Canada's Nuclear Regulator

The Science of Safety

CNSC Research Report

2015–16

Canadian Nuclear Safety Commission

Commission canadienne de sûreté nucléaire

Canada

The Science of Safety: CNSC Research Report 2015–16

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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)
Facsimile: 613-995-5086
Email: cnsc.information.ccsn@canada.ca
Website: nuclearsafety.gc.ca
Facebook: facebook.com/CanadianNuclearSafetyCommission
YouTube: youtube.com/cnscccsn
Twitter: @CNSC_CCSN

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Table of contents

Message from the President

The Canadian Nuclear Safety Commission (CNSC) has a mandate to protect the health, safety and security of Canadians and the environment; to implement Canada's international commitments on peaceful nuclear energy use; and to disseminate scientific, technical and regulatory information to the general public. Our regulatory research is essential to delivering on that mandate, providing us with the objective knowledge that forms the basis for safe and secure regulatory decisions.

The following is the CNSC's third annual research report, which summarizes the various research projects we have funded and completed in the 2015–16 fiscal year. By being transparent in our activities and sharing the results of the research we conduct across the nuclear industry both in Canada and abroad, we are ensuring Canadians are well educated on our regulatory activities.

All of the information in this report, unless otherwise indicated, is publicly available on our website. All readers, whether technical or not, are encouraged to read the summaries provided in this report and, if interested, click on the associated links in each summary to access the more detailed research results.

That's the science of safety.

Michael Binder
President and Chief Executive Officer,
Canadian Nuclear Safety Commission

Introduction

Purpose of this report

Part of the CNSC's mandate is to disseminate scientific, technical and regulatory information to the general public. While information on the CNSC's research and research-related projects is publicly available on its website, the associated research documents often contain very technical and scientific language. As such, the CNSC publishes *The Science of Safety* report each year to summarize the research and make the results more accessible to a general audience. A glossary of terms is provided to further assist readers in understanding the technical language used in this document. Words that are underlined are linked to their respective definition in the glossary.

Regulatory research

Our regulatory research is used in many ways. It supports our regulatory decisions. It helps us protect the health, safety and security of Canadians and the environment by identifying issues that may lead to eventual hazards – and developing tools and techniques to address those issues. It is also used to create stronger safety standards for the benefit of the nuclear industry and the general public alike.

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

- collect independent advice in support of regulatory decisions
- develop tools capable of addressing health, safety, security or environmental issues
- develop nuclear safety standards

These objectives can be further defined into 10 main goals:

- strengthening the CNSC's licensing, compliance and regulatory framework in preparation for long-term/post-refurbishment operation of Canadian nuclear power plants
- enhancing the CNSC's capability to independently assess hazards (particularly natural hazards) and to analyse/respond to severe reactor accidents
- supporting CNSC staff in preparation and conduct of vendor design reviews
- enhancing the CNSC's understanding of the environmental transport and behaviour of hazardous/nuclear substances and associated environmental exposures
- informing the CNSC's radiation protection knowledge base to reflect the best available science with respect to the protection of workers and the public
- supporting CNSC staff in their evaluation of licensing or other submissions related to waste repositories
- furthering the CNSC's understanding of the long-term behaviour of both uranium mining and milling waste
- supporting the update of the CNSC's regulatory framework to reflect modern human performance approaches
- supporting Canada's safeguards commitments and influencing international safeguards efforts
- strengthening Canada's nuclear forensics capability

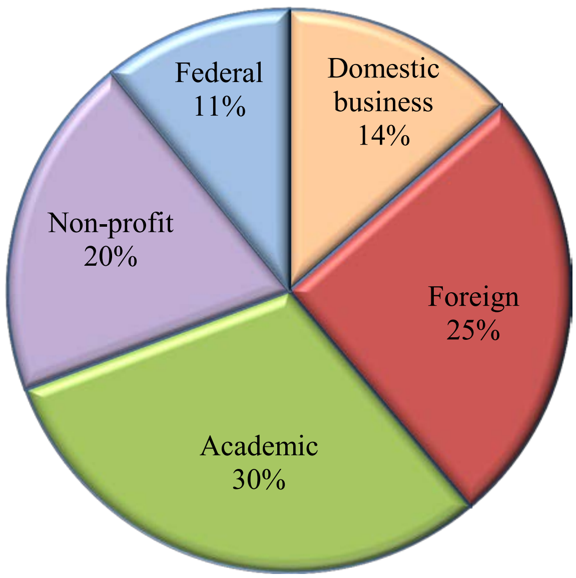
This report categorizes our research by three general categories: "Ensuring the safety of nuclear power plants," "Protecting workers" and "Protecting the environment".

Each chapter provides quick summaries of all the research projects and similar work completed by the CNSC from April 1, 2015 to March 31, 2016. Project topics are not limited to commercial nuclear power; there are multiple projects spread across every aspect of the Canadian nuclear industry that is regulated by the CNSC, including uranium mining, nuclear research facilities and more.

Our research universe

The CNSC funds research in the private sector, academic institutions, governmental organizations and non-governmental organizations, primarily through competitive contracting processes. This research is not limited to Canada but includes international funding as well. Our research program shares some costs and other information with national and international partners.

CNSC research funding by organization type



Type of research organization	*Funding percentage (%)*
Federal	11
Domestic Business	14
Non-Profit	20
Academic	30
Foreign	25

This year our primary research partners were academic institutions, making up 30 percent of the total research spending – up from 14 percent in 2014–15. Some of these institutions included Carleton University, the University of Manitoba, McMaster University, the University of Ottawa, Queen's University, the University of Calgary and the University of Toronto, as well as the University Network of Excellence in Nuclear Engineering. Agreements with non-profit organizations were another area of growth, with 20 percent of research spending going to organizations such as the CSA Group, the Canadian Nuclear Society and the Deep River Science Academy – up from just one percent in 2014–15. The CNSC also had significant collaboration with foreign vendors (as is typical each year), including foreign governments and consultants such as the Nuclear Energy Agency and Areva.

Ensuring the safety of nuclear power plants

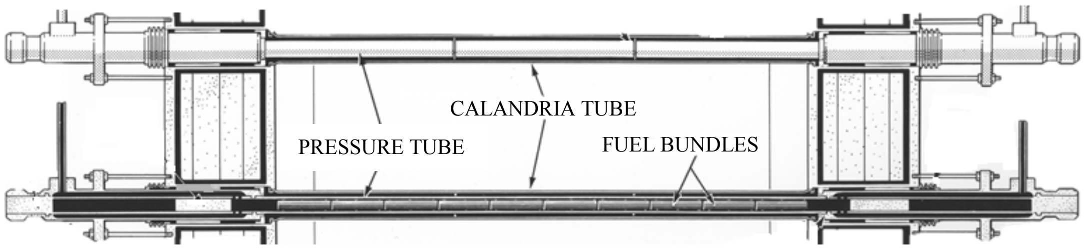
There are four nuclear generating stations operating in Canada. As a direct part of the CNSC's mission and mandate, the use of nuclear energy must be well regulated to protect the surrounding population and the environment. Our research is a vital component in supporting the regulation of nuclear energy: it is used to ensure the various station structures, systems and components are functioning properly and will continue to do so over the lifetime of the nuclear facility. The following summaries briefly explain each research project completed this year that had relevance to the continued safety and reliability of nuclear power plants in Canada.

Aerial photograph of the Pickering Nuclear Generating Station in Pickering, ON.

Ontario Power Generation's Pickering Nuclear Generation Station is an eight-unit station (only six units are currently in operation, with two in a safe shutdown state). Capable of producing over 3,000 MW of power, Pickering can completely supply a city of approximately 1.5 million people.

Expert review of probabilistic blister susceptibility assessment

The Canadian nuclear industry has always used probability to analyze the potential for contact between the pressure tube and calandria tube: two internal reactor parts whose temperature differences could cause a blister and, ultimately, pressure tube failure. The typical process for predicting tube contact consisted of several input variables with larger safety margins than necessary, mainly the pressure tube creep ratio and end slopes. The Canadian nuclear industry has developed a new method to estimate the frequency of tube contact and failure, which uses the measured gap between the pressure tube and calandria tube (rather than an estimate) to derive the creep ratio and end slopes.



Simplified diagram of internal CANDU reactor parts, including labelled pressure and calandria tubes.

As CNSC staff determined that this method used newly developed techniques, an independent technical expert was contracted to review and assess its technical adequacy. It was determined that the new method is based on several assumptions with weak supporting evidence; however, the industry has the ability to address these concerns and strengthen the method for use.

Refer to the CNSC website for the final report: *Expert review of technical basis for probabilistic assessments of pressure tube to calandria tube contact and blister susceptibility*.

Application of Bayes method to evaluate neutron overpower protection trip setpoints

The CNSC has initiated a multi-phase research project to develop a Bayesian statistical framework and software to better assess the value of the neutron overpower protection (NOP) trip setpoints established by its licensees. (If the neutron flux in the reactor reaches the NOP trip setpoint, the reactor will be automatically shut down.) The framework and software will be used to evaluate the frequency of failure of the NOP system and to calculate the uncertainty associated with a licensee's current trip setpoint value.

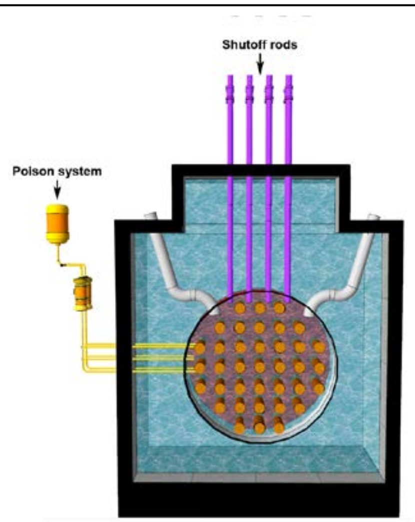
The full research report includes the theory and model of the proposed Bayesian statistical framework, the software specifications, and the guidelines for developing and selecting the performance criteria for testing and qualification. The actual software using the proposed framework will be developed as part of this project's second phase.

Refer to the CNSC website for the final report: *Application of Bayes method in evaluation of ROP/NOP trip setpoint*

Application of the single-failure criterion

The single-failure criterion is a safety requirement typically applied to nuclear power plant safety systems. It states that in the presence of any single failure of a component or system, the safety systems must still be able to perform their safety functions. The objective of this project was to recommend regulatory requirements for the single-failure criterion in new reactors by reviewing international best practices in this area.

Current single-failure criterion requirements from the International Atomic Energy Agency (IAEA), the Western European Nuclear Regulators Association and the European Utility Requirements – as well as the requirements set by nuclear regulators in the United States, United Kingdom, Russia, Korea, Japan, China and Finland – were reviewed and compared with the Canadian requirements.



A diagram displaying a CANDU reactor with both shutdown systems (shutoff rods and poison) in case one system fails.

The report makes comprehensive recommendations for future changes to the CNSC's regulatory framework regarding the single-failure criterion. To summarize, the CNSC should use more common requirements and approaches from IAEA documents, include references to Western European Nuclear Regulators Association documents, produce additional guidance on applications for allowed outage time and establish guidance for the demonstration of maintenance effectiveness.

