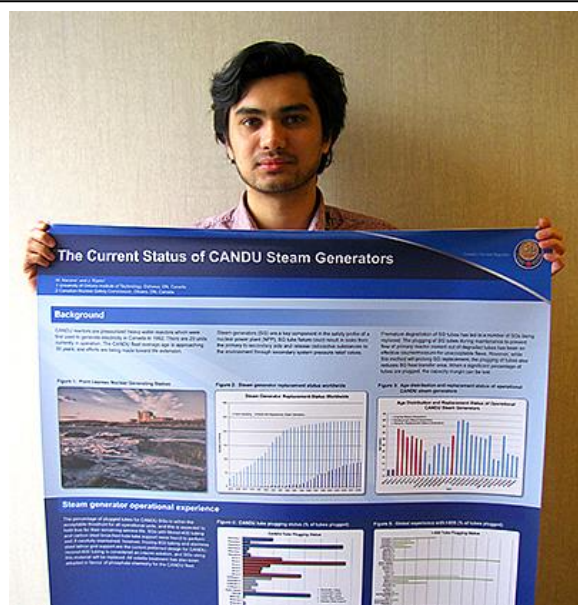
Mayur Patel, co-op student and co-author of this report, presenting to CNSC staff on the work he completed during his first work term at the CNSC.



The CNSC’s 2017–18 co-op students receive recognition for the successful completion of their 15-month terms. At the end of each work term, the students present an overview of their term work to help develop their presentation skills. After their final work term and presentation, each student is awarded a plaque to show recognition of their hard work and dedication to their placement at the CNSC.

From CNSC co-op student to new grad employee

Matthew Naraine, a previous CNSC co-op student, completed his undergraduate degree and returned to the CNSC to continue his career through the student bridging program. During his co-op term at the CNSC, Naraine attended the 25th International Conference on Nuclear Engineering (ICONE). ICONE is a global conference on nuclear reactor technologies and explores the technical issues and solutions for challenges faced by the industry. The ICONE student program fosters the development of future nuclear professionals. Naraine’s research paper on steam generator lifecycle management and his poster on it earned him the ICONE25 Sanqiang Best Poster award in the student competition. Through his rotations at the CNSC and research opportunities with Dr. Jovica Riznic, Naraine developed the necessary skills to prepare for his career as a project officer with the CNSC’s New Major Facilities Licensing Division.



Matthew Naraine with his research poster on steam generators that won first place at the 25th ICONE Conference.

Future research at the CNSC

Regulatory research plays an important role in providing information and enhancing CNSC staff's knowledge so they can better support the CNSC in its regulatory mission.

In the coming years, the CNSC will continue to support projects that aim to fulfill the CNSC's research goals and strengthen its regulatory framework.

But what will the areas of interest look like? They will be varied and include:

- aging management of reactor facilities, to ensure the ongoing safe operation of nuclear power plants
- waste management to prepare for potential waste repositories
- new technologies, such as [small modular reactors](#), to prepare for future, as-yet-unknown, regulatory challenges

The CNSC's research program will continue to evolve so that CNSC staff will have access to the latest scientific information to supplement their assessment capabilities.

Working with both domestic and international stakeholders to share information and best practices will remain an integral part of the CNSC's research program. Collaborating with organizations such as the IAEA, UNENE, Atomic Energy Canada Limited and the federal nuclear science and technology program will greatly contribute to ensuring that the global nuclear industry maintains the safest practices.

Finally, the CNSC will continue to publish this annual report to popularize information on its research initiatives and involvement in the nuclear field, as part of its mandate to disseminate objective scientific, technical and regulatory information to the public.

Glossary of terms

argillaceous rock: A type of sedimentary rock.

bentonite horizons: Horizons, from a geological perspective, that describe a surface which marks a change in the rock sequence.

