



# The Science of Safety

CNSC Research Report

2016–17



## **The Science of Safety: CNSC Research Report 2016–17**

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### **Document availability**

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## Message from the President

I am pleased to introduce the fourth annual research report of the Canadian Nuclear Safety Commission (CNSC), which summarizes the various research projects and initiatives we have supported and completed during the 2016–17 fiscal year. The regulatory research outlined in this report plays an essential role in the continued fulfillment of our mandate to protect health, safety, security and the environment; implement Canada’s international commitments on the peaceful use of nuclear energy; and disseminate objective scientific, technical and regulatory information to the general public.

Many of the projects and activities highlighted in this report have associated technical papers that are publicly available on our website, posted in the form originally submitted by their authors. No matter your level of technical knowledge or expertise, I invite you to read through this report and, should you have an interest in exploring any of the research further, download the more detailed papers that are found linked in their corresponding summaries.

With my time as the CNSC’s President and Chief Executive Officer coming to a close, this is the last annual research report to be published during my tenure. I take great pride in the growth in the variety of work and versatility achieved by our research program over the past four years. I am also very proud of how these reports have evolved to clearly communicate to the public the important work being done by our research program – and I expect them to continue to do so for many years to come.

That’s the science of safety.

A handwritten signature in black ink that reads "M. Binder". The signature is written in a cursive, flowing style.

**Michael Binder**  
President

# 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. Therefore, 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

The CNSC uses regulatory research in many ways. It supports regulatory decisions. It helps 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:

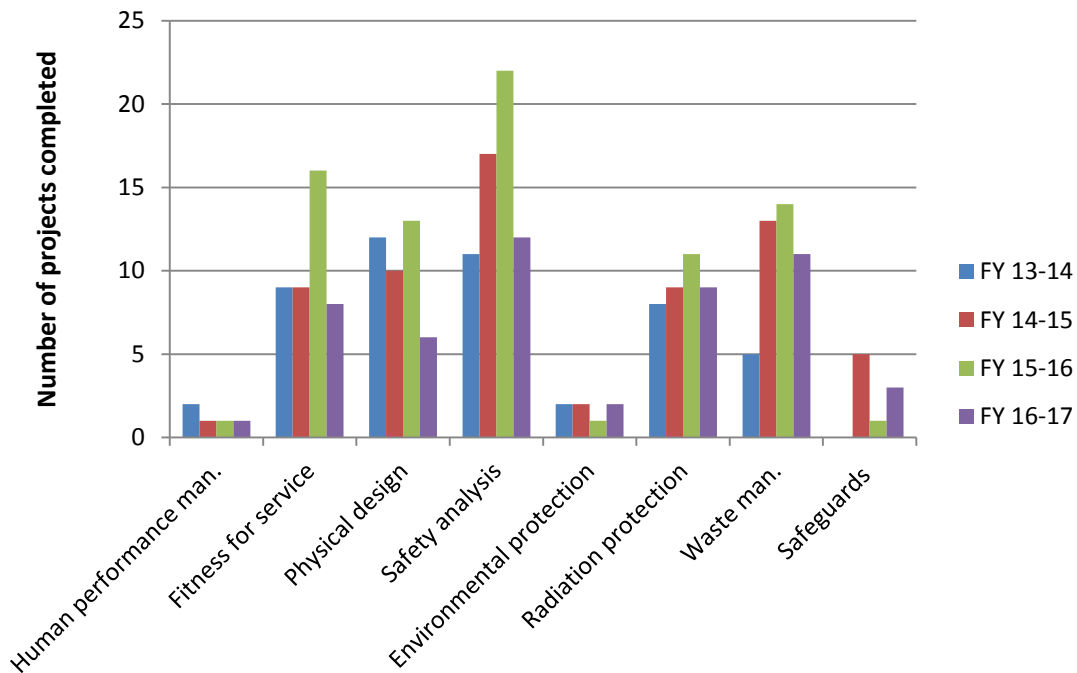
- strengthening the CNSC's licensing, compliance and regulatory framework in preparation for long-term/post-refurbishment operation of Canadian nuclear power plants
- enhancing the CNSC's capability to independently assess hazards and to analyze/respond to severe reactor accidents
- supporting CNSC staff 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

The research projects conducted or supported by the CNSC are categorized according to the CNSC's 14 safety and control areas. By evaluating how well licensees meet their regulatory requirements and safety performance standards in each of the 14 safety and control areas, the CNSC has been able to direct its research to those areas where more attention may be required, specifically:

- human performance management
- fitness for service
- physical design
- safety analysis
- environmental protection
- radiation protection
- waste management
- safeguards

By categorizing research in this way, the focus of a given project can be quickly and generally conveyed. This categorization also allows major areas of focus in research overall to be tracked. The following graph and table depict the eight safety and control areas in which the CNSC conducts its research as well as the number of projects completed in each area over the past four fiscal years.

**CNSC research by safety and control area**



Safety and control Area	Fiscal year			
	FY 13-14	FY 14-15	FY 15-16	FY 16-17
Human performance management	2	1	1	1
Fitness for service	9	9	16	8
Physical design	12	10	13	6
Safety analysis	11	17	22	12
Environmental protection	2	2	1	2
Radiation protection	8	9	11	9
Waste management	5	13	14	11
Safeguards	0	1	1	3

More information about the safety and control areas is available on the [CNSC website](#). Links to research projects previously completed by the CNSC are sorted by their categorized safety and control area on the [CNSC “Scientific and technical information” Web page](#). That page also includes links to previous years’ annual research reports.

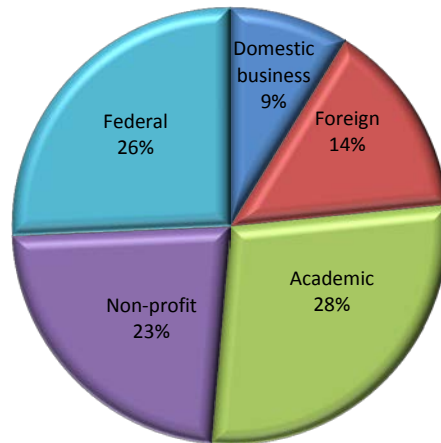
Each chapter of this report provides quick summaries of all the research projects and similar work completed by the CNSC from April 1, 2016 to March 31, 2017. Project topics are not limited to commercial nuclear power; there are multiple projects spread across every aspect of the Canadian nuclear industry that is regulated by the CNSC, including waste management facilities, nuclear research facilities and more.



### The CNSC's research universe

The CNSC funds research in the private sector, academic institutions, governmental organizations and non-governmental organizations and does so primarily through competitive contracting processes. This research is not limited to Canada but includes international funding as well, as shown below. The CNSC 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	26
Domestic business	9
Non-profit	23
Academic	28
Foreign	14

As seen in previous years, the CNSC's primary research partners were again academic institutions. This funding went toward 10 institutions, including McMaster University, McGill University, the University of Ottawa and the University of Toronto, as well as the University Network of Excellence in Nuclear Engineering. This support plays an important role in the development of the nuclear research capabilities of Canada's universities. Non-profit organizations also remained one of the largest beneficiaries of CNSC research spending in 2016–17. Supporting non-profits such as Let's Talk Science and the Canadian Nuclear Society allows the CNSC to be involved with a wide range of work, from youth education and development to technical conferences. Significant research funding was also directed to federal organizations such as Atomic Energy of Canada Limited (AECL) and Health Canada. A number of the facilities and research opportunities available through AECL cannot be found anywhere else in the world, making the work that the CNSC conducts with AECL highly valuable.

## Ensuring the safety of nuclear power plants

There are currently 19 commercial reactors operating at four nuclear power generating stations in Canada. There are also research reactors in operation at various academic and dedicated research locations across the country. A major part of the CNSC's role in nuclear safety is the licensing, regulating and inspection of these plants to ensure the wellness of workers, the public and the environment. The research the CNSC performs plays a crucial role in enabling the safe overview of nuclear reactors and facilities over the entirety of their lifetimes. The following section provides a brief summary of the research completed this past fiscal year that pertained to ensuring the quality of all of Canada's nuclear power facilities.



Aerial view of Chalk River Laboratories, circa 1945.



Aerial view of Chalk River Laboratories, circa 2007.

Atomic Energy of Canada Limited's (AECL) Chalk River Laboratories (CRL) was the site of Canada's first experimental research reactor, which began operation in 1945. The facility had been managed by AECL from 1952 until 2015, when it switched over to a "Government-owned, Contractor-operated (GoCo)" model. It has since been operated by Canadian Nuclear Laboratories (CNL). For over 70 years, CRL has been one of Canada's most complex laboratories, acting as the site for nuclear research and development in diverse fields.