Although CNSC regulatory document REGDOC 2.5.2, *Design of Reactor Facilities: Nuclear Power Plants*, provides guidance and requirements on the single-failure criterion, more clarification is needed to ensure Canadian licensees are meeting state-of-the-art international approaches. These recommendations will be taken into account in future regulatory framework changes.

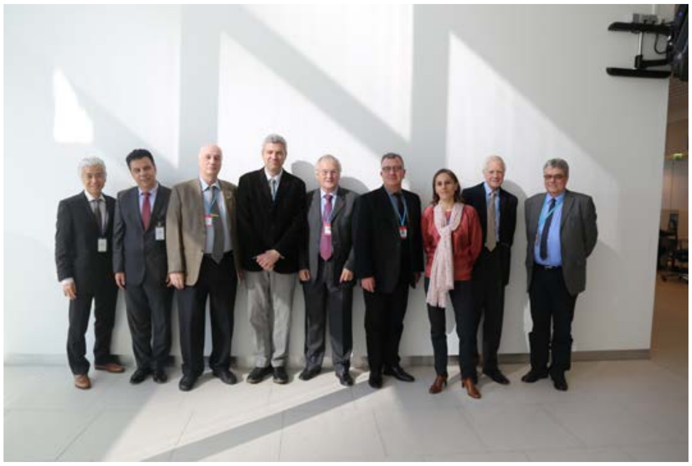
Refer to the CNSC website for the final report: *Assessing regulatory requirements and guidelines for the single-failure criterion*

Did you know? The single-failure criterion requires each safety group to be able to perform all safety functions required for an event assuming any single component failure, as well as:

- all failures caused by that single failure
- all identifiable but non-detectable failures, including those in non-tested components
- all failures and system actions that cause (or are caused by) the event

Seismic assessment and soil–structure interaction at nuclear power plants

The study of the impact of earthquakes on nuclear facilities is an important part of a safety assessment. The CNSC has completed two research projects to improve the ability to predict the impact of seismic events, taking into account a structure's interaction with the soil on which it is placed.



CNSC staff and members from different nuclear regulators at an IAEA International Seismic Safety Centre meeting to discuss the soil–structure interaction during seismic events.

The simulation of ground motion during an earthquake must be based on a solid understanding of the phenomena governing earthquake wave motion as well as the nuclear power plant's response. The goal of the first research project on this topic – the development of analytical tools for soil–structure analysis – sought to develop the technical basis and synthetic motion data required to simulate realistic seismic events. Using the motion data defined in the first project, the second project was able to simulate realistic earthquake soil–structure interactions, leading to the development of new methodologies and the improvement of existing methodologies for modelling and simulating earthquake soil–structure interaction at nuclear power plants.

These forward-looking projects have sparked significant international interest, including a large-scale project based on their developments that was initiated by the U.S. Department of Energy.

The ultimate objective of this research is to develop a regulatory approach to assess earthquake soil–structure interaction. The CNSC currently leads the drafting team of an IAEA technical document (TECDOC) related to earthquake soil-structure interaction, which will incorporate the findings of these research projects.

Refer to the CNSC website for the final reports: *Development of analytical tools for soil–structure analysis* and *Interfacing seismological description of strong ground motion with engineering analysis of soil–structure interaction for nuclear power plants*

Contact boiling water experiments

In CANDU reactors, the moderator acts as a heat sink to prevent fuel channel failure if a pressure tube contacts the calandria tube under accident conditions. As the moderator temperature has to be sufficiently low to perform its function, licensees have developed an analytical model to determine the minimum moderator temperature requirements. This model was validated against sets of contact boiling experiments.

Following a CNSC review, it was determined that there was a need for additional experiments to support parts of the model and the acceptance criterion set by licensees. For this reason, the CNSC supported six further contact boiling experiments performed at Canadian Nuclear Laboratories (CNL), formerly Chalk River Laboratories. The results of these experiments supported the licensee's acceptance criterion. They also revealed the likelihood of factors related to the limiting value of this criterion that could lead to disastrous incidents.

In general, the CNSC research provided valuable additional information to the existing industry experimental database that can better support future modelling. At the same time, the new information gained will allow the CNSC to continue to successfully evaluate the safety case for CANDU reactors.

CNSC cannot share the deliverables from this project (such as the final report) as they contain proprietary information subject to access restrictions.

An external view of Point Lepreau Generating Station.

Point Lepreau Generating Station is a CANDU 6 design that features a wall thickness of 1.1 m of reinforced pre-stressed concrete lined with epoxy for leak-tightness. This design is able to withstand containment pressures from severe-accident scenarios including a loss-of-coolant accident combined with a hypothetical loss of the plant's emergency core cooling system.

Flood hazard assessment for nuclear facilities in Canada

Following the Fukushima Daiichi nuclear accident in Japan in 2011, the CNSC decided to have licensees review and, if needed, update their flood protection procedures. The CNSC also determined that, prior to its review of the regulatory framework on flood protection, there should be a review of national and international best practices and Canadian licensee approaches to flood hazard assessment.

A recently installed flood barrier at Darlington Nuclear Generating Station.

The CNSC hired an external contractor to perform a literature review of state-of-the-art flood hazard assessment approaches from around the world, as well as a gap analysis on Canadian licensees' practices. It was determined that licensee documents vary significantly and CNSC regulatory documents do not provide guidance on how to assess flood hazards. It was recommended that the CNSC develop guidance on flood hazard assessments to assist licensees in complying with the regulations.

Refer to the CNSC website for the final report: *Flood hazard assessment for nuclear power plants in Canada*.

Did you know? As a response to the Fukushima accident, the CNSC addressed more than 50 action items intended to strengthen defence in depth at major nuclear facilities in Canada, enhance emergency preparedness, promote international collaboration, improve communication and public consultation, and improve regulatory frameworks and processes.

Development of severe irradiated fuel bay PKPIRT package

Following the Fukushima accident, the CNSC determined it would be beneficial to develop new computer codes to model and simulate potential fuel bay accidents. The main objective of this research project was to produce a package of phenomena and key parameter identification and ranking tables (PKPIRT), which would serve as the primary information source for a panel of experts who would then perform a study on the expected progression of a hypothetical CANDU fuel bay accident. The panel's work will be used to help develop models to further understand such accidents and, as a result, improve and reinforce current mitigation strategies.

The final PKPIRT package contained a significant collection of literature from Canadian and international sources, including proprietary reports as well as information specific to light water reactor spent fuel pool accidents. In total, more than 100 literature items were collected and organized by source and subject matter. This package will support the CNSC's future efforts in creating a tool to estimate source terms and predict the progression of potential fuel bay accidents.

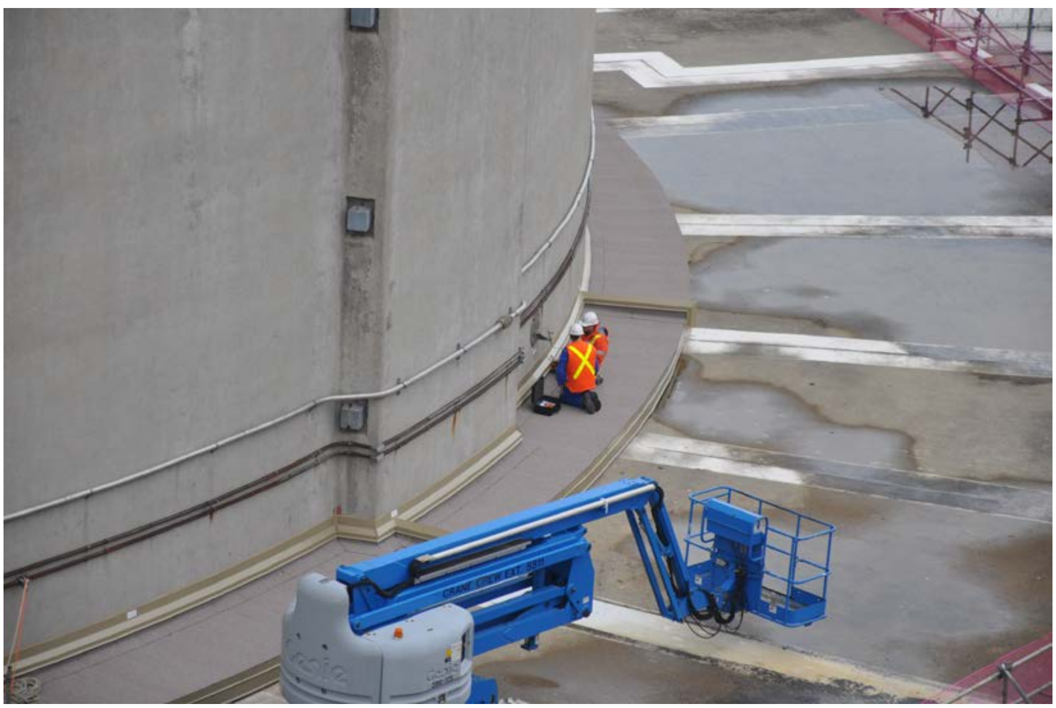
The CNSC cannot share the deliverables from this project (such as the final report) as they contain proprietary information subject to access restrictions.

Expert review of containment radionuclide behaviour

During certain severe accidents at nuclear power plants, radioactive fission products can escape from the fuel and be carried into containment (i.e., the reactor building). To assess the potential of radioactivity releasing from containment to the environment – and to calculate the potential dose to public – the behaviour of radionuclides within containment must be known.

Licensees currently use three different computer codes for containment safety analysis. One of these codes, the Simple Model for Activity Removal and Transport, was recently updated, prompting the CNSC to conduct a review of its new version. This project concluded that the updated code is suitable for design-basis accidents and is in good agreement when compared to other codes. With these findings, the CNSC can provide feedback to licensees on the acceptability of this new code and update its regulatory positions on public dose calculations.

The CNSC cannot share the deliverables from this project (such as the final report) as they contain proprietary information subject to access restrictions.



CNSC employees inspecting Bruce's containment building.

Feasibility of an uncertainty framework with application to reactor physics simulations

CNSC REGDOC-2.4.1, *Deterministic Safety Analysis*, allows the use of "best estimate" reactor analysis simulation with consideration of uncertainties. ("Best estimate" refers to the estimate that is based on the most accurate methods and assumptions that are known at the time.) The understanding and measurement of uncertainty sources is an essential requirement of a best estimate analysis, as it allows for the assessment of the reliability of the predictions produced by the simulation. Although it would be much simpler to check the accuracy of simulation predictions by comparing the predicted measurements to known measurements, the true value of a best estimate simulation lies in its ability to analyze reactor conditions for which measurements are unavailable. As such, there is a need to characterize all sources of uncertainty to reliably use the results of best estimate calculations in the various aspects of reactor design, operation and safety.

In preparation for its regulatory technical review of safety cases using best estimate with consideration of uncertainties, the CNSC initiated a study to investigate the feasibility of the development of an integrated framework that would allow for an accurate characterization of uncertainties (with a particular focus on uncertainties in CANDU neutronics calculations). The goal of this study is to provide a scientifically defendable methodology for characterizing uncertainties in all best estimate reactor analysis calculations, ensuring the simulation produces accurate and safe predictions. This methodology would then be used in the independent verification of licensees' safety cases. The first phase of this project is complete and plans are underway to continue with its second phase over the next few years.