Cerenkov light: An electromagnetic radiation emitted when a charged particle passes through a dielectric medium at a speed that is faster than the phase velocity of light in the medium.

civil society organizations: Non-governmental organizations or associations in which people are enabled to pursue shared interests; for example, community organizations, environmental groups, independent research institutes, and interest groups.

colloid: A two-phase mixture where one substance is dispersed in another.

creep: With respect to material science, a phenomenon of solids to deform under stresses. Creep is a process that gradually changes the characteristics of a structure and acts as an aging mechanism.

glacial striation: Gouges that have been cut into bedrock as a result of glacial movements.

inherent behaviour: The types of safety designs that avoid a hazard rather than having a system in place to control the hazard.

leachates: A liquid that has dissolved parts of its surrounding medium as it passes through it.

monotonic test: A test meant to obtain mechanical properties of a medium; examples include tension and compression tests.

multiple-barrier system: An independent series of engineered and natural barriers working together as a system. Having multiple rather than a single barrier increases the safety of the system.

non-proliferation: The use of nuclear technology for peaceful purposes.

Paleozoic era: The period of Earth's history from 252 million to 359 million years ago.

passive behaviour: A safety design that activates without outside intervention. The behaviour automatically reacts when a hazard is present to try to control it.

permeability: The ability of a porous material to allow fluids to pass through it.

Precambrian era: The period of Earth's history from 541 million to 4,600 million years ago.

service life: The period from initial operation to final withdrawal from service of a structure, system or component.

small modular reactor: As defined by the IAEA, an advanced reactor that produces up to 300 MWe per module. Traditional reactors produce an output from 700 to 1650 MWe. (MWe or megawatt electrical is a measure of the electric power produced by a reactor).

smectite: Clay that has the ability to swell when in contact with water.

triaxial: Possessing or including three axes.

Annex: CNSC technical papers, presentations and articles

The CNSC is well recognized by its peers through papers published in scientific journals as well as presentations made at conferences, workshops, and meetings of NEA and IAEA.

The following is a list of technical papers, presentations and articles published/presented by CNSC staff in fiscal year 2017–18.

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
The Pseudo-Resonant Isotope Model for Predicting the Resonance-Interference Effect in Self-Shielding Calculation	Abstract of a technical paper / presentation	International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering	April 16–20, 2017	Jeju, Republic of Korea	Wei Shen
Validation of Thermalhydraulic Computer Codes Used in Safety Analysis: Regulatory Perspective	Abstract of a technical paper / presentation	ASME Verification and Validation Symposium (V&V)	May 3–5, 2017	Las Vegas, Nevada	J.E. Kowalski
CNSC Regulatory Research on Geological Disposal	Abstract of a technical presentation	CNSC-EA Information Exchange Teleconference	May 9, 2017	Ottawa/UK (teleconference)	T.S. Nguyen
Assessment of the Effect of the Advanced Drift-Flux Model of ASSERT-PV on CHF, Flow and Void Fraction Distributions	Abstract of a peer-reviewed technical journal paper	<i>Annals of Nuclear Energy</i>	June 2017	Elsevier	N. Hammouda, Y.F Rao
Application of Bayes Method in Evaluation of ROP/NOP Trip Setpoint	Abstract of a peer-reviewed technical journal paper	37th Annual Conference of the Canadian Nuclear Society	June 2017	Niagara Falls, Ontario	Dumitru Serghiuta

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
Integrated Framework for Propagation of Uncertainties in Nuclear Cross-Sections in CANDU Steady-State and Transient Reactor Physics Simulations	Abstract of a technical paper	37th Annual Conference of the Canadian Nuclear Society	June 2017	Niagara Falls, Ontario	Dumitru Serghiuta
CANDU Reactors: Long-Term Operation and Refurbishment, CNSC Perspective	Abstract of a technical paper / presentation	37th Annual Conference of the Canadian Nuclear Society and 41st Annual CNS/CNA Student Conference	June 4–7, 2017	Sheraton on the Falls Hotel, Niagara Falls, Ontario	M. Santini, A. Omar
Reflecting Digital I&C Design Lessons Learned in Technology-Neutral Design Requirements	Abstract of a technical paper	International Conference on Topical Issues in Nuclear Installation Safety: Safety Demonstration of Advanced Water-Cooled NPPs	June 6–9, 2017	Vienna, Austria	Zhao Chang Zeng, Guna Renganathan, Marcel de Vos, Jean-Yves Fiset, Jason Churchill, Gilbert Chun
Performance of MX-80 Bentonite Seal Materials in a Brine Environment	Oral presentation	Nuclear Waste Management Organization Geoscience Seminar	June 7–8, 2017	Toronto, Ontario	G. Su
Enhancing Workload Estimates for Validation Activities Associated With DBA and BDBA Scenarios	Oral presentation of a conference paper	10th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies	June 11–15, 2017	San Francisco, California	Aaron Derouin and Alice Salway
Progress of CNSC Regulatory Research on Geological Disposal	Oral presentation	IAEA URF Technical Meeting on Global Progress in Developing Geological Disposal Solutions	June 19–23, 2017	Turku, Finland	Grant Su
Beyond the Modified Kersey's Method	Abstract of a technical presentation	Canadian Organization of Medical Physicists Annual Scientific Meeting	July 13, 2017	Ottawa	Adam Dodd and Kevin Shimotakahara