**Did you know?** "GoCo" stands for "government owned, contractor operated" and is a governance model commonly adopted in North America. It allows each organization in the partnership to focus on the duties it is better suited for: the government defines mission areas while the contractor takes over the management and operation of the facilities. In the case of CRL, the site is owned by AECL, a federal Crown corporation, and operated by Canadian Nuclear Laboratories (CNL).

### **Testing and development of regulatory requirements for steel-plate concrete structures**

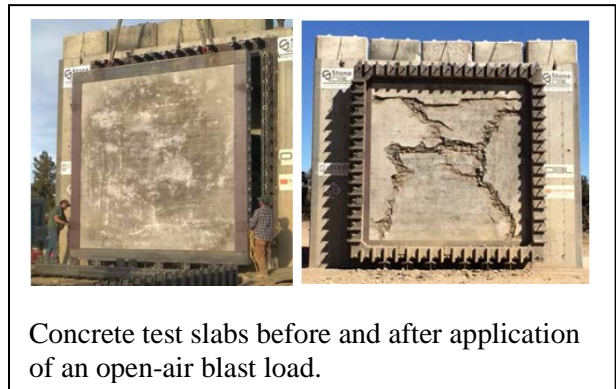
Composite steel-plate concrete construction, where concrete is poured between a “sandwich” of pre-fabricated steel plates, is both faster and cheaper than traditional reinforced concrete construction. As a result, composite structures are commonly proposed in various areas of new nuclear power plant designs, including the reactor shielding building and internal reactor structures. However, regulatory requirements are not yet in place for modular steel-plate concrete structures in new-build reactor designs.

To guide regulatory framework development on the use of this construction technique, the CNSC worked with the University at Buffalo as well as Bowen Laboratory at Purdue University to examine the effects of simultaneous [in-plane and out-of-plane stresses](#) on steel-plate concrete wall piers. Both physical testing and simulations of different stress-loading configurations were conducted to test the behaviour and structural capacity of the wall piers. It was found that combinations of in- and out-of-plane stresses significantly reduced the structural capacity of walls using the modular steel-plate concrete design – findings that will be essential to providing up-to-date guidance on the design of new reactors.

Refer to the CNSC website for the final report: [Testing and Development of Regulatory Requirements for Steel-Plate Concrete Structures](#).

### **Testing of pre-stressed concrete slabs under impulse loading**

Pre-stressed concrete is a common construction material used in nuclear containment structures worldwide. By introducing compressive stresses into the concrete before service begins, the pre-stressing process gives the resulting structure the strengths of both steel and concrete. Some of the building standards for pre-stressed concrete members are outlined by the Canadian and American standards CSA S850-12 and ASCE 59-11, which detail requirements for structures under blast loads. Currently, the standard provisions for pre-stressed concrete structures are much more stringent than those for traditional reinforced concrete structures, despite the fact that pre-stressed concrete is, in theory, better able to withstand blast loads. If this is true, adopting more realistic acceptance criteria for pre-stressed concrete structures would be appropriate and beneficial to vendors, designers and regulators.



To test this theory, the American Society of Mechanical Engineers (ASME), with the financial support of several international partners (including the CNSC), performed a series of eight open-air blast tests on pre-stressed concrete slabs. ASME found that the actual response of the test structures fell between the lower theoretical limit and the upper standard-defined limit. This means there is the potential for current standards to be readjusted, but further research needs to be performed before amendments to current standards should be implemented. This further research should examine other responses of representative concrete slabs, such as concrete disengagement and concrete-crushing controlled responses.

Refer to the CNSC website for the final report: [Bonded Pre-Stressed Concrete Slabs Open-Air Blast Testing](#).

### Evaluation of probabilistic leak-before-break methods for CANDU pressure tubes

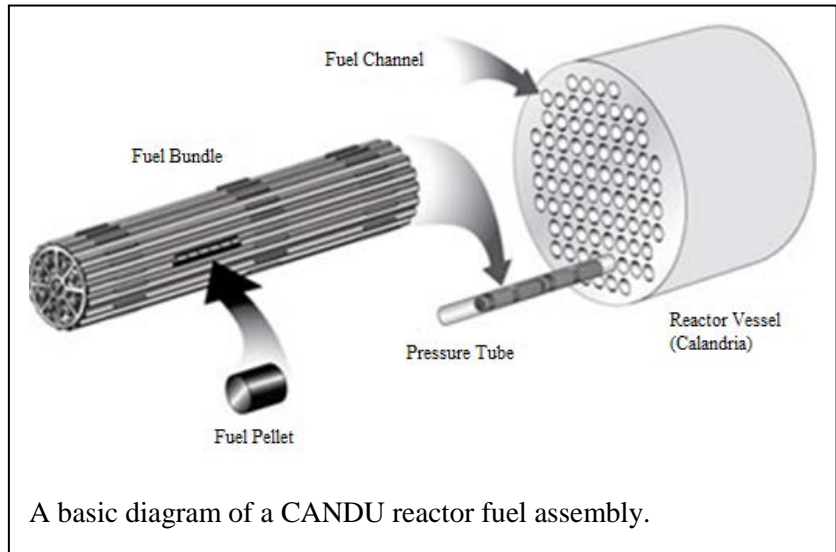
When anticipating physical phenomena in a reactor system, predictions may be made using either deterministic or probabilistic mathematical models. In a deterministic model, certain inputs will conclusively give a single, predetermined result. In a probabilistic model, certain inputs will instead have multiple potential results, each with a different probability of occurring. Deterministic [leak-before-break](#) evaluations had successfully been used as part of the [defence-in-depth](#) strategy for pressure tubes in CANDU reactors for decades. However, these evaluations were challenged by increasing hydrogen concentrations that developed later in the tubes' service lifetimes. The presence of hydrogen in pressure tubes causes the production of [hydrides](#), which in turn can cause material degradation and lead to crack initiation and growth by [delayed hydride cracking](#).

In response to the limitations in the deterministic leak-before-break evaluations, two new probabilistic methodologies were proposed in 2013 by the CANDU industry. These methodologies were designed to meet the requirements of CSA standard N285.8-10, *Technical requirements for in-service evaluation of zirconium alloy pressure tubes in CANDU reactors*.

The CNSC initiated a third-party review to assess the two methodologies to determine whether they are technically adequate and meeting current

knowledge and best engineering practices. The project scope involved using these methodologies to perform independent evaluations of a single pressure tube as well as the entire reactor core. Additionally, an independent computer program based on one of the probabilistic leak-before-break methodologies was created to verify the industry-proposed methodology.

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



A basic diagram of a CANDU reactor fuel assembly.

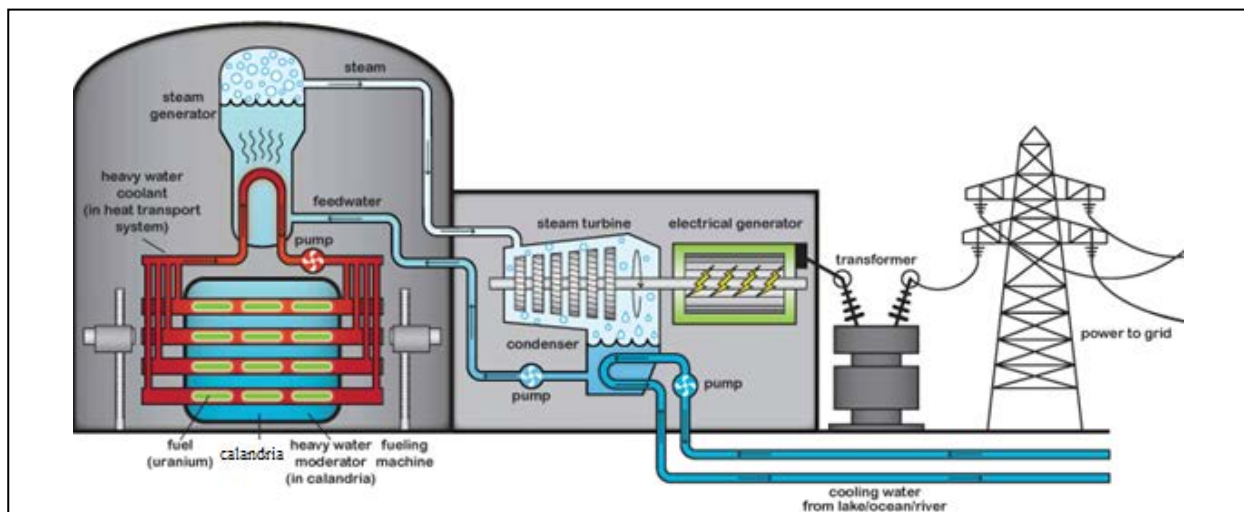
**Did you know?** In a CANDU reactor fuel assembly, fuel pellets comprising uranium dioxide ( $\text{UO}_2$ ) are held in a fuel bundle. In each fuel channel of the [calandria](#) is a pressure tube that houses 12 fuel bundles. The number of fuel channels in a calandria depends on the type of CANDU reactor; for example, there are 380 fuel channel assemblies in the CANDU 6 reactor design and 480 in the CANDU 9 reactor design.