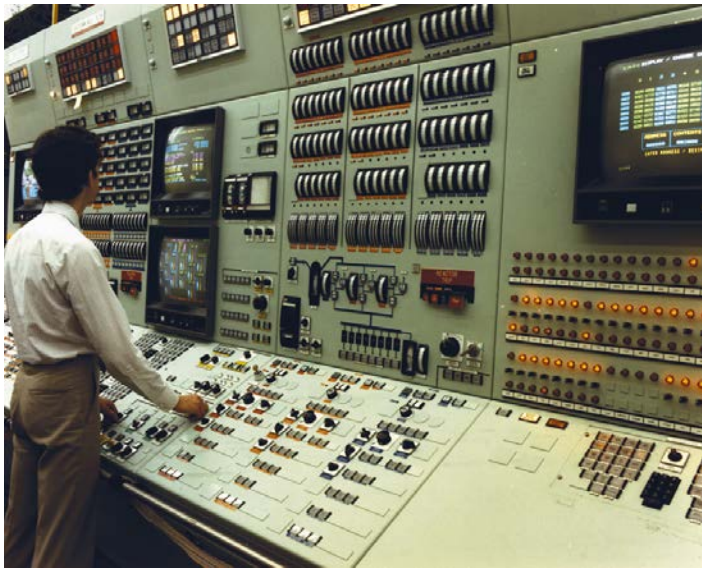
Refer to the CNSC website for the final report: *Feasibility study of an integrated framework for characterization of uncertainties with application to CANDU steady state and transient reactor physics simulation*.

Did you know? Queen's University has completed a $17.5M project to build its new Reactor Material Testing Laboratory. This facility features a proton accelerator that can simulate the effects of a reactor on material samples. This new capability will allow researchers to study how materials operate within a reactor and provide valuable information to help better understand material degradation and corrosion.

To learn more, visit the Reactor Materials Testing Laboratory Web page.

Review of regulatory requirements and best practices for ensuring minimum staff complement

The minimum staff complement is the minimum number of qualified workers who must be present at all times to ensure the safe operation of a nuclear facility. CNSC staff use Regulatory Guide G-323, *Ensuring the Presence of Sufficient Qualified Staff at Class I Nuclear Facilities – Minimum Staff Complement*, to assess the adequacy of the minimum staff complement at its licensees' facilities.



A worker at Bruce Nuclear Generating Station using the control room simulator.

Prior to reviewing and potentially updating G-323, the CNSC initiated a research project to review the regulatory requirements, best practices and scientific literature related to minimum staff complement, looking at not only the nuclear industry but also the requirements of the aviation, marine, chemical and other sectors. Interviews were also conducted with internal and external stakeholders to seek feedback about their experience using G-323.

The literature review helped the CNSC identify existing strengths as well as places where G-323 could be improved. For example, the use of simulation holds promise for the nuclear industry as part of a systematic approach to setting and validating staffing levels. Other strengths of G-323 include the guidance it offers licensees and applicants about minimum staff complement and the way it explicitly addresses topics such as periodic reviews, change requests, and licensed and non-licensed workers.

Based on feedback from the interviews, stakeholders indicated that the minimum staff complement is an important defence against accidents and G-323 supports a more rigorous, scientific-based approach to determining and managing minimum staff complement.

The final report includes more than 50 best practices and recommendations that will be considered during the upcoming review of G-323.

Refer to the CNSC website for the final report: *Minimum staff complement: A review of regulatory requirements, industry practices, scientific literature and experience of stakeholders*

Protecting workers

It is the CNSC's responsibility to regulate the Canadian nuclear industry to ensure workers are protected from all potential work-related injuries and harm. Whether it's conventional hazards like fire or electric shock or radiation hazards such as radiation dose, the CNSC tracks these events and ensures the industry consistently attempts to prevent risks to worker health. CNSC research forms the backbone of worker protection by providing strong evidence for all choices in worker safety and allowing for new developments to be distributed within the industry.

A CNSC inspector at Bruce Nuclear Generating Station checks measured licensee radiation fields.

Contamination levels and radiation doses in nuclear facilities are an ever-present hazard. The CNSC ensures received doses are as low as reasonably achievable so licensees can be compliant with radiation protection programs, which are a critical to protecting workers.

Characterization of alpha radiation hazards

During maintenance operations, workers at CANDU facilities can be exposed to small doses of aerosols containing alpha-emitting radionuclides such as plutonium or americium. Because the doses are so small, however, regular bioassay methods cannot be used to detect intake levels corresponding to dose. The current process for determining internal dose from these sources is measuring a major radionuclide (such as plutonium) in excreta and estimating the amounts of the other radionuclides depending on the ratio of that radionuclide to the plutonium in the inhaled aerosol. The problem is that this method is based on the assumption that all radionuclides are absorbed in the lungs at the same rate, despite no studies verifying that assumption.

This research project determined that reactor burn-up significantly affects the biological solubility of radionuclides in the lungs, alpha-emitting radionuclides cause the highest internal dose (despite mass or activity), and overall solubility differs between radionuclides. These results will improve Canadian radiation protection programs by providing a better estimate for internal dose from alpha-emitting radionuclides. They will also help the CNSC better assess licensee's methods for determining worker doses from these radionuclides.

Refer to the CNSC website for the final report: *Characterization of alpha radiation hazards: Biosolubility of radionuclides within CANDU reactor aerosols and implications for internal dosimetry*

Mortality risks in the pooled analysis of Canadian and German uranium processing workers

While there have been many studies on the effects of radon and gamma exposures on uranium miners and other workers in the nuclear industry, few studies have looked specifically at the health risks faced by uranium processing workers. These workers are exposed to a wide range of radioactive and chemical exposures from ore dust but, in comparison to uranium miners, receive lower doses of radioactive decay products.

The interior of the Blind River Refinery in Blind River, ON.

Blind River is the world's largest and most modern commercial uranium refinery. It started operation in 1983 and is licensed until 2022. The facility refines yellow cake uranium from around the world.

This research report presented the results of a pooled cohort of 7,431 uranium workers from Port Hope (Canada) and Wismut (Germany) facilities first employed sometime between 1932 and 1989. This study provides the CNSC with a larger data set to better understand the health risks to uranium processing workers.

Studying the effects of doses to past workers is important in understanding the risk to health and mortality – and in continuously improving radiation protection programs to ensure worker health is protected. Continued follow-up as well as the inclusion of other worker data was recommended for future study.

Refer to the CNSC website for the final report: *Mortality risks in the pooled analysis of the Canadian and German uranium processing workers*

Did you know? There are currently five licensed uranium processing and fuel-fabrication facilities in Canada, all of which are located in Ontario. Each facility is periodically inspected by CNSC staff to evaluate operations and verify compliance with regulatory requirements and licence conditions.

Studies on the toxicity of tritium

The 2010 *Health Effects, Dosimetry and Radiological Protection of Tritium* report (INFO-0799) was one of many research studies initiated by the CNSC to expand its knowledge on tritium and further enhance existing regulatory oversight of tritium-related activities in Canada. One of the recommendations coming out of that report was to conduct additional research on the stochastic effects from exposure to tritium (i.e., the effects that have a random probability of occurring and can not be predicted precisely, such as cancer).

A new research project was launched to address that recommendation. It was divided into multiple tasks addressing different aspects of tritium exposure, including the relative toxicity of low-energy beta and gamma-radiations as well as biokinetic models for tritiated water and organically bound tritium uptakes. Major highlights from the study conducted on mice included a longer retention time in the body for organically bound tritium compared to tritiated water, and slightly higher physiological toxicity in various organs that were exposed to organically bound tritium than those exposed to tritiated water.

This study was undertaken by the CNSC in collaboration with the Institut de radioprotection et de sûreté nucléaire (IRSN) and the CANDU Owners Group (COG). The results of the project require further processing and interpretation before being published as peer-reviewed articles in several scientific journals. For this reason, the final report will be available on the CNSC website at a later date.

CNSC employees testing for tritium in the air outside SRB Technologies in Pembroke, ON.

SRB Technologies is licensed by the CNSC and uses tritium to make a number of products, including self-luminous emergency exit signs, landmine markers, watch dials and other safety products that do not require batteries or other external power sources.

Protecting the environment

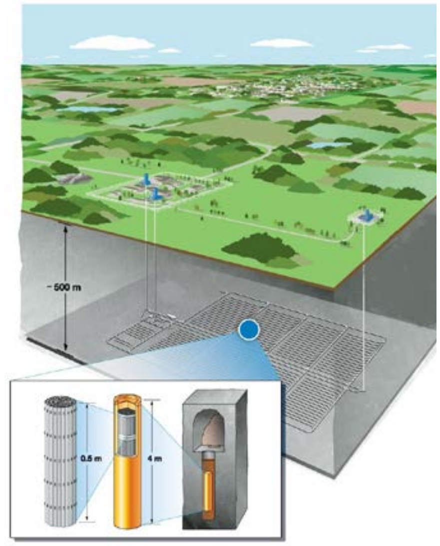
Protecting the environment is a vital part of the CNSC's mission and mandate. To uphold our commitment to environmental protection, we monitor every facility that is part of Canada's nuclear industry. Whether it is an environmental assessment of a new uranium mine or mill site, an unexpected release to the environment from a nuclear station, or a plan to dispose of nuclear waste, we are present at every step of the process to ensure the environment is protected. Our research supports this goal by keeping CNSC staff and industry informed of new developments in environmental science, risk assessment and waste management.

CNSC employees conduct a water sample assessment on the shores of Lake Ontario, just west of Pickering Nuclear Generating Station (in background).

Regular environmental sampling is performed around Canadian nuclear facilities as a part of the CNSC's Independent Environmental Monitoring Program. This program samples water, air, soil, sediment, vegetation and some local food to check contaminant concentrations and ensure they are within proper levels.

Coordinated Assessment and Research Program

The Coordinated Assessment and Research Program is a CNSC research program created in 2007 to investigate potential long-term safety issues in deep geological repositories. It involves conducting independent research in collaboration with a variety of international experts in addition to sharing information on geological repositories. During the past year, three projects were completed under the Coordinated Assessment and Research Program.



A deep geological repository design concept for used fuel.

The entire facility is several hundred meters underground. Spent fuel bundles are placed within secure containers, buried and then access is backfilled.

Natural and anthropogenic analogues

Most studies define natural analogues as either naturally occurring or anthropogenic (i.e., man-made) systems. This project looked more closely at the differences between these two types of natural analogues and how they can contribute to the safety case of deep geological repository projects. It found that anthropogenic analogues generally provide non-technical or anecdotal illustrations of concepts and processes for the safety case, while naturally occurring analogues can provide technical and quantitative information. In addition, naturally occurring analogues can provide information over massive geological time (millions of years) and spatial (kilometers) scales; anthropogenic analogues provide information over a much more limited time scale (just hundreds or thousands of years). As the safety case for deep geological repositories requires scientific information for long-term safety assessment – a million years or longer – naturally occurring analogues can provide information and data over geological time and spatial scales that cannot be extrapolated from laboratory experiments. This information will prove useful in providing evidence that will increase confidence in the safe geologic disposal of high-level radioactive waste.