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
A Systemic View of Human Factors: Connecting the Domains Through a Human Performance Program	Abstract of a technical presentation	Applied Human Factors and Ergonomics Conference	July 17–21, 2017	Los Angeles, California	Alice Salway
Technetium 99m – From Reactors to Accelerators – Regulatory and Safety Aspects	Abstract of a technical presentation	International Topical Meeting on the Nuclear Applications of Accelerators	August 2, 2017	Québec City	Abdul Alwani
Role of Tritiated Hydrogen in Formation of HTO and OBT in Soil and Vegetation in Vicinity of a Tritium Processing Facility	Abstract of a technical paper / presentation	4th International Conference on Radioecology and Environmental Radioactivity (ICRER 2017)	September 3–8, 2017	Berlin, Germany	M. Ilin, M. Rinker
Analysis of Mortality in a Pooled Cohort of Canadian and German Uranium Processing Workers With No Mining Experience	Peer-reviewed journal article	<i>International Archives of Occupational and Environmental Health</i>	September 22, 2017	Springer	Lydia B. Zablotska, Nora Fenske, Maria Schnelzer, Sergey Zhivin, Dominique Laurier, Michaela Kreuzer
Effect of Brine on Swelling Pressure of MX-80 Bentonite and Bentonite-Sand Mixture	Abstract of a technical presentation	Clay Conference 2017 – The 7th International Conference on Clays in Natural and Engineered Barriers for Radioactive Waste Confinement	September 24–27, 2017	Davos, Switzerland	G. Su, T.S. Nguyen, K. Lange, J. Brown, Z. Li
Quantification of Plant-Level HCLPF Capacity in Probabilistic Safety Assessment-Based Seismic Margin Assessment	Abstract of a technical paper	International Topical Meeting on Probabilistic Safety Assessment and Analysis	September 24–28, 2017	Pittsburgh, Pennsylvania	Zhaoliang Wang, Smain Yalaoui, Yolande Akl

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
WGRISK Site-Level PSA Project: Status Update and Preliminary Insights for the Risk Aggregation Focus Area	Abstract of a technical paper	International Topical Meeting on Probabilistic Safety Assessment and Analysis	September 24–28, 2017	Pittsburgh, Pennsylvania	Smmain Yalaoui, Yolande Akl, Marina Röwekamp (GRS)
Environmental Qualification Program Requirements for the Long-Term Operation of Canadian Nuclear Power Plants	Abstract of a technical paper / presentation	Fourth International Conference on NPP Life Management	October 23–27, 2017	Lyon, France	Meliha Vlatkovic
Role of Soil-to-Leaf Tritium Transfer in Controlling Leaf Tritium Dynamics: Comparison of Experimental Garden and Tritium-Transfer Model Results	Peer-reviewed journal article	<i>Journal of Environmental Radioactivity</i>	November 2017	Elsevier	Masakazu Ota, Nana-Owusua A. Kwamena, Steve Mihok, Volodymyr Korolevych
Hydro-Mechanical Behaviour of the Cobourg Limestone	Peer-reviewed journal paper	<i>International Journal of Rock Mechanics and Mining Sciences</i>	February 2018	Elsevier	M.H.B. Nasser, R.P. Young, X. Su, T.S. Nguyen, Z. Li
Canadian Approach to Defence in Depth, Design Extension Conditions and Severe Accident Management	Abstract of a technical presentation	Technical Meeting on Current Approaches in Member States to the Analysis of Design Extension Conditions for New Nuclear Power Plants – IAEA	March 19–23, 2018	Vienna, Austria	Noredidine Mesmous