## Review of recommended practices for monitoring and managing flow accelerated corrosion

[Flow accelerated corrosion](#) is a form of material degradation, often seen in carbon and low-alloy steel piping systems, that can cause significant loss in pipe-wall thickness and may ultimately result in ruptures. Many instances of damage (including several significant failures) have occurred in the [balance-of-plant](#) piping systems of pressurized water reactors as a result of flow accelerated corrosion. In response, the Electric Power Research Institute (EPRI) has developed recommended practices for programs to monitor and manage flow accelerated corrosion.

In Canada, the EPRI practices have been adopted for the maintenance of CANDU balance-of-plant systems as well as for the larger-diameter CANDU reactor [primary-side](#) piping. While CANDU primary-side piping systems are also composed of carbon steel, their water chemistry and operating conditions are different from those of the balance-of-plant systems for which the EPRI recommended practices were originally developed. As CANDU plants are entering periods of extended operation, remaining life assessments and aging management strategies for large-diameter primary-side piping must address the potential for pipe-wall loss due to flow accelerated corrosion. A technical review of the applicability of the EPRI recommended practices to CANDU primary-side piping systems was therefore commissioned by CNSC staff. It should be noted that this review was not applicable to the corrosion of smaller-diameter feeder piping used in the CANDU plant design, which is instead addressed through component-specific [aging management plans](#) (also called lifecycle management plans).



A simple cross-sectional diagram of a CANDU reactor nuclear power plant.

Primary-side nuclear power plant components include the calandria and steam generators, while the balance of plant systems includes the steam turbine, condenser and electrical generator.

The results of this research confirmed that, in general, the current practices can be effectively applied to both the balance-of-plant and primary-side piping systems in CANDU plants. Guidance was given for possible areas of focus unique to CANDU primary-side piping systems, which CNSC staff may consider when evaluating licensees' aging management strategies and fitness-for-service evaluations to address flow accelerated corrosion.

Refer to the CNSC website for the final report: [Review of EPRI Recommendations for an Effective Flow Accelerated Corrosion Program and their Applicability to CANDU Reactors](#).

### **Assessment of corrosion of steel H-piles at nuclear generating stations**

Power plant licensees are responsible for demonstrating that the support structures of their facilities are sufficient to withstand design loads for the entire lifetime of a site. Steel H-piles, which are metal beams set deep into the ground, are just one of the support structures present in the builds of nuclear power plant sites. These beams provide support to civil structures under normal operating conditions as well as in extreme events such as earthquakes.

A common source of damage to these beams is corrosion, the rate of which depends on factors such as soil type and contents, water and oxygen concentrations, and soil [resistivity](#). It can be difficult to monitor corrosion damage to these beams, however, because they are set too deep in the ground for visual examination and soil sampling directly at the site of a beam can compromise stability. The purpose of this research was for CNSC staff to determine if representative estimates of steel H-pile corrosion damage could be made through the use of the [American Association of State Highway and Transportation Officials \(AASHTO\) R27 standard, \*Standard of Practice for Assessment of Corrosion of Steel Piling for Non-Marine Applications\*](#). According to this standard, an assessment of soil resistivity in representative samples can be used to make useful estimates on the corrosion situation of steel piles.

From the data produced by an independent review of the Pickering Nuclear Generating Station site, it was concluded that successful conservative assessment of beam corrosion can be made through a framework following the AASHTO R27 standard. In the case of the Pickering site, it was further recommended that systematic analysis of soil conditions at a minimum of 12 representative sites surrounding steel H-piles be conducted to assess stability conditions.

Refer to the CNSC website for the final report: [Corrosion of steel H-piles at nuclear generating stations](#).



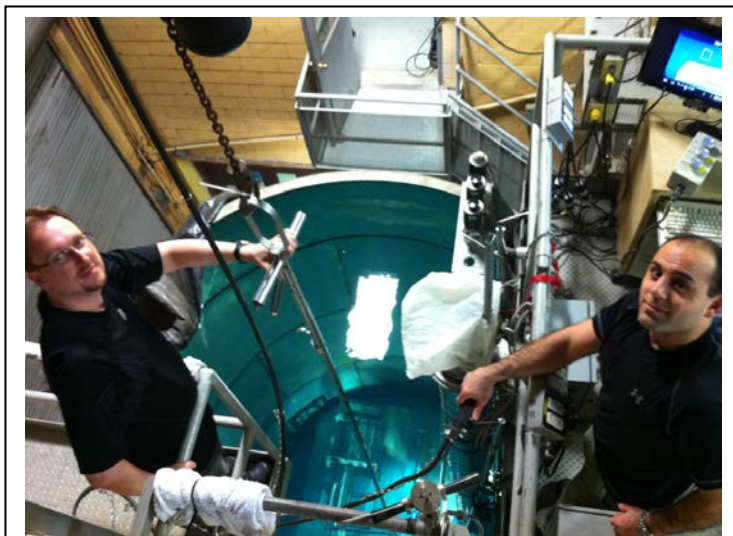
A recent photo of the Pickering Nuclear Generating Station, owned by Ontario Power Generation and located in Pickering, Ontario.

At all operating nuclear power generating stations in Canada, the CNSC has onsite offices with full-time staff who perform inspections to evaluate operations and verify compliance with regulatory requirements and licence conditions. The CNSC also has a number of regional offices across Canada, including locations in Ontario, Quebec, Saskatchewan and Alberta.

### Development of PKPIRT package for analysis of severe irradiated fuel bay accidents

Since the Fukushima Daiichi accident in March 2011, the CNSC has been working to develop new computer codes to model and simulate potential fuel bay accidents. At a nuclear power plant, the onsite irradiated fuel bay is an area containing a pool of water that normally provides short-term, safe storage of used nuclear fuel discharged from the reactor. As no computer code to model the progression of a severe irradiated fuel bay accident currently exists, it is difficult to define safety margins to mitigate the consequences of extreme events in this area.

The phenomena and key parameters associated with a hypothetical severe accident within a CANDU irradiated fuel bay were identified and analyzed – using the [phenomena and key parameter identification and ranking tables \(PKPIRT\)](#) package developed during the previous year’s work on this project – by a panel of experts independent from both the CNSC and the industry. Through the work sponsored by the CNSC and Canadian Nuclear Laboratories (CNL), which included an open-literature review of nearly 70 sources, a total of 86 phenomena were identified for the panel to rank in terms of importance and current level of knowledge. Of the phenomena identified, 58 were ranked as having a medium-level importance or greater. Additionally, 18 of these phenomena were identified as requiring further research to expand the existing knowledge base. This information will form part of the reference material for future code development by CNSC staff, and can additionally be used as input to the problem definition, theoretical background and requirement-specification phases in the code-development process.



CNSC employees Wade Grant (left), a Technical Specialist in the Physics and Fuel Division, and Ali El-Jaby (right), a Senior Technical Advisor in the Directorate of Security and Safeguards, on a visit to Stern Laboratories in Hamilton, Ontario. They are disassembling a mock fuel bundle as part of a fuel inspector training course.

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

**Did you know?** Under any accident condition, being able to predict and understand the reactor conditions and resultant phenomena is crucial to effectively monitor the system and ensure that system parameters stay within safety margins.



### Validation of the RELAP5 code for modelling natural circulation in the CANDU system

One of the fundamental safety concepts of nuclear power plants is to ensure that cooling of the fuel is maintained at all times. This is normally accomplished through the pumping of coolant through the reactor by the primary heat transport system. Even under certain accident conditions where the pumping system is lost, the reactor system is designed so that the circulation of coolant can occur naturally.

In the event that the pumping system is lost, the ability to predict and understand the [thermalhydraulic](#) behaviour of the system is crucial. Although a number of CANDU-specific modelling codes related to thermalhydraulic behaviour exist, the most widely used industry code internationally available is the Reactor Excursion and Leak Analysis Program (RELAP5). Because this code was developed in the United States, it is based around a style of reactor that differs from the CANDU reactor – specifically in terms of the orientation of the reactor core (see photo, right). The purpose of this research, conducted by McMaster University, was to establish the accuracy of the RELAP5 code in terms of modelling natural circulation conditions in CANDU reactors.