A key recommendation from this project is that a concerted effort should be made to ensure there is a transfer of data from the complex natural analogue field studies to the simplistic models that, by necessity, are used in performance assessment. Field studies should be planned to align with laboratory experiments and, ultimately, field experiments when the final repository site is selected. This will provide a more quantitative use of natural analogue data in support of a deep geological repository concept.

Refer to the CNSC website for the final report: *Natural and anthropogenic analogues for high-level nuclear waste disposal repositories: A review*

Did you know? There are many examples of natural or anthropogenic analogues. Natural analogues can include natural uranium deposits, clay minerals or underground caverns. Anthropogenic analogues can include man-made items such as ancient Roman nails, the Iron Pillar of Delhi or Hadrian's Wall.

Safety assessment code

Part of the safety assessment for deep geological repositories includes the use of computer modelling – meaning the verification and validation of computer codes are an essential part of a safety assessment evaluation. One of the ways to verify and validate computer code is to compare the results with other independent codes. In Canada, the Nuclear Waste Management Organization (NWMO) conducted modelling for groundwater flow, contaminant transport and dose to humans in a case study on a generic deep geological repository in Canada. This CNSC project compared the results of the NWMO safety assessment with those produced by the Scoping of Options and Analyzing Risk (SOAR) code developed by the U.S. Nuclear Regulatory Commission. Overall, the results from the two codes were similar. This project concluded that SOAR is a robust, user-friendly and flexible scoping tool that CNSC staff may use, with certain modifications, for evaluating safety assessments of deep geological repository license submissions in the future.

Refer to the CNSC website for the final report: *Evaluation of safety assessment code for used fuel disposal facilities*.

Triaxial tests

CNSC worker taking vegetation samples at Bruce Power to be tested for contamination.

The excavation of galleries and shafts of a deep geological repository can induce damage in the surrounding rock, including fractures and micro-cracks. The damaged surrounding rock is referred to as the excavation damage zone, which has higher permeability and could act as a pathway for the migration of radionuclides. This project focused on sedimentary rocks such as limestone and shale (specifically Cobourg limestone and Tournemire shale) to confirm their hydro-mechanical behaviour under undamaged and damaged conditions.

The Rock Fracture Dynamics Facility at the University of Toronto was used to experimentally determine the hydro-mechanical behaviour of the two rock types. Triaxial and permeability tests were done on the samples to obtain mechanical and hydraulic properties and responses, and other geophysical methods were used to detect any damage to the samples. Overall, the measured permeability in damaged limestone rock is two to three orders of magnitude higher than intact rock. In other words, the damaged sedimentary rock is more likely to allow liquids and gases to pass through than undamaged sedimentary rock. The data collected in this experiment will be used to develop a mathematical model of host rock and assess the long-term performance of repositories.

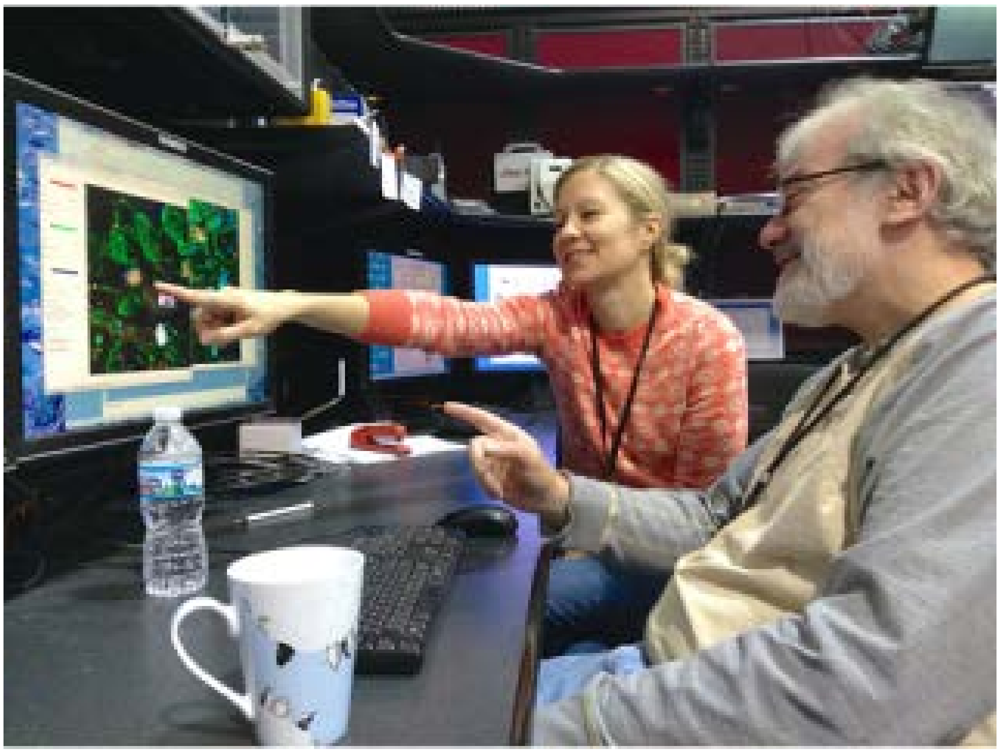
Refer to the CNSC website for the final report: *Laboratory triaxial and permeability tests on Tournemire shale and Cobourg limestone*.

Did you know? Cobourg limestone is a candidate rock type for a proposed deep geological repository in Canada. Tournemire shale is a rock type taken from the Tournemire underground research laboratory in France.

Detecting radium-226 in uranium mine tailings

Understanding the behaviour of long-lived radionuclides in uranium tailings is a key element in the CNSC's oversight of the long-term behaviour of tailings management facilities to ensure protection of the environment. For this project, tailings samples were taken from the McClean Lake tailings facility and analyzed using synchrotron techniques to determine the structure and forms of uranium in the tailings (which determines the behaviour and mobility of the radionuclides). This project has shown that synchrotron techniques can provide insight into the geochemistry and mineralogy of uranium in tailings. The results will help strengthen tailings management strategies and directly support regulatory decisions regarding Canadian uranium mines.

Refer to the CNSC website for the final report: *Synchrotron X-ray microspectroscopy for detecting Ra-226 and its daughters in tailings and mill waste from uranium mining operations*

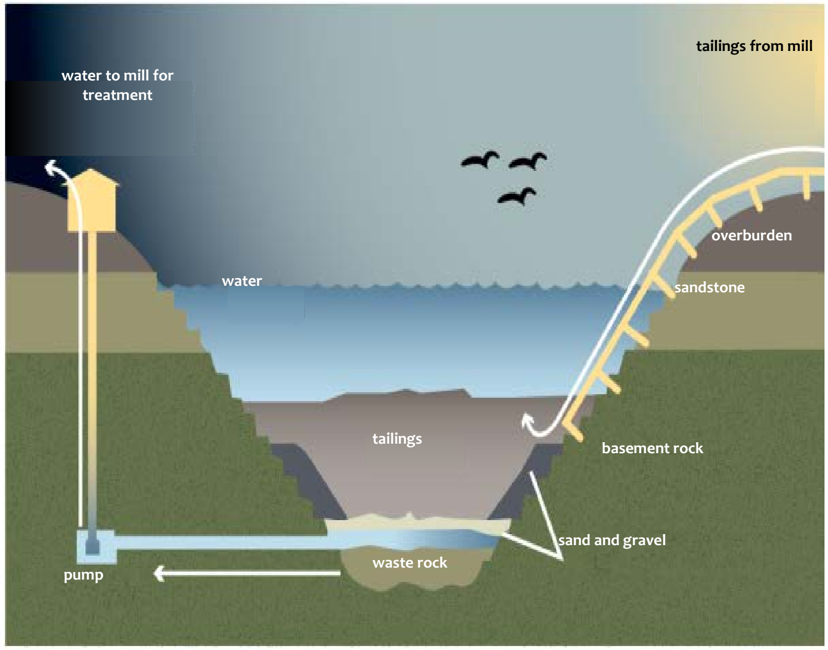


Dr. Karina Lange (CNSC), with Dr. Tony Lanzirotti at the Center for Advanced Radiation Sources at Argonne National Laboratory, points out detected uranium in a tailings sample.

Did you know? Tailings are waste produced during uranium mining and milling after grinding the ore and chemically removing most of the uranium. Tailings management facilities are designed to isolate the tailings from the surrounding environment for thousands of years.

Permafrost degradation due to mining disturbances

Uranium mining produces waste in the form of mine tailings and mine waste rock, both of which must be adequately managed to protect the environment. The CNSC received a project proposal for a uranium mine and mill facility that, if licensed under the *Nuclear Safety and Control Act*, would be the first such facility in Canada's continuous permafrost zone. Potential thawing of the permafrost could affect the integrity of the tailings management facilities. Predicting the permafrost degradation during the lifecycle of the project is important for environmental assessment and licensing decisions.



A typical mine tailings pit.

This research project investigated the effects of the mine on permafrost both during operation and after decommissioning. It concluded that, during mine operation, permafrost degradation around the open pits and the tailings management facilities would be limited and their integrity would not be compromised.The long-term thermal behaviour of permafrost surrounding tailings management facilities was assessed with consideration of different climate change scenarios. When no climate change is assumed, there would be a slight reduction in permafrost thickness. With a climate change scenario of 5°C temperature increase in 100 years, the permafrost surrounding the tailings management facilities would reduce greatly in the long-term. However, approximately 35-metre thick permafrost layer would be produced on the top of the tailings management facilities, which would prevent any tailings pore water from migrating upward to reach the ground surface. When assuming a 7°C temperature increase in 100 years, the entire permafrost layer would eventually thaw. However, the ground water level around the mine tailings management facilities would be approximately 35 meters below ground surface, meaning tailings pore water would not likely migrate upward to reach the ground surface even after the permafrost has completely disappeared.

Therefore, with an appropriate design and decommissioning plan, deposition of the tailings into the converted tailings management facility would not likely cause any significant adverse impacts to the surface environment immediately surrounding the decommissioned tailings management facilities.

Refer to the CNSC website for the final report: *Permafrost degradation within continuous permafrost zones due to mining disturbances in Canadian northern regions*

Did you know? Uranium mines differ from traditional mines in that they have greater levels of radioactive elements (such as thorium, radium and other decay products) as waste products. As such, they must be continually monitored by CNSC staff.

Spotlight on CNSC research staff: Andrei Blahoianu

Through its regulatory research, the CNSC uses the knowledge and expertise of many technical specialists and experts, including Mr. Andrei Blahoianu. Educated in mechanical engineering, Mr. Blahoianu was a professional engineer with a career spanning more than 45 years designing and regulating nuclear facilities. At the CNSC, Mr. Blahoianu was the director of the Engineering Design Assessment Division. In this position he led regulatory activities on pressure-retaining components; civil engineering; fire protection; aging management; and the protection of structures, systems and components against impacts. As the director of a division with a very broad technical mandate, Mr. Blahoianu effectively used the CNSC research program and also maximized cost-free CNSC participation in various international projects related to nuclear safety. These projects touched on topics such as engineering protection against natural hazards (e.g., earthquakes) and man-induced hazards (e.g., missiles), fire protection and aging management of concrete structures. He relied heavily on the technical and leadership skills of his expert staff in initiating and leading these research projects successfully.


Mr. Andrei Blahoianu, past director of the CNSC's Engineering Design Assessment Division.

Mr. Blahoianu has also represented the CNSC on a variety of committees of the CSA Group (formerly the Canadian Standards Association), including N287, *Requirements for containment*; N289, *Seismic qualification requirements*; and N291, *Requirements for structures*, among others. Mr. Blahoianu has been the vice chair of the CSA Group technical committees for pressure-retaining components, seismic qualification, concrete containment and civil structures of CANDU nuclear power plants.

Mr. Blahoianu's involvement in nuclear engineering activities has not been limited to Canada; he chaired the Nuclear Energy Agency's Working Group on Integrity and Ageing of Components and Structures from 2006 to 2012, and was a member of several international committees and groups. These include the Advisory Board of International Association for Structural Mechanics in Reactor Technology, the Global Steering Committee of the International Forum for Aging Management, the Organisation for Economic Co-operation and Development – Nuclear Energy Agency Working Group on External Events, and the International Atomic Energy Agency (IAEA) International Seismic Safety Centre. A major achievement of his work with the International Seismic Safety Centre was access to an earthquake-notification system that provides ground-shaking data at nuclear facilities within minutes of an earthquake.

Beyond this, Mr. Blahoianu has co-authored papers in various international journals; chaired international events in Canada, China, Finland, France, Japan, India, Norway, Poland and the United States; and participated in several IAEA expert missions. His efforts and leadership led to him receiving the Canadian Standards Association Award of Merit in 2012.

Spotlight on CNSC research staff: Michel Couture

Dr. Michel Couture, past director of the CNSC's Physics and Fuel Division, receiving the CNSC Leadership Award in 2011.

The CNSC research program has benefited greatly from the knowledge and expertise of Dr. Michel Couture, whose strong technical background prepared him well for the complex technical issues he would face at the CNSC. He obtained a bachelor degree in physics from the College Militaire Royal de St. Jean in 1971, and his master's and doctorate degrees in theoretical physics from McGill University in 1975 and 1981, respectively. He earned several academic honours, including the Governor General of Canada Medal for Academic Excellence in 1969, the National Science and Engineering Research Council of Canada Centennial Scholarship in 1971, and a National Science and Engineering Research Council of Canada post-doctoral fellowship held at Chalk River Nuclear Laboratories (1980–82).

Dr. Couture joined the CNSC's Physics and Fuel Division in 1999, serving as a fuel specialist until 2007, when he was named director of the division. In that role from 2007 to 2016, he led the regulatory technical activities related to reactor physics, nuclear fuel (including fuel thermal hydraulics) and out-of-core nuclear criticality safety. His division is also an important contributor to the deterministic safety analysis for nuclear reactors and nuclear fuel-cycle facilities.

The Physics and Fuel Division has always been an important contributor to the CNSC's research program. As director, Dr. Couture was a strong supporter of his staff's involvement in the program. His belief in the benefits of international cooperation as a means of strengthening staff technical expertise and contributing to nuclear safety worldwide led to staff participation in many international working groups as well.

Before joining the CNSC, Dr. Couture was a member of the Theoretical Physics Branch (1980–96) and the Fuel Safety Branch (1996–99) at the Chalk River Nuclear Laboratories. His research activities during that period covered topics in nuclear fuel modelling, accelerator physics (computational electromagnetics), condense matter physics and mathematical physics. He has collaborated in various research projects with scientists from Canada, the United States, China and the former Czechoslovakia. Dr. Couture is also the author and co-author of more than 35 publications in technical journals and conference proceedings.

Advancing regulatory perspectives

As regulatory perspectives change all the time, the CNSC must work in close partnership with nuclear regulators from around the world to share and keep up to date on these perspectives. Collaboration with foreign regulators is important as it allows us to give and receive information on the newest advances in nuclear technology – such as the development of new reactor designs – as well as lessons learned from other regulators to ensure Canada's nuclear regulatory framework remains strong and robust.

IAEA Small Modular Reactor Working Group

Member States of the IAEA expressed the need for a regulators' forum to be able to communicate and cooperate in facing challenges brought by the development of small modular reactor (SMR) facilities. The IAEA has agreed to a two-year trial in which it will provide secretariat services and a meeting facility for this forum, which will facilitate the sharing of knowledge and experience among Member States and allow more informed regulatory decisions to be made about small modular reactors. Through this forum, the CNSC can improve the quality of vendor design reviews and licensing technical assessments for projects regarding small modular reactor designs.

CNSC staff with other representatives from IAEA Member States at the IAEA Small Modular Reactor Regulator's Forum.

Did you know? Small modular reactors have been claimed by industry to be cheaper and faster to bring to commercial operation. They are also claimed to be amenable to smaller power grids, including remote areas such as Canada's north. Designs under development include water-cooled reactors, high-temperature gas-cooled reactors and liquid metal cool reactors.

Multinational Design Evaluation Programme

Established in 2006, the Multinational Design Evaluation Programme (MDEP) combines the resources and knowledge of its 15 participating national regulatory authorities, including the CNSC, as well as other stakeholders to review the designs of new nuclear power reactors and to harmonize regulatory approaches around common topics of interest such as novel I&C designs, vendor inspection cooperation and codes and standards. Its goals include helping different regulatory frameworks work together by sharing resources and encouraging multinational convergence of regulatory codes and standards. MDEP has organized three conferences to date – in 2009, 2011 and 2014 – and also distributes press releases to communicate its major events and accomplishments.

Support for CSA Group nuclear standards

The CSA Group is a Canadian not-for-profit that publishes standards in several industries, including nuclear, many of which are referenced in CNSC regulations. The CNSC supports the CSA Group and its standards program through an in-depth contribution agreement. The CNSC has contributed to the CSA Group for standards development using lessons learned from the Fukushima Daiichi nuclear accident, and has provided support for the Nuclear Safety Standards Program, the Communities of Interest platform to provide greater access to nuclear standards, and the Association’s annual conference and committee week.

CNSC staff along with members of national regulatory bodies of countries that own CANDU power plants, attending the annual CANDU Senior Regulators’ Meeting in Toronto, ON.

The annual CANDU Senior Regulators’ Meeting provides a forum for different regulators to share CANDU-related regulatory experiences and practices to improve overall safety and regulatory effectiveness.

International commitments

The CNSC's research program is not limited to Canada – it includes a large variety of international collaboration as well. We work in cooperation with organizations such as the United States Nuclear Regulatory Commission, the Organisation for Economic Co-operation and Development's Nuclear Energy Agency, and the International Atomic Energy Agency. We continue to show our support to these organizations by participating in international initiatives such as the International Generic Lessons Learned and Committee of Safety of Nuclear Installations. In addition, memoranda of understanding between the CNSC and other nuclear regulatory agencies ensure our research knowledge is shared and disseminated around the world.

Various delegates discuss during the 59th IAEA General Conference, prior to the presentation of the Report on the Fukushima Daiichi Accident – Lessons Learned.

With Canada as a member of the IAEA, the CNSC and its staff are regularly involved in IAEA activities such as the General Conference. In 2015, Mr. Ramzi Jammal, CNSC Executive Vice-President and Chief Regulatory Operations Officer, presented a description and context of the Fukushima Daiichi accident. The CNSC was a direct contributor to the IAEA Director General's report on the accident and its five technical volumes. Read the presentation on our website.

Did you know? A memorandum of understanding is an agreement between parties that establish some sort of official partnership or cooperation. The CNSC has more than 15 memoranda of understanding (and many other agreements) with other regulatory agencies, often agreeing to share and exchange nuclear information.

Agreement with the European Commission

CNSC has entered an agreement with the European Commission to work together to support the Sustainable Network for Independent Technical Expertise of Radioactive Waste Disposal (SITEX) II initiative and the FAST Nuclear Emergency Tools (FASTNET) project. Both of these projects fall under the Horizon 2020 movement, which aims to break down barriers and share a single market for research knowledge and innovation.

The SITEX II initiative is a two-year project that looks to address any possible safety issues related to the long-term management of high-level radioactive waste from the use of nuclear fuel. Its main purpose is to reinforce or make necessary changes to improve the licensing process and requirements for geological repositories. The four-year FASTNET project looks to qualify a graduated response methodology, which would integrate multiple tools to ensure the diagnosis of severe-accident progression and estimate possible consequences to nuclear power plants or spent fuel pool facilities in Europe. The CNSC will be involved in four of the six FASTNET work packages.

The CNSC's involvement in both these projects will allow for a relationship where experiences and knowledge can be shared by partners and other international regulators. This allows the international nuclear industry to grow as a whole and leads to a safer and more effective industry. This opportunity also opens the door for collaboration on future research projects.

International SITEX members (including CNSC staff) attending the first SITEX II Plenary meeting at Millau, France standing in front of the Tournemire Underground Research Laboratory.

Organization for Economic Co-operation and Development / Nuclear Energy Agency initiatives

The Organization for Economic Co-operation and Development (OECD) is a forum where 34 countries work together to understand and help governments address challenges related to the economy, the environment and an aging population.

A specific branch of the OECD is the Nuclear Energy Agency (NEA): the only intergovernmental agency that brings countries from North America, Europe and the Asia-Pacific region into a non-political environment to provide a means for cooperation and to disseminate the latest news in nuclear technology. Within the NEA is the Committee on the Safety of Nuclear Installations (CSNI), which comprises regulatory authorities as well as senior scientists and engineers with responsibilities in safety technology and research programs. As an active member of the CSNI, the CNSC works to further develop scientific and technical knowledge to be able to better assess the safety component of nuclear reactors and fuel cycle facilities.

CNSC staff with other NEA member countries attending the Component Operational Experience, Degradation and Ageing Programme (CODAP) inaugural meeting.

The Component Operational Experience, Degradation and Ageing Programme (CODAP) is a program that combines follow-ups on the Pipe Failure Data Exchange Project and the stress corrosion cracking portion of the Stress Corrosion Cracking and Cable Ageing Project. These two projects were combined due to the relevance in plant aging management.

North American Technical Center – Information System of Occupational Exposure

The NEA created the Information System of Occupational Exposure in 1992 to improve the management of occupational radiation exposures – and, as a result, worker safety – by enabling radiation protection professionals to share dose information and related operational experience. The CNSC entered into a three-year agreement with the University of Illinois, which operates the North American Technical Center, in 2014. The CNSC uses the Information System of Occupational Exposure data to inform the development of its regulatory framework and improve the guidance provided to licensees. Access to the database has provided CNSC staff with a better understanding of radiation protection initiatives, experience, best practices and current challenges – helping them review and assess licensee radiation protection programs.

Visit the Organisation for Economic Co-operation and Development or Information System of Occupational Exposure websites for more information.