The report produced by McMaster University included data obtained from the use of the RELAP5 code to model and simulate a particular system; the modelled system was designed to have conditions matching that of an actual experiment conducted at the Cold Water Injection Test Facility in Hamilton, Ontario. By comparing the experimental and simulation results, CNSC staff determined that the RELAP5 code has a strong capability to generally model and predict the relevant phenomena and behaviour of the CANDU system for natural circulation conditions. This said, degrees of overestimation and underestimation were observed in certain key parameters, particularly those related to the venting of steam from the horizontal fuel channels. For this reason, the use of the RELAP5 code requires further research and modification for full applicability to CANDU systems.

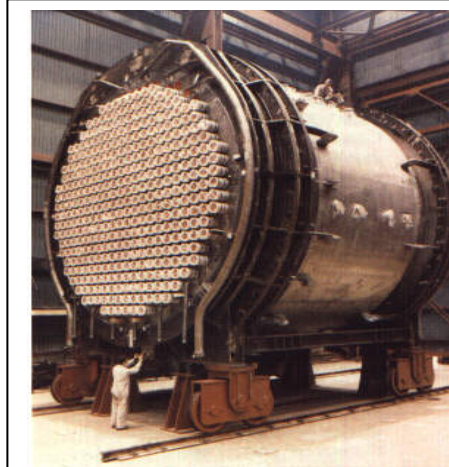


Photo of a worker next to the detached calandria of a CANDU reactor.

The fuel of a nuclear reactor is held in pressure tubes, which are housed in the channels of a large cylindrical body called the calandria. In CANDU-style reactors, the orientation of the calandria and the pressure tubes is horizontal. In other common reactor types around the world, such as boiling water reactors, a vertical orientation is used.

Refer to the CNSC website for the final report: [Assessment of RELAP5 for Natural Circulation](#).

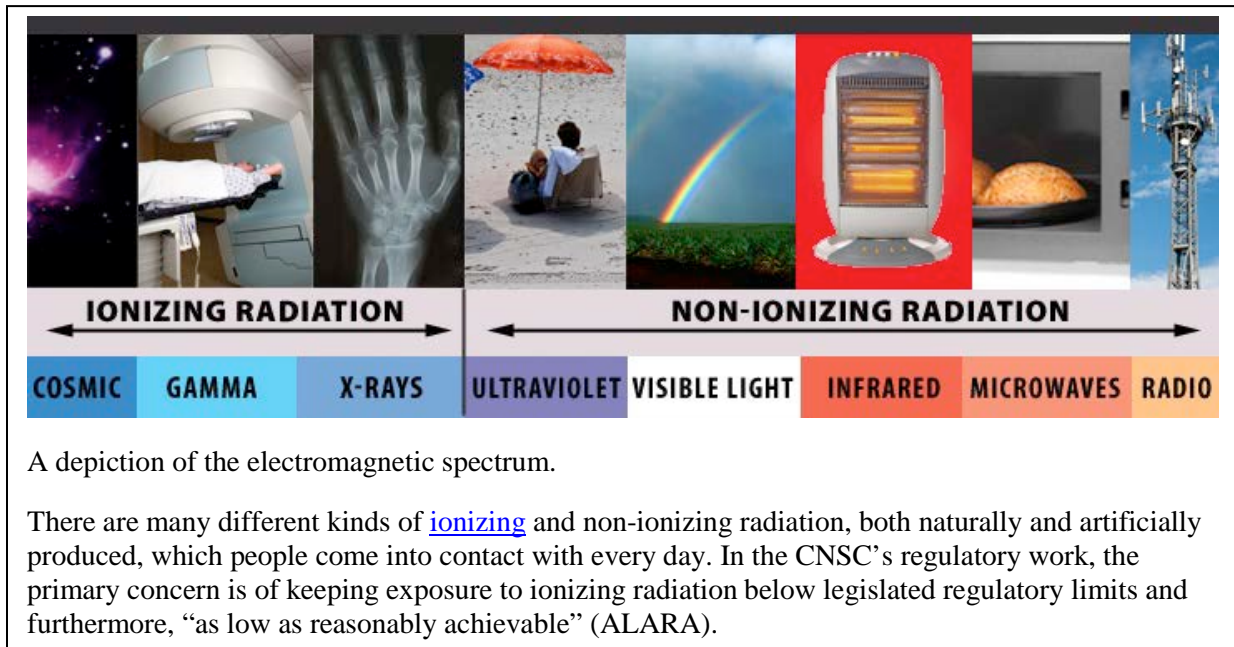
**Did you know?** In all types of nuclear power plants, three fundamental safety concepts (known as the “Three Cs”) are considered to govern the operation of a plant:

- cooling the fuel
- controlling the reactor
- containing the radiation



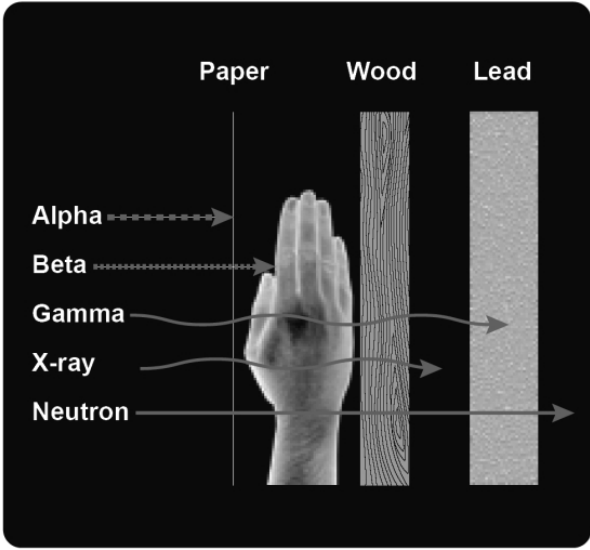
## Protecting workers

There are approximately 3 million workers worldwide who are exposed to occupation-related radiation, often on a daily basis. About 800,000 work in the nuclear industry, with the Canadian nuclear industry employing some 40,000 people. The CNSC's research ensures that nuclear energy worker health and safety standards, practices and limits are based on strong evidence and designed to keep work-related injuries low.



### Investigation into the shielding capabilities of protective eyewear

The lens of the eye is one of the most [radiosensitive](#) tissues in the body – and to prevent the incidence of radiation-induced cataracts, nuclear regulatory bodies worldwide have set dose limits for the lens of the eye. In Canada, dose limits for both nuclear energy workers and the public are prescribed by the *Radiation Protection Regulations*. Currently, the prescribed dose limits are 150 [millisieverts \(mSv\)](#) per one-year dosimetry period for nuclear energy workers and 15 mSv per calendar year for members of the public. However, recent studies suggest cataracts may develop from exposure to much lower doses of



The diagram illustrates the penetration of five types of ionizing radiation through three different materials: Paper, Wood, and Lead. The radiation types are listed on the left: Alpha, Beta, Gamma, X-ray, and Neutron. Arrows indicate the path of each radiation type. Alpha particles are stopped by a sheet of paper. Beta particles are stopped by a sheet of plastic. Gamma rays and X-rays are stopped by a block of lead. Neutrons are stopped by a block of water.

The attenuation of ionizing radiation particles through different mediums.

In regulated nuclear activities, worker health concerns usually surround providing barriers to the four types of ionizing radiation: [alpha](#), [beta](#), photon ([gamma](#) and [X-ray](#)) and [neutron](#). Providing adequate protection requires different barriers depending on the type of radiation. Alpha particles can be completely blocked merely by a sheet of paper and beta particles can be blocked by plastic. Photon and neutron particles, in contrast, cannot be entirely blocked – but they can be significantly reduced by lead and water barriers, respectively.

ionizing radiation than previously thought. In response to these findings, and in alignment with recommendations made by the International Commission on Radiological Protection (ICRP), the CNSC is proposing to amend the one-year dose limit for the lens of the eye and introduce a new five-year dose limit for nuclear energy workers.

To better understand the role of eye protection in radiation exposure, experimental and theoretical investigations were made into the shielding factors of six different types of eyewear that are readily available in Canada and three different eyewear lens materials. Multiple investigations were carried out using different experimental geometries, with the measurement data compared to detailed simulations to verify the validity of the experimental data obtained. Shielding factors were evaluated for both X-rays and beta radiation beams typical of CNSC-regulated nuclear activities. While the study found that the eyewear provided little shielding for X-rays, the shielding provided for beta radiation was more significant. Additionally, no significant difference was observed in the shielding properties of the three materials tested. This work serves as a basis for future potential work to determine more realistic shielding factors considering different sources of beta radiation.

Refer to the CNSC website for the final report: [Review of Eye Protection Provided by Eyewear](#).