Fire Incident Records Exchange project

The CNSC participated in Phase IV of the OECD Fire Incident Records Exchange (FIRE) project. The purpose of the FIRE project is to provide a platform for collaboration and the exchange of data from fire events at all nuclear power plants in the member countries. The objectives of Phase IV included further enhancing the database, grouping events and performing trending analysis from fire events to better understand root causes, and extending analyses to estimate fire frequencies. The CNSC will use the knowledge gained through this initiative to strengthen its regulatory framework. This may include the next revision and maintenance of CSA Group standard N293, *Fire protection for nuclear power plants*. Due to the success of this project, the CNSC is looking to continue its participation in Phase V.

The Point Lepreau Generating Station fire response team inspecting a new fire truck.

High Energy Arcing Fault Events project

A high-energy arcing fault is a massive electrical discharge that can occur in electrical switching components and be caused by poor electrical connections, environmental conditions (e.g., corrosion) or the introduction of a conductive foreign object (e.g., a wrench). The OECD started the High Energy Arcing Fault Events project in 2012, conducting experiments to determine damage mechanisms; extent of affected areas; methods of protecting systems, structures and components; and possible calculation methods for modelling high-energy arcing fault events as applicable to fire protection in nuclear power plants. Testing using full-sized equipment is complete and data has been shared with project participants. The current stage of the project involves data analysis, which is ongoing.

The results from this project may be incorporated into the next revision of CSA Group standard N293, *Fire protection for nuclear power plants*. They may also support the development of a CNSC regulatory document on fire protection as well as deterministic and probabilistic safety analyses on fire events (important given that high-energy arcing fault events have caused several fires in the past), and identify potential weaknesses in defence-in-depth plant design.

Visit the Organisation for Economic Co-operation and Development website for more information.

International Atomic Energy Agency initiatives

The International Atomic Energy Agency (IAEA) is an international organization that works with its Member States, including the CNSC, and other global partners to verify the non-proliferation of nuclear facilities and substances. The CNSC partners with the IAEA on a number of projects, including International Generic Ageing Lessons Learned (IGALL) and the IAEA International Seismic Safety Centre.

CNSC President Michael Binder (middle) and Executive Vice-President and Chief Regulatory Operations Officer Ramzi Jammal (left) welcome Mr. Yukiya Amano (right), Director General of the IAEA

International Seismic Safety Centre

The International Seismic Safety Centre was created in 2008 to assist the global nuclear industry in ensuring safety at its facilities during extreme natural or man-made hazards. It enhances the ability of IAEA Member States to manage and improve nuclear safety by providing better information for nuclear site selection and evaluation, strengthening the engineering designs of new facilities as well as modifications at existing facilities, improving safety evaluations, and collecting operating experience and lessons learned from previous extreme external events.

The CNSC participates in the International Seismic Safety Centre through contributions, staff involvement in working areas and the dissemination of results from CNSC research. The CNSC benefits through the exchange of information with experts from around the world, which ensures Canadian regulations are consistently up to date. For example, the IAEA Earthquake Notification System is a Web-based system that automatically sends notification to registered recipients after a seismic event occurs anywhere around the world, including a description of the location, the location's coordinates, the magnitude of the event and the distance to the nearest nuclear installations. This information could be used as a tool to create better scenarios for estimating the potential damage to nuclear installations due to hypothetical earthquakes.

International Generic Ageing Lessons Learned

The International Generic Ageing Lessons Learned (IGALL) database is an international platform for discussion between regulators and utilities on implementing acceptable aging-management programmes. The IAEA is currently in its third phase of the project, which consists of the implementation of IGALL on nuclear power plants as well as further enhancement of database completeness. The IAEA expects to update the IGALL database in 2016.

CNSC staff and IGALL committee members at the IGALL Steering Group meeting in Vienna.

Other international involvement

U.S. Nuclear Regulatory Commission – Code Applications and Maintenance Program

CNSC continues to be a member of the U.S. Nuclear Regulatory Commission (NRC) Code Applications and Maintenance Program (CAMP). The U.S. NRC and its international partners formed the Code Application and Maintenance Program in order to exchange information and experience on thermalhydraulic safety issues related to reactor and plant systems, including code errors and inadequacies. It also promotes cooperation to resolve deficiencies, the sharing of user experience on facilities modelling and code assessment, and more. By participating in this program, the CNSC has access to the CAMP computer codes, which provide modern, independent and, in many aspects, more advanced computer code capabilities for safety analysis.

Delegates at the 2015 Canadian Organization of Medical Physicists Winter School in Kelowna, BC.

Did you know? The Canadian Organization of Medical Physicists is the main professional body for practicing medical physicists in Canada. Each year it holds a winter school on quality and safety in radiation oncology, which is supported by the CNSC. This past year, almost 100 delegates attended from Canada, the United States, the United Kingdom, Ireland and Australia. Delegates consisted of physicists, radiation therapists, radiation oncologists and administrators, regulators and industry representatives. The winter school consists of four days of presentations on topics such as the tools needed to make improvements to safety and quality in radiation oncology; details on tools such as statistical process control, human factors, safety management systems, in-vivo dosimetry and change management; and the path forward for radiation medicine. As a result of the winter school, faculty and delegates will take new knowledge back to improve the quality and safety of patient treatments.

Canadian Safeguard Support Program initiatives

The IAEA is responsible for providing assurances that nuclear material and facilities are used solely for peaceful purposes. It fulfils this responsibility through the implementation of verification measures known collectively as safeguards. The Canadian Safeguards Support Program (CSSP) was established in 1977 as one of the first member state support programs in order to assist the IAEA in developing the equipment and processes required for safeguards. The CSSP supports the implementation of safeguards and the IAEA by providing technical assistance and resources, including the development of nuclear safeguards equipment and technologies. This support demonstrates Canada's commitment to nuclear non-proliferation. The following are summaries of the achievements made by the CSSP during the 2015–16 fiscal year.

Technical support for the prototype portable handheld Laser-Induced Breakdown Spectroscopy system

Laser-induced breakdown spectroscopy (LIBS) uses a pulsed laser to excite and assess a sample of nuclear material. It includes specialized software to analyze the emitted radiation, identifying not only elements but also compounds. In particular, LIBS can identify a variety of nuclear materials that are relevant to safeguards. While this technique is well established in laboratory equipment, developing a handheld instrument that can be used in the field by IAEA inspectors has proven to be a challenge.

The National Research Council of Canada, through CSSP funding, is developing a portable LIBS device and the associated chemometrics analysis software. It will be able to identify different types of uranium ore concentrate (also known as "yellow cake") and assess other non-radioactive indicators of the nuclear fuel cycle. The device was delivered to the IAEA in summer 2016 for further evaluation. The IAEA will then use this portable device as a benchmark device to evaluate commercial handheld laser devices. The ultimate goal of the portable LIBS device is to enable IAEA inspectors to screen samples in the field, cutting down on the number of samples needing to be shipped to the IAEA laboratory for analysis.

A portable laser-induced breakdown spectroscopy (LIBS) device.

The IAEA will use this portable device as a benchmark to evaluate commercial handheld laser devices.

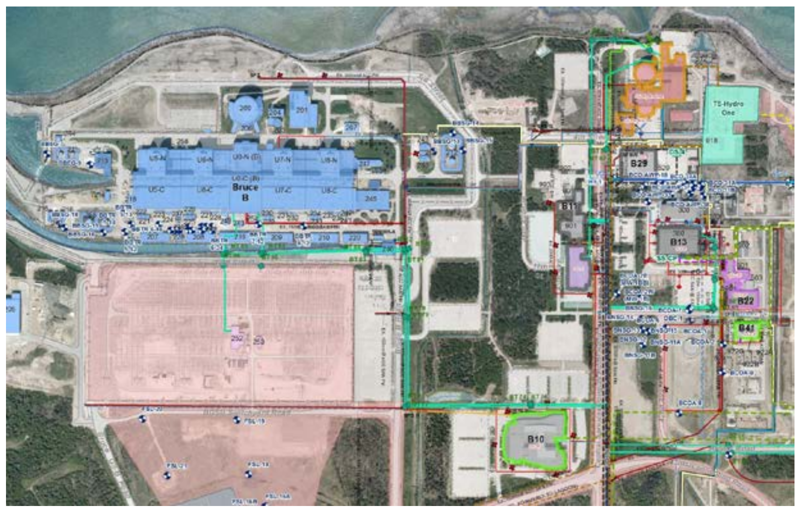
Development of advanced prediction models for Cerenkov radiation emission in spent fuel

The CSSP is working with the Swedish safeguards support program on the use of Cerenkov light emissions to characterize spent reactor fuel. For this task, the IAEA requested assistance in acquiring the capability to accurately estimate Cerenkov light emission for spent fuel assemblies of any design while taking into account initial fuel composition, irradiation history and fuel design.

This project builds on Canadian technology (specifically, the digital Cerenkov viewing device) to enhance the capability to verify and detect the diversion of spent fuel in wet storage. The CSSP has supported the development of the digital Cerenkov viewing device since its inception and this project continues that commitment.

Digital declaration site maps

Although site maps are required as part of IAEA Member States' Additional Protocol (AP) declarations, most are submitted in paper format. Bruce Power volunteered for a pilot project (with overall coordination by the CNSC) to assist the IAEA in developing a standard format and method for submitting digital site maps into the IAEA's existing and evolving information systems. Digital site map submissions will significantly improve the IAEA's ability to develop, maintain and update accurate site maps to guide its verification activities.



An integrated digital site map for declarations under the IAEA Additional Protocol.

Through consultations and ongoing development over a three-year period, the IAEA developed a framework document providing guidance to its Member States for the submission of digital maps for AP declarations. Based on this framework, Bruce Power has submitted a digital map to the IAEA as part of its AP declaration for 2015.

A collaborative paper by the CNSC, Bruce Power and the IAEA on this project was presented at the 2016 annual meeting of the Institute of Nuclear Materials Management in Atlanta, Georgia.

Development of the Next-Generation Autonomous Data Acquisition Module

Verifying the loading and unloading of fuel from CANDU reactors presented a safeguards verification challenge for the IAEA. The VXI Integrated Fuel Monitoring (VIFM) system was developed under the CSSP to meet this challenge and is used to safeguard CANDU reactors in Canada and elsewhere. To provide information to the IAEA in real time, the VIFM system depends on the Autonomous Data Acquisition Module (ADAM). The Next-Generation ADAM Module (NGAM) currently being developed replaces legacy hardware and incorporates new capabilities with respect to data storage and connectivity.

In 2015–16, the IAEA finalized the requirements for the second phase of NGAM development. Eight tasks under these requirements were issued and completed by the selected contractor, Bot Engineering. The results of these completed tasks are currently under IAEA review and evaluation.

Application of Safeguards to Geological Repositories

The objective of the Application of Safeguards to Geological Repositories (ASTOR) project is to allow the dissemination between IAEA Member States and researchers of the latest developments relevant to applying IAEA safeguards to a geological repository for the long-term containment of spent nuclear fuel. This project included CNSC participation in and contributions to the 2015 ASTOR meeting in Gyeongju, South Korea. Each Member State representative gave a presentation on the status of their national programs and equipment developers, and researchers presented on diverse new technologies and techniques that could be applied to safeguarding spent fuel in a geological repository.

CNSC's Executive Vice-President and Chief Regulatory Operations Officer Ramzi Jammal speaking at the Seventh Review Meeting of the Convention on Nuclear Safety in Vienna.

IAEA inspector training

The VXI Integrated Fuel Monitor (VIFM) system, which allows the IAEA to remotely monitor the discharge of fuel from CANDU reactors, was developed under the CSSP and is widely utilized by the IAEA in CANDU facilities all around the world. The primary objective of this project was to provide training to IAEA inspectors on the fuel monitoring system. The course touched on the architecture, function and application of the VIFM system; data monitoring, analysis and interpretation; and the importance of continuity of knowledge. Upon completing the course, IAEA inspectors will have acquired knowledge that can be used to support the implementation of effective IAEA safeguards inspections at CANDU facilities. Eton Systems successfully delivered the updated course in February 2016.

In addition, Canada partnered with Sweden and Finland to deliver two training courses to IAEA inspectors in 2015–16: one on digital Cerenkov viewing device (DCVD) partial defect verification and the other on spent fuel verification (SFV). These courses were requested by the IAEA to give inspectors the comprehensive knowledge and skills needed to verify spent fuel for safeguards purposes. The theoretical portion of both the SFV and DCVD courses were delivered primarily by a Canadian instructor at IAEA headquarters in November 2015. The practical portion, including workshops and field exercises, was delivered in Sweden in March 2016. There were 12 participants in the SFV course and eight participants in the DCVD course. The feedback indicated that these courses were well received and met their objectives.

A digital Cerenkov viewing device (DCVD).

A DCVD can be used as a non-intrusive method of inspecting and verifying spent nuclear fuel with an improved detection of partial defects (e.g., missing fuel pins).

Cost-free* Experts*: Secure communications and satellite imagery

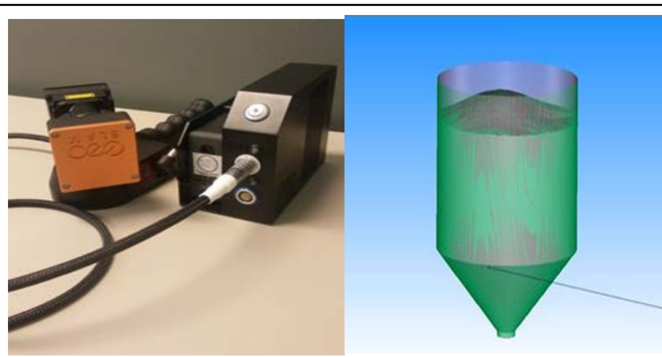
A Cost-free Expert (CFE) is an individual with specialized skills who works for the IAEA but whose salary is paid by the sponsoring Member State. The CSSP funded two CFEs in 2015–16:

- An expert from the CNSC's Information Management Technology Directorate worked on updating the IT infrastructure of the IAEA Safeguards Department to provide a secure electronic channel for uploading official reports and other sensitive communications to the IAEA. This work is facilitating the CNSC's delivery of safeguards reports to the IAEA under an automated system.

- An expert from Defense Research and Development Canada is working on the integration of synthetic aperture radar (SAR) into the IAEA's satellite imagery unit. This CFE is also providing training on the application of SAR to safeguards analysts in the IAEA. The use of radar imagery will enhance the IAEA's ability to draw effective and efficient safeguards conclusions for Member States, which contributes to the CNSC's mandate to uphold Canada's international obligations on the peaceful use of nuclear energy.

Evaluation of the 3D laser scanner for powder measurements in large containers

To improve physical inventory taking at uranium-processing facilities, new technologies are being evaluated to assess the quantity of uranium-containing powders in large vessels. Measurement uncertainties of traditional techniques are large, complicating the material balance evaluation process that is critical for both the IAEA and the CNSC to implement successful safeguards. During the 2015–16 fiscal year, the Canadian Safeguards Support Program funded a project to procure 3D laser scanning equipment that would establish a method of accurately measuring the volume of bulk powder in large uranium-containing vessels, improving the confidence in Canada's declarations of nuclear material inventories. The 3D laser scanning equipment will be used by CNSC staff during the 2016 physical inventory taking processes at major uranium processing facilities.



The 3D laser scanner (left) is used to obtain the volume of nuclear material in a vessel (right).

Safeguards outreach

Through this outreach initiative, the CNSC is informing research institutions and companies in Canada about safeguards and related obligations – including the reporting requirements for nuclear material and research related to the nuclear fuel cycle in Canada. The outreach was funded through support of the Canadian Safeguards Support Program mandate of improving the safeguards regime in Canada. Eight licensees were selected for the initial outreach, including universities and private sector organizations. It is expected that all visited sites will be able to improve the quality of their safeguards reporting as a result of this outreach.

Inspector training for fall arrest and respirator fit

IAEA inspectors must be certified before working at heights at Canadian nuclear facilities. Because each Canadian facility has its own certification requirements, inspectors must complete multiple time-consuming courses – and inspector scheduling faces many limitations. As such, the IAEA requested that the CNSC investigate a method for a streamlined approach to fall arrest training. After considering a number of options and the requirements under different provincial jurisdictions, the CNSC concluded that the most cost-effective approach would be to deliver the training in Vienna before the arrival of IAEA inspectors in Canada.

The Canadian Safeguards Support Program funded training for 24 IAEA inspectors, which took place in March 2016, allowed these inspectors to be certified for three years at all but one of the nuclear facilities in Canada that require fall arrest training. Additional commitments were obtained from the remaining facility to streamline training for inspectors.

CNSC Technical Support Branch Vice-President Terry Jamieson gives a speech at Canada's International Physical Protection Advisory Service (IPPAS) Mission 2015.

The IPPAS mission was created by the IAEA to assist Member States in strengthening their national nuclear security regime. The CNSC had its physical protection system reviewed under this mission, which it successfully passed.

Neutron detector evaluation

An evaluation of the neutron signal from uranium-bearing slag and historical material in Port Hope, ON was carried out in fall 2015. This evaluation was part of a study to examine the effectiveness of an IAEA proposal to use neutron detectors to quantify the amount of safeguarded nuclear material that is to be deposited into the long-term waste management facility outside of Port Hope. The contractor submitted a full report of the measurements taken over a two-day period. Samples of the material were also sent for analysis to the CNSC's laboratory. The analysis confirmed that a neutron signal could be detected from the material in question, supporting the possibility of the IAEA using neutron detectors to verify this material prior to final deposition in the long-term waste management facility.

Variation of powder density with fill height and vessel geometry

As part of the CNSC's effort to improve the material balance evaluation of nuclear material in uranium-processing facilities at the time of physical inventory taking, it is also important to improve the assessment of volumes, densities and uranium content of uranium-bearing powders inside facilities. To better understand how density varies and what factors are important, the Canadian Safeguards Support Program contracted for a literature survey on this subject. In March 2016, the CNSC procured 3D laser scanning equipment to improve the measurement of the volume or uranium powders in large vessels. The evaluation of the equipment will take place during the 2016 physical inventory taking at selected uranium-processing facilities. Further work is also being planned to investigate variations in the density of material in these large vessels and its impact on uranium mass determination.

A CNSC employee checking for radiation levels outside a waste transport truck.

Radioactive waste cannot be disposed of using the same methods as regular waste. Radioactive waste must be properly sealed and stored to ensure no radiation is released to the environment or the public.

Strengthening the next generation

Participating in outreach activities helps the CNSC meet one of the major objectives in its mandate: the dissemination of scientific, technical and regulatory information. The CNSC's participation also helps establish the CNSC's dedication to maintaining the public's safety and trust as well as helping strengthen the next generation. One of the methods the CNSC achieves this is by supporting activities through various contributions and grants to academic and non-profit institutions. The CNSC also participates in activities involving educating elementary school students, university co-op programs and public events. The CNSC believes fulfilling its initiative to strengthen the next generation will help the next generation of scientists, engineers and technical specialists grow to lead our research and fulfil the goals of our research program.

CNSC employees educating children at the Cool Science Saturday 2016 event.

University Network of Excellence in Nuclear Engineering

Every year the CNSC contributes to the University Network of Excellence in Nuclear Engineering (UNENE), which is a partnership between the nuclear industry and Canadian universities, research and regulatory agencies. Established in 2002, UNENE has three main objectives: to train and develop highly qualified personnel through research and education; to create a pool of scientific experts available for consultation by government and industry; and to support and fund nuclear research in universities. UNENE provides working professionals an education in the form of a master's of engineering program intended to enhance and build student knowledge. The CNSC sits on various UNENE committees including the Board of Directors and Research Advisory Committee.

The first place winner of the 2015 UNENE student workshop, with UNENE president Dr. Basma Shalaby.

Every year UNENE hosts a student workshop and poster session where graduate students from across the country have the opportunity to present their research to the nuclear industry. Three winners are chosen each year; the work of last year's first-place winner focused on the corrosion of carbon steel under deep geological disposal conditions for spent nuclear fuel waste.

Visit the UNENE website for more information.

Let's Talk Science

Let's Talk Science is a not-for-profit organization that uses a variety of science-based learning programs and services to encourage Canadian youth to pursue careers in science, technology, engineering and math. In the past year, Let's Talk Science engaged with more than one million youth and 15,000 educators in 1,500 communities across the country.

The CNSC contributes to Let's Talk Science to engage students and educators on the topic of nuclear technology. To this end, Let's Talk Science has provided engagement opportunities to CNSC staff, developed articles showcasing different parts of the nuclear industry, posted videos (some of which were produced by the CNSC), developed a case study on nuclear technology, included information on nuclear imaging and nuclear power during student events, added nuclear technology to its outreach kit, and included nuclear science in its high school symposia. Let's Talk Science also intends to use more volunteers who have an expertise in nuclear science and technology, and will continue to showcase collaboration with the CNSC to raise awareness of the nuclear field.

Visit the Let's Talk Science website for more information.

Renewing the CNSC workforce

To counteract the loss of technical expertise as older employees retire, the CNSC has implemented a program to draw more university graduates to the nuclear industry. More than 70 new employees – almost 10 percent of the current CNSC workforce – have been brought into the organization through this program since 2014. Spread throughout the CNSC (but with the majority placed in science or engineering positions), these new graduates are given the opportunity to rotate on assignments within the organization and further develop their skills, forming a diverse talent pool to support the CNSC in the years to come. Many of these new graduates will compete for internal positions and may become future research leaders at the CNSC.

CNSC co-op program

CNSC co-op students from the University of Ontario Institute of Technology.

The CNSC hired eight co-op students for 15-month terms in 2015 and five more students in 2016. As part of the 15-month program, students rotate every four months into different divisions within the CNSC and present on their work at the end of each division work term.

Co-op student & co-author of this report, Harishan Manoharan, during a visit to Canadian Nuclear Laboratories.