**Did you know?** The biological effectiveness of absorbed radiation is described in terms of the sievert (Sv), which is a unit within the International System of Units. The sievert takes into account both the type of radiation as well as the specific tissue being exposed (such as the lens of the eye) to describe the biological impact of an exposure incident. Quantities are often reported as millisieverts (mSv), where 1 Sv is equivalent to 1,000 mSv.

### **CNSC support in the 63rd annual UNSCEAR session**

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) provides the scientific basis for the evaluation of radiation risk and the techniques used for its mitigation. Governments and organizations worldwide consider UNSCEAR's assessments as authoritative and use them as a guideline in the establishment of national radiological protective procedures.

At the 63rd UNSCEAR session, the Canadian delegation included representatives from the CNSC and Health Canada. The CNSC also engaged Dr. Ed Waller (President of RadSci Research Inc. and a professor at the University of Ontario Institute of Technology) to complement the Canadian delegation. Through previous work, Dr. Waller was influential in developing two important UNSCEAR documents:

- *Methodology for estimating public exposures due to radioactive discharges*
- *Radiation exposures from electricity generation*

These two documents were finalized during the 63rd UNSCEAR session and were subsequently included in UNSCEAR's 2016 report to the UN General Assembly.

Refer to the UNSCEAR website for the final report: [Sources, effects and risks of ionizing radiation; UNSCEAR 2016.](#)

**Did you know?** UNSCEAR is composed of 27 worldwide designated states. Each year, a session is held where technical reviews of the work produced by UNSCEAR are conducted by the member states.

For more information about UNSCEAR, including a comprehensive list of its member states, visit the [official UNSCEAR website.](#)

## Protecting the environment

Protecting the environment against radiological or nuclear activity-based harm is one of the core elements of the CNSC mission. Environmental research ensures that the CNSC's knowledge base is up to date so it can more effectively guide environmental monitoring and protection.

The knowledge gained from environmental research is essential to verifying that licensees are meeting the requirements of their mandated environmental monitoring programs. It also strengthens the CNSC-implemented Independent Environmental Monitoring Program (IEMP), which complements the CNSC's regular and ongoing compliance-verification activities by taking independent samples at public areas around nuclear facilities and analyzing their radiological or hazardous (non-radiological) contents.



IEMP staff taking water samples near the Deloro Mine site in Ontario.

Environmental sample types can include water, vegetation, air, soil, sediment, agricultural produce or other natural foodstuffs. The IEMP is implemented in all segments of the nuclear fuel cycle: uranium mines and mills, uranium and nuclear processing facilities, nuclear power plants, research and medical isotope production facilities, and waste management facilities.

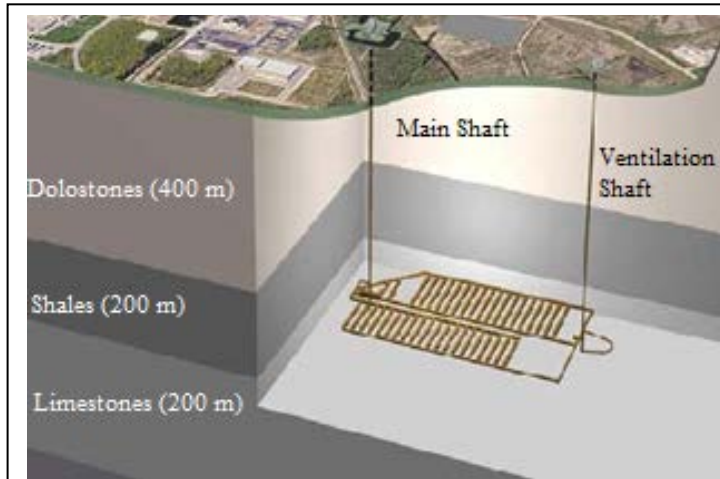


**Did you know?** Within the first weeks following the devastating wildfire in the area of Fort McMurray, Alberta, CNSC staff were onsite and in communication with Alberta and British Columbia licensees to verify the locations and integrity of their radiation sources and devices. The fire began on May 1, 2016; by May 6, CNSC staff had begun working with licensees affected by the fire to ensure the safe storage of all inventories and to verify the status of any nuclear materials and devices. A line of communication was also opened between the CNSC and first responders, with information on radiological risks provided by the CNSC to the Canadian Transport Emergency Centre and the Alberta Provincial Operations Centre. By May 12, two CNSC specialists had been deployed to the area and finished conducting field inspections to confirm that no devices or sources had been affected by the fire and no radiation leaks existed that might endanger the public or the environment.



Depicted here are CNSC specialists inspecting a Fort McMurray site to ensure that no radiation had leaked from licensed devices. The specialists can be seen measuring the radiation levels in the area using a personal radiation detector device. While many nuclear devices (such as [radiography cameras](#) or [nuclear gauges](#)) hold strong radiation sources, these sources are contained in highly durable capsules to ensure that no threat is posed to workers, the public or the environment. For example, the gamma sources in radiography cameras are shielded by depleted uranium, double-encapsulated in stainless steel and must pass a 30-minute 800°C burn test as part of their safety certification.

## CNSC independent research on geological repositories



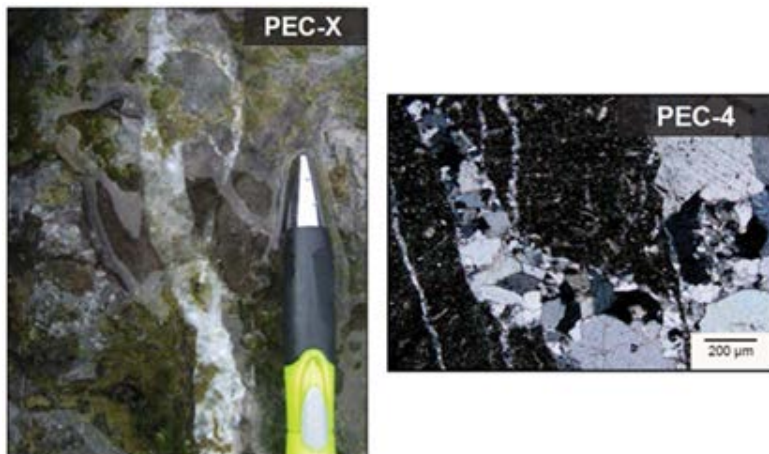
Conceptual diagram of a deep geological repository for low- and intermediate-level radioactive waste in southern Ontario.

A deep geological repository is constructed underground, usually at a depth of several hundreds of meters. Once the radioactive waste has been emplaced, the excavated tunnels and shafts are backfilled.

A [deep geological repository \(DGR\)](#) is constructed underground, usually at a depth of several hundreds of metres or more below the surface in a stable host rock. Geological repositories rely on multiple barriers (for example, the waste form, container, engineered seals, and host rock) for the long-term containment and isolation of radioactive waste.

The CNSC is involved in independent and internationally collaborative research focusing on long-term safety issues related to the disposal of radioactive waste, including used nuclear fuel in both crystalline and sedimentary rock formations. This research program helps in the development and update of regulatory documents that form the basis for CNSC staff recommendations to the Commission on DGRs and DGR licence applications.

The long-term stability of southern Ontario is relevant for regions currently being proposed to host a DGR (for low- and intermediate-level waste). This was a field-based study of the stability of the geosphere that focused on the potential for fault reactivation in southern Ontario by studying fracturing and secondary mineral precipitation within those fractures (calcite).



Photos of calcite-filled fractures in this study, from Prince Edward County, Ontario. PEC-X: field photograph. PEC-4: photomicrograph

This research was led by a professor and graduate student at the University of Ottawa's Department of Earth and Environmental Sciences. In consultation with CNSC staff, they selected a field site where evidence of faulting is preserved in sedimentary rocks of a similar type and age as those at the proposed host site for a DGR in southern Ontario. To investigate the possible causes and timing of fault reactivation, they carried out structural analyses of faults and fractures, and [radiometric age dating](#) of fracture-filling calcite. One of the major conclusions drawn from this project is that fluids that precipitated calcite-infill were mobilized ~100 million years ago via inherited joints from structures in the underlying Precambrian basement, and relate to far-field tectonic events at that time. This research provides the CNSC with information about [stratigraphically](#) similar sites, as well as key insights into methods for determining the tectonic stability and geological suitability of a region. This knowledge can be used in the potential licensing and regulation of DGRs in Canada.