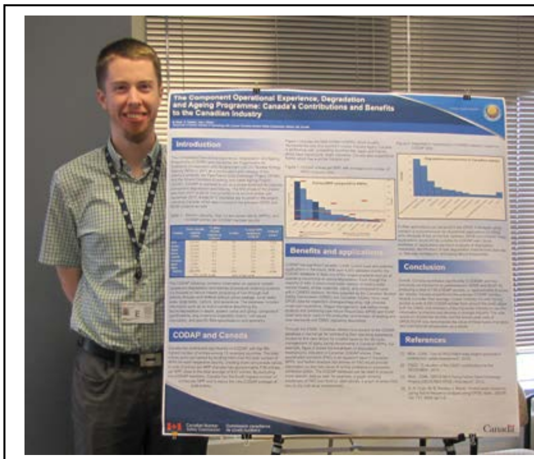
As part of the CNSC's co-op program, students are given the opportunity to get hands-on experience by visiting nuclear facilities.

Every year the CNSC hires university students into a 15-month co-op program, rotating them through four different divisions within the organization to give them meaningful work and hands-on experience in the nuclear industry. As part of the CNSC co-op program, students are often given opportunities to travel and participate in work outside of the Ottawa office. Some examples include inspections of facilities such as nuclear power plants or uranium mines, technical meetings with licensees, training sessions and a variety of industry conferences.

In 2015, eight students were brought into the CNSC through the co-op program. A total of 46 students have been involved with the co-op program since its inception in 2006, with 52 percent of these students being hired as full-time workers at the end of their terms – and of those hires, 88 percent are still with the organization. The CNSC is always looking for skilled individuals who are engaged, curious and willing to learn.

CNSC student participation at the Canadian Nuclear Society annual conference

Through the CNSC co-op program, some students are given the opportunity to attend conferences and present their work. One CNSC student attended the 2016 Canadian Nuclear Society annual conference to present work on a CNSC research project related to the Nuclear Energy Agency Component Operational Experience, Degradation and Ageing Programme (CODAP): an international database of passive component degradation and failures with a focus on pressure-retaining systems. Canada has been involved with CODAP since its inception in 2011 as well as its two precursor projects. The work presented at the Canadian Nuclear Society conference provided an introduction to the project, discussed Canada's involvement compared to the other member countries, and explained its potential benefits and applications.



Co-op student and co-author of this report, Michael Rivet, with work he presented at the 36th Annual Canadian Nuclear Society conference.

Future research at the CNSC

Regulatory research continues to play a major role in generating knowledge and information to support CNSC staff in its regulatory mission.

In the coming years, the main areas of focus for CNSC research will continue to be in the areas of aging management of reactor facilities, waste management in preparation for potential waste repositories, and keeping abreast of new technologies such as small modular reactors. The CNSC's research program will also continue to evolve to ensure CNSC staff are able to acquire the latest scientific information to supplement their assessment capabilities.

Working with both domestic and international stakeholders to share information and best practices will continue to be an integral part of the CNSC's research program. Working with organizations such as the International Atomic Energy Agency, the University Network of Excellence in Nuclear Engineering, and Atomic Energy Canada Limited and its federal nuclear science and technology program will continue to ensure the global nuclear industry maintains the safest practices.

Finally, the CNSC will continue to publish this annual report to disseminate information on its research projects and involvements in the nuclear industry to fulfil its mandate to disseminate objective, technical and regulatory information to the public.

Glossary of terms

Additional Protocol declarations: A legal document that gives the International Atomic Energy Agency legal authority to verify a Member State's safeguard obligations.

Bayes method (Bayesian): A statistical method that assigns probabilities or distributions to events or parameters based on experience or best guesses.

Bioassay: A type of scientific experiment that uses live tissue or cells to determine the biological activity of a substance.

Biokinetic: The scientific study of the growth changes and movements that take place during the development of organisms.

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.

Characterization of uncertainties: The characterization of situations where it is impossible to exactly describe either the existing state, a future outcome or more than one possible outcome.

Chemometrics: A methodical approach to chemical analysis.

Continuous permafrost zone: A zone where more than 80 percent of the ground surface is underlain by permafrost.

Creep ratio: The creep index with respect to the compression index.

Deep geological repository: A nuclear waste repository excavated deep within a stable geologic environment.

Deposition: The act of depositing something onto a surface or area over a period of time.

End slopes: The angles between the axis of the pressure tube and end-fitting locations and the line that connects the tow ends of the pressure tube.

Excreta: Waste matter discharged from the body, including feces and urine.

Fission product: The lighter atomic nuclei produced by the splitting of heavier nuclei.

Minimum staff complement: The minimum number of qualified workers who must be present at all times to ensure the safe operation of a nuclear facility. The number and qualifications of the workers in the minimum staff complement must be adequate to successfully respond to all credible events, including the most resource-intensive conditions for any facility state.

Neutron flux: The rate of flow of neutron (i.e., the number of neutrons passing through a unit area in unit time).

Neutron (Regional) Overpower Protection system: A system that includes a detector inside the reactor core of a nuclear power plant for the purpose of initiating a reactor shutdown when the neutron flux, in any place in the reactor core, exceeds the specified trip setpoint.

Neutronics: The study of the characteristics and distribution of neutron populations within a system.

Nuclear fuel cycle: The series of industrial processes that are part of the process of producing electricity from uranium in nuclear power plants.

Oncology: The study and treatment of tumors.

Ore dust: The dust of a naturally occurring material from which a metal or valuable mineral can be profitably extracted.

Organically bound tritium: Tritium that is bound to carbon.

Permeability: The degree of which a magnetisable substance can modify the magnetic flux in a magnetic field.

Phenomena and key parameter identification and ranking tables: A systematic way of gathering information from experts on a specific subject and then ranking the importance of that information to meet some decision-making process objective.

Radon: A radioactive gas found naturally in the environment through the decay of uranium in soil, rock or water.

Radionuclide: An atom with excess nuclear energy causing it to be unstable.

Reactor burn-up: A measure of how much energy is extracted from a primary fuel source in the reactor.

Slag: Waste matter separated from metals during the smelting or refining of ore.

Spectroscopy: The study of interaction between matter and electromagnetic radiation.

Synchrotron: A cyclotron in which the magnetic field strength increases with the energy of the particles to keep their orbital radius constant.

Synthetic aperture radar: Radar that generates high-resolution remote-sensing imagery.

Tailings: The leftover material after the valuable fraction is separated from the uneconomic fraction of an ore.

TECDOC: Technical guidance documents to help regulatory bodies, designers, vendors and operating organizations understand the International Atomic Energy Agency safety requirements.

Thermalhydraulics: The study of hydraulic flow in thermal fluids.

Triaxial: To possess or include three axes.

Trip: The automatic or manual shutdown of a nuclear power plant.

Tritiated water: A radioactive form of water where the usual hydrogen atoms are replaced with tritium.

Tritium: A hydrogen isotope containing two neutrons and one proton.

Uranium ore concentrate (yellow cake): A type of uranium concentrate powder that is an intermediate step in the processing of uranium after it is mined.

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 the Nuclear Energy Agency and International Atomic Energy Agency (IAEA).

The following is a list of technical papers, presentations and articles published/presented by CNSC staff in fiscal year 2015–16.

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
Determination of hydrazine at Ontario nuclear power plants	Peer-reviewed journal article	*Analytical Methods*, 7, 9825–9834	October 2015	Royal Society of Chemistry	S. Jovanovic, T. Zakharov, H. Mulye, D. Kim, K. Fagan
In situ measurements of tritium evapotranspiration (3H-ET) flux over grass and soil using the gradient and eddy covariance experimental methods and the FAO-56 mode	Peer-reviewed Journal article	*Journal of Environmental Radioactivity*, 148	October 2015	Elsevier	O. Connan, D. Maro, D. Hebert, L. Solier, P. Caldeira Ideas, P. Laguionie, N. St-Amant
Canadian inter-laboratory organically bound tritium (OBT) analysis exercise	Peer-reviewed Journal article	*Journal of Environmental Radioactivity*, 150	December 2015	Elsevier	S.B. Kim, J. Olfert, N. Baglan, N. St-Amant, B. Carter, I. Clark, C. Bucur
A study on the levels of radioactivity in fish samples from the experimental lakes area in Ontario, Canada	Peer-reviewed Journal article	*Journal of Environmental Radioactivity*, 153	March 2016	Elsevier	J. Chen, M.D. Rennie, B. Sadi, W. Zhang, N. St-Amant
Should we ignore U-235 series contribution to dose?	Peer-reviewed Journal article	*Journal of Environmental Radioactivity*, 151, 114-125	September 2015	Elsevier	K. Beaugelin-Seiller, R.R. Goulet, S. Mihok, N.A. Beresford

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
Impact of environmentally based chemical hardness on uranium speciation and toxicity in six aquatic species	Open-access peer-reviewed journal article	*Environmental Toxicology and Chemistry*, 34(3), 562-574	2015	Elsevier	R.R. Goulet, P.A. Thompson, K.C. Serben, C.V. Eickoff
Tritium dynamics in soils and plants grown under three irrigation regimes at a tritium processing facility in Canada	Peer-reviewed journal article	*Journal of Environmental Radioactivity*, 153,176-187	2016	Elsevier	N-O.A. Kwamena, S. Mihok, M. Wilk A. Lapp, N. St-Amant, I. Clark
Non-targeted effects and radiation-induced carcinogenesis: A review	Open-access peer-reviewed article	*Journal of Radiological Protection*	February 24, 2016	IOP Publishing	J.J. Burtt, P.A. Thompson, R.M. Lafrenie
The use of rod-based guaranteed shutdown state in CANDU reactors	Abstract of a technical paper	2015 International Congress on Advances in Nuclear Power Plants	May 3–6, 2015	Nice, France	D. Serghiuta, J. Tholammakkil
On the aspect of evaluation of critical channel power and associated uncertainty in CANDU slow loss-of-regulation event analysis	Abstract of a technical paper	16th International Topical Meeting on Nuclear Reactor Thermal Hydraulics	August 30 – September 4, 2015	Chicago, IL	Y. Guo, N. Hammouda
Severe accident progression without operator action	Abstract of a technical paper	none stated	October 7, 2015	Ottawa, ON	CNSC staff
Status of Canadian NPPs' LTO preparation	Abstract of a technical presentation	International Conference on Operational Safety	June 23–26, 2015	Vienna, Austria	A. Blahoianu

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
Current fire protection regulatory approach for nuclear facilities in Canada	Abstract of a technical presentation	1st Technical Meeting on Fire Safety and Emergency Preparedness for the Nuclear Industry, Canadian Nuclear Society	June 17–19, 2015	Mississauga, ON	A. Bounagui, I. Bolliger, A. Blahoianu
Regulatory considerations in long-lead items for nuclear reactor facilities	Abstract of a technical paper	15th Symposium on Information Control Problems in Manufacturing	May 11–13, 2015	Ottawa, ON	D. Mroz, N. Shykinov, G. Schwarz, M. de Vos
Adequacy of bleed condenser/degasser condenser relief valves capacity in the CANDU operating plants to mitigate consequences of a total loss of heat sink accident	Abstract of a technical paper	none stated	none stated	Ottawa, ON	CNSC staff
Emergency power systems at Canadian nuclear power plants, including portable alternating current power sources	Abstract of a technical presentation	Emergency Power Systems at Nuclear Power Plants Symposium	April 23–24, 2015	Munich, Germany	J. Vucetic, N. El Dabaghi