Refer to the CNSC website for the final report: [Coordinated Assessment and Research Program \(CARP\): Age-dating fracture infill minerals.](#)

**Did you know?** Radioactive waste from nuclear power plants can be defined as being either low-, intermediate- or high-level. This describes what levels of radioactivity are emitted from the waste, which in turn informs how it should most safely be disposed. Low-level radioactive waste contains low levels of nuclear substance like cleaning materials used inside a nuclear facility. This waste requires little or no isolation. Intermediate-level radioactive waste is material containing large amounts of radioactive material that requires some form of isolation. High-level radioactive waste, which includes the used nuclear fuel from nuclear power plants, requires long-term isolation and containment from workers and the environment.

### **CNSC support for the Independent Advisory Group on deep geological repositories**

In 2007, the Government of Canada chose the Adaptive Phased Management approach as its plan for the safe, long-term management of used nuclear fuel. This plan is being implemented by the Nuclear Waste Management Organization (NWMO), which is considering the construction of a deep geological repository for the long-term management of Canada's used nuclear fuel.

It is international best practice for the regulator to be involved during the early and pre-licensing phases of a new nuclear project; such early involvement helps build the independent scientific knowledge needed to review future applications related to that project. With that in mind, the CNSC has been preparing for the review of an anticipated NWMO licence application for a long-term used nuclear fuel management facility.

To assist in this process, the Independent Advisory Group (IAG) was formed to provide CNSC staff with objective, independent advice on the scientific aspects of a deep geological repository. The IAG is managed by Carleton University and has a membership that includes geoscientists and engineers from Carleton University, Queen's University, McMaster University, the University of Manitoba and the Geological Survey of Canada. The IAG was tasked to identify any gaps in research or methodology that need to be addressed prior to a licencing request. To this end, the activities of the IAG have included:

- reviewing the NWMO's research programs, annual reports and specified technical documents
- reviewing the CNSC's research program and providing advice on its effectiveness, as well as recommending future areas of research
- advising on how the NWMO's research program compares with repository research internationally

The IAG produces an annual report to document its activities and make recommendations. Refer to the CNSC website for the 2015–16 report: *IAG-CNSC annual report April 2016*.



The 2016–17 members of the IAG. Pictured from left to right: Paul Van Geel, Carleton University; John Percival, Natural Resources Canada; Victoria Remenda, Queen's University; Stan Pietruszczak, McMaster University; and Mostafa Fayek, University of Manitoba.



### CNSC workshop on tritium research

[Tritium](#) is a radioactive form of hydrogen that occurs naturally through interactions between cosmic rays in the upper atmosphere as well as artificially as a by-product of CANDU nuclear reactors and tritium-processing facilities. As tritium is an important contributor to public radiation doses, the CNSC regulates and carefully monitors releases of tritium from nuclear facilities to protect the health and safety of Canadians and the environment.

From April 25 to 27, 2016, the CNSC hosted a tritium workshop at its headquarters with the purpose of identifying new directions and emerging topics for tritium research. Workshop participants included staff from the CNSC, Canadian Nuclear Laboratories (CNL), l'Institut de Radioprotection et Sûreté Nucléaire (IRSN) and the University of Ottawa. The three-day event included presentations on research previously or currently being conducted, a discussion of current research gaps, and a discussion on paths forward for future research projects and collaborations between participants. The main areas identified for future investigations included better characterization of background tritium levels at sites not influenced by nuclear facilities; investigating the presence of other forms of tritium (such as aerosols) in the environment; and improving sampling and analysis methodologies for [organically bound tritium](#) in environmental samples, particularly for soils and at low tritium concentrations.



In this image, CNSC staff in the Directorate of Environmental and Radiation Protection Assessment (DERPA) are conducting experiments to measure the organically bound tritium content of planted barrels.

In 2007, CNSC staff initiated a series of research projects to better inform regulatory oversight of tritium processing and releases in Canada. In the years following, seven CNSC reports were published examining topics such as the environmental fate of tritium in the atmosphere, soil and vegetation; health effects and radiological protection from tritium; and evaluations of guidelines for drinking water content and annual releases of tritium.

To read these reports or to find more information on the role of tritium in the environment and Canada's nuclear industry, visit the [official CNSC website](#).



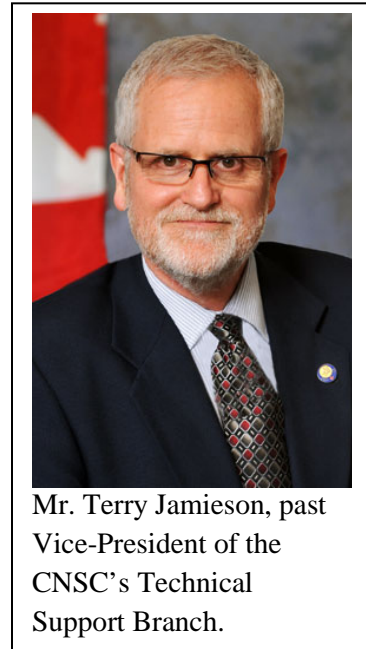
**Did you know?** Tritium has many applications in everyday society. One of the most common is its use in glow-in-the-dark lighting and signs. By combining tritium gas with phosphor, a light can be produced that requires no electric powering – ideal for ensuring that exit and emergency signs will remain bright even during a loss of power.

## Spotlight on CNSC staff

### Terry Jamieson, M.A.Sc., P.Eng

Terry Jamieson has more than 35 years' experience in the Canadian nuclear, safety and environmental industries, and has held technical and management positions in the areas of radiation protection, environmental protection, nuclear security, and safeguards and safety assessment. His bachelor's and master's degrees in engineering, both earned from the University of Toronto and specializing in nuclear applications, provided the educational background to his career.

Before his retirement this year, for the past 10 years Mr. Jamieson was the Vice-President of the CNSC's Technical Support Branch (which is responsible for security and safeguards, assessment and analysis, environment and radiation protection and assessment, and safety management), where he directed a staff of about 300. In addition to his official responsibilities, he acted as an authority who could provide guidance and oversight on any scientific or technical matter. During his time with the CNSC, Mr. Jamieson was extensively involved in research (mainly in support of the Technical Support Branch) and gave more than 30 presentations to local and international audiences. He also chaired major forums, most notably acting as the CNSC's Multinational Design Evaluation Programme (MDEP) Policy Group member and, for the past three years, as the second to chair on the Technical and Scientific Support Organizations Forum of the International Atomic Energy Agency (IAEA).



Mr. Terry Jamieson, past Vice-President of the CNSC's Technical Support Branch.

Prior to joining the CNSC, Mr. Jamieson spent 18 years with Science Applications International Corporation (SAIC Canada), where his work focused on CANDU reactor safety analysis, emergency planning, radiation detection/measurement, nuclear/radiological engineering, and reactor containment behaviour and release pathways. Mr. Jamieson rose to the position of Chief Operating Officer, Vice-President and Division Manager at SAIC Canada, where he was responsible for the nationwide operations of the company.

Mr. Jamieson began his career as a nuclear design engineer at Ontario Hydro. He then went on to become a researcher in the Library of Parliament's Science/Technology Research Branch, where his areas of specialization included nuclear power, nuclear safety and high technology, particularly as it related to the energy field. Mr. Jamieson then became Senior Nuclear Engineer at ECS Power Systems, where he was responsible for the design of a small, mobile nuclear reactor for use in a research submarine. During this time, he and several colleagues held a patent for a new small reactor design.

Throughout his career, Mr. Jamieson has been involved in a long, varied list of groups and projects, receiving many accolades. In 2010, he was made a Fellow of the Engineering Institute of Canada. In 2000, the Canadian Nuclear Society awarded Mr. Jamieson the J.S. Hewitt Team Achievement Award for the creative conceptualization and innovative application of a thermal neutron-activation-based system for detecting non-metallic land mines, allowing for the more effective detection and removal of these deadly devices. Early in his career, in his free time Mr. Jamieson developed an analytical engine to power CANDU emergency response projection codes, which has been in use by the nuclear industry since 1985. He also authored numerous technical publications and received the American Nuclear Society's Best Paper Award in 1996 for a paper he co-authored titled *Assessment of the Cosmic Radiation Field at Jet Altitude*.

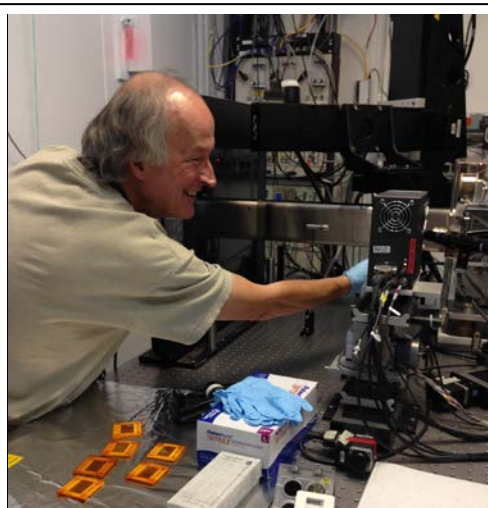
## Steve Mihok, PhD

The work and research that the CNSC conducts is supported by the vast expertise of its technical specialists and scientists. Before his retirement this year, this support included that of Dr. Steve Mihok for the past 17 years. Over a 42-year scientific career, Dr. Mihok has worked as a government regulator, a research scientist, an international development biologist/manager, a public affairs officer and a university lecturer. His career began with field research in the arctic in 1975, which earned him a PhD in small mammal behavioural ecology from the University of Alberta in 1979.

Joining the CNSC in 2000, Dr. Mihok worked as an environmental risk assessment specialist in several divisions and directorates, including most recently the Environmental Risk Assessment Division. His work involved assessment and compliance activities to ensure that the public and the environment are protected. Early in his job at the CNSC, he researched molybdenum as a contaminant of concern at uranium mines, leading to its eventual inclusion in effluent treatment strategies. As a senior biologist, he specialized in radioecology and environmental modelling, often bridging the gap among specialists on both protection of the environment and people. He also contributed to many external activities, interacting with the IAEA, ICRP and UNSCEAR, and regularly presented information on CNSC science/regulation and environmental protection at international meetings, conferences and workshops. He was also proactive in developing innovative research projects and workshops through the CNSC Research and Support Program on topics such as alpha radiation effects on fish and mammals, tritium environmental science, and synchrotron characterization of uranium in mine tailings.

Prior to his work at the CNSC, Dr. Mihok's career entailed diverse responsibilities in Canada and Africa. Following his PhD, he taught wildlife ecology and statistics at the University of Dar es Salaam in Tanzania for a brief period. He then returned to Canada to work at the Environmental Research Branch of AECL at Whiteshell Laboratories in Manitoba until 1988. While there, he conducted research on the health and ecology of small mammals exposed to chronic gamma radiation under natural conditions. To date, he remains one of the very few scientists to complete experimental field studies of this kind. Dr. Mihok then returned to work in Africa for 10 years as a research scientist at the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya, where he conducted research and outreach throughout Africa on vector-borne diseases of humans, wildlife and livestock in the context of sustainable development. He trained about 150 veterinarians and biologists in [tsetse](#) control, and acted as the technical lead in a new disease vectors management program. While at ICIPE, he invented the Nzi trap, a device that is now in widespread use for capturing tsetse and other biting flies.

Dr. Mihok has contributed to about 100 publications during his extensive and varied career, including 86 scientific articles in mostly peer-reviewed journals, 10 CNSC regulatory or information documents, and three IAEA technical documents. He has also reviewed articles and book chapters for 37 publishers, and research grants for five agencies. Through his work at the CNSC, Dr. Mihok has been recognized with a number of CNSC awards reflecting his contributions to licensing, assessment, research and outreach.



Dr. Steve Mihok at Argonne National Laboratory, inserting a sample of uranium mine tailings for synchrotron micro analysis.



## Advancing regulatory perspectives

To ensure the safe overview of nuclear technologies and applications, regulatory perspectives must evolve both with the development of new technologies and the understanding of current technologies. Every year, the CNSC is involved with research and knowledge-sharing groups and activities that focus on the development of regulatory perspectives.



### **Global Energy Regulators Summit**

Nuclear regulators face challenges that transcend geographical boundaries, including providing accurate and timely assessments of the environmental, social and political risks related to energy production, transportation and delivery – while also fostering public confidence in their activities. In 2015, Dr. Cary Coglianese was commissioned by the Alberta Energy Regulator to investigate and report on how regulators worldwide were addressing these issues. In September 2015, he published a report that examined topics like public confidence and risk assessment, and also looked to answer the question of what regulatory excellence looks like.

The topic of regulatory excellence was further explored this past fiscal year at a Canadian consortium organized by the Public Policy Forum that consisted of the CNSC, the Alberta Energy Regulator, the National Energy Board, and Ernst & Young. Over the course of three separate events, the work presented in Dr. Coglianese’s report was examined and discussed by federal, provincial, territorial and international energy regulators. Presentations by CNSC President Michael Binder and Vice-President and Chief Communications Officer of the Regulatory Affairs Branch Jason Cameron afforded the CNSC the opportunity to demonstrate Canada as having leading regulatory regimes.

**Did you know?** As of 2017, there are nearly 450 operable commercial reactors around the world. These reactors are located across 48 countries, with reactors in each continent except Australia and Antarctica.

### **CSA Group**

The CNSC has had a long history of cooperation with the CSA Group (formerly the Canadian Standards Association), an independent, third-party organization that provides a structured and accredited process for developing standards. The CNSC has been a major participant in the CSA Group’s Nuclear Standards Program – which develops, reviews, amends, and publishes standards for the nuclear power industry – since its establishment in the 1970s due to the CNSC’s strong interest in the development of safety standards for the nuclear industry. Standards developed under this program have formed integral components of the CNSC’s regulatory framework and are referenced in regulatory instruments such as licences, licence condition handbooks, and regulatory and guidance documents.

The contributions the CNSC makes to the CSA Group continue to support their Nuclear Safety Standards Program and the Group’s annual conference and committee week. This support also facilitates public access to CSA nuclear standards through the free, online Communities of Interest portal and through CNSC and CSA Group coordinated communications releases which invite the public to review and comment on draft nuclear standards. This plays an important role in ensuring consultation for CSA Group Standards occurs in a manner similar the same level of transparency is maintained in CSA Group standards development as for to other CNSC regulatory documents.

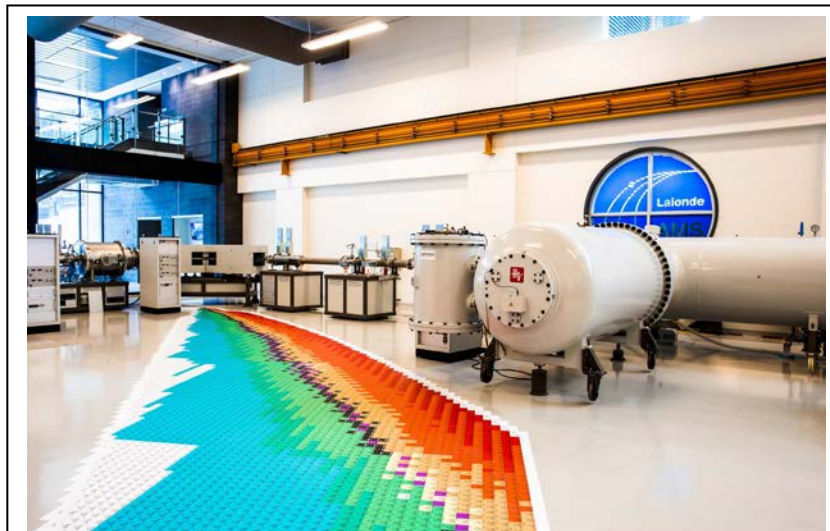
The CNSC also participates in technical committee meetings in which members discuss the drafting, review, amendment and scientific development of CSA Standards. During the 2016-17 fiscal year the CNSC participated in multiple technical committee meetings, seven CSA document reviews, two Nuclear Strategic Steering Committee meetings and a committee meeting pertaining to the updating of an exposure device operator personnel certification program.

## Enhancing Canada’s nuclear forensic capabilities

Nuclear forensics involves the scientific analysis of radioactive/nuclear materials (or evidence contaminated with radioactive/nuclear materials) to support the broader investigation into a nuclear security event. Through an iterative process, administrative identifiers as well as isotopic, chemical and physical material signatures can be exploited to link materials to people, places and events.

Since 2013, the CNSC has been involved in several whole-of-government initiatives aimed at enhancing and expanding Canada’s national nuclear forensics capabilities. One of these initiatives was the development of the National Nuclear Forensics Library (NNFL): a large data repository that catalogues material signature data and other information pertaining to radioactive or nuclear material under Canadian regulatory control. The CNSC is the lead federal agency responsible for developing, maintaining and operating the NNFL on behalf of the Government of Canada. The NNFL is a tool that can assist in conducting comparative queries and assessments as part of a broader investigation into security threats or events involving radioactive or nuclear materials. Its main function is to assist in the attribution of such materials in the event they are found outside of regulatory control.

In the interest of improving the NNFL’s attribution capabilities, a research initiative was taken to measure the U-236 content of [uranium ore concentrate](#) samples currently held in CNSC inventory. This particular [isotope](#) of uranium is potentially a highly discriminant signature data type, a feature that, like a fingerprint, could significantly improve the ability of the NNFL to establish the geological origins of uranium ore concentrate samples of unknown origins. U-236 measurements were conducted at the André E. Lalonde Accelerator Mass Spectrometry Laboratory in the University of Ottawa’s Advanced Research Complex, and the assessment of U-236 as both a standalone and complementary signature is currently underway in partnership with the National Research Council of Canada.



Pictured is the André E. Lalonde Accelerator Mass Spectrometry Laboratory at the University of Ottawa’s Advanced Research Complex. The laboratory houses a variety of state-of-the-art equipment, including a large mass spectrometer seen on the right, which enables the detection and analysis of low concentrations of isotopes in natural samples.

(Source: <https://media.uottawa.ca/news/CFI-AMS>)

### Advancement of sample analysis methods at the CNSC laboratory

Inductively coupled plasma-mass spectrometry (ICP-MS) is an analytical technique used to detect and quantify certain elements in aqueous samples. Analysis of solid samples (such as uranium dioxide (UO<sub>2</sub>) fuel pellets) requires dissolution of the sample in concentrated acids. As an alternative, the CNSC laboratory has been developing new techniques that use [laser ablation](#) (LA) along with ICP-MS to remove the need for sample dissolution. Laser ablation focuses a laser beam on the surface of a sample to generate small particles that ICP-MS can analyze. By not requiring sample dissolution, LA-ICP-MS greatly simplifies sample preparation and reduces the amount of acid waste generated by the lab.

The LA-ICP-MS technique has been studied as part of two Canadian Safety and Security Program projects: the Nuclear Material Signature and Provenance Assessment Capability Development Project as well as the National Nuclear Forensics Capability Advancement Project. The newly developed analysis methods using LA-ICP-MS will be useful for analyzing trace element concentrations in uranium concentrates, measuring uranium isotope ratios in uranium rich samples (such as uranium concentrate, UO<sub>2</sub> and uranium trioxide) and the surface analysis of solid objects (such as UO<sub>2</sub> fuel pellets). Additionally, the CNSC laboratory has developed and validated the LA-ICP-MS method for determining the purification date of uranium rich materials, which is an important signature for determining the origin of a nuclear material in nuclear forensics investigations.

In 2016, the CNSC represented Canada in the Collaborative Materials Exercise organized by the Nuclear Forensics International Technical Working Group. Here, LA-ICP-MS was used to examine the surfaces of two UO<sub>2</sub> fuel pellets and determine their purification date and enrichment. The CNSC was the only lab to use the LA-ICP-MS technique, which gave results in excellent agreement with much more expensive and specialized techniques.



The LA-ICP-MS equipment housed at the CNSC laboratory.

The basic principle of ICP-MS detection is that a high-temperature [inductively coupled plasma](#) source is used to convert the atoms of the elements in a sample into their [ions](#), which are then separated and detected by a [mass spectrometer](#).

**Did you know?** In 2016, the CNSC laboratory received ISO 17025 accreditation from the Standards Council of Canada to calibrate gamma survey meters. Including the calibration, maintenance and storage of radiation detection devices (such as survey meters and radiation isotope identifiers), the role of the CNSC laboratory includes the collection and analysis of environmental samples as well as research.

In addition to the two main headquarters offices, the CNSC's dedicated laboratory facility is also in the Ottawa region.

## Research activities as part of readiness to regulate new reactor technologies

Interest in the potential use of new reactor technologies has grown over the past several years. This includes technologies such as third- and fourth-generation large nuclear power plant designs as well as smaller nuclear power plant concepts commonly called small modular reactors (SMRs).

Some of the technological features being introduced in these new designs include the use of reactor coolants that outperform the cooling properties of water, the use of modular construction practices, and the increased use of automation and passive/inherent safety features.

While these new features have great potential to improve safety performance and operational efficiency, it is important for CNSC staff to understand the state of the science and technology that supports any such claims. (As an example, new types of coolants may present significant chemistry issues to the long-term operation of a power plant.) It is also important to determine how these features and reactor types will be regulated, particularly if they have never been built or operated before.

The CNSC regulatory research program is used strategically in concert with other activities (such as pre-licensing vendor design reviews) to provide CNSC staff with supplemental information to:

- assist with interpreting and clarifying regulatory requirements and guidance
- inform technical assessments for the purposes of licensing
- establish compliance programs for activities proposed by an applicant for a license

**Did you know?** Although the term “small modular reactor” has many different interpretations around the world, it generally describes a nuclear power plant that is smaller in output than more traditional nuclear power plants (which range from 700–1650 [MWe](#) in electrical output) and has some or all of the following characteristics:

- An SMR takes advantage of modular manufacturing and construction approaches to reduce construction time.
- To make up the loss of economy of scale provided by a larger reactor, an SMR generally introduces a greater number of technological features that can reduce capital, operating and maintenance costs.
- An SMR may be a facility composed of one or more self-contained reactors that could be built in sequence as power demand increases.

While the SMR acronym most commonly refers to a small modular reactor, the International Atomic Energy Agency (IAEA) interprets it as “small and medium-sized reactors”, where a small reactor produces less than 300 MWe and a medium reactor produces up to 700 MWe.



### **Multinational Design Evaluation Programme**

The Nuclear Energy Agency established the Multinational Design Evaluation Programme (MDEP) in 2006 to leverage the resources and knowledge of regulatory authorities around the world tasked with the review of new nuclear reactor designs. The nuclear regulatory authorities of 15 countries participate in the Multinational Design Evaluation Programme, which includes five design-specific working groups and three issue-specific working groups. Design-specific working groups focus their efforts on specific reactor designs and are formed when three or more countries express an interest in collaboratively examining a particular design. Issue-specific working groups are established for selected technical and regulatory process areas.

The CNSC is actively involved in the design-specific AP1000 Working Group, leads the issue-specific Codes and Standards Working Groups, and participates in two other issue-specific working groups (the Vendor Inspection Cooperation Working Group and the Digital Instrumentation and Control Working Group). In addition, the CNSC participates in both the Multinational Design Evaluation Programme Policy Group and the Steering Technical Committee, which are responsible for overseeing the entire program.

The CNSC recently extended its participation agreement by one year. This extension will help ensure a seamless transition of leadership of the Codes and Standards Working Group to the Committee on Nuclear Regulatory Activities, and will also keep the CNSC engaged with the AP1000 Working Group so it can benefit from the data being acquired during the initial commissioning of the AP1000 reactor design.



### **IAEA SMR Regulators' Forum**

The International Atomic Energy Agency (IAEA) formed the SMR Regulators' Forum in 2015 to identify and understand the key challenges emerging during SMR regulatory discussions. Its members include Canada, China, Finland, France, Korea, Russia, the United Kingdom and the United States. The role of scientific secretary is fulfilled by the IAEA, giving the forum access to IAEA expertise on an as-needed basis.

A two-year pilot project was launched in 2015 to provide the forum with a better understanding of each member's views on common regulatory issues. By capturing international best practices in this area, the knowledge gained through this project will enable regulators to inform changes, if necessary, to their regulatory requirements and practices. The role of the CNSC in this pilot project was to provide technical expertise to the forum's working groups on emergency planning zones, the application of defence in depth, and the application of the graded approach to regulatory decisions involving the novel technologies being proposed by SMR developers.



The CNSC participated in steering committee and working group meetings hosted by the IAEA over the past fiscal year. In addition to assessing the progress of the forum's three working groups, these meetings presented an opportunity to discuss future areas of work that continue to develop and to integrate the efforts of the working groups to support future licensing by IAEA Member States.

A report on the pilot project is being assembled by the forum and will reflect the conclusions and recommendations of the three working groups, including recommendations for the next phase of work from 2017 to 2020. The report will be published as one of the IAEA's many technical documents, which are available to the public on the [official IAEA website](#).

Given the accelerating interest in SMRs around the world and the need to increase the level of regulatory cooperation related to SMR technologies, CNSC staff recommended that the contribution agreement held with the IAEA SMR Regulators' Forum be renewed to further enhance the international sharing of best practices in this area.

### **IAEA study on the applicability of SSR-2/1 to SMRs**

Since its first Safety Series publication in 1958, the IAEA has worked to produce integrated, comprehensive and consistent sets of up-to-date, user-friendly safety standards. These documents are intended to harmonize, at a global level, the standards for protecting people and the environment from the harmful effects of ionizing radiation. Within the set of Specific Safety Requirements is SSR-2/1, *Safety of Nuclear Power Plants: Design*, which contains 82 requirements related to topics such as management of safety in design as well as general and specific plant system designs. While these requirements were produced primarily in reference to large, land-based, stationary plants with water-cooled reactors, they may also be applied, with judgment, to other reactor types to determine the requirements that must be considered during design development.

With the growing interest in SMR technologies, the IAEA initiated a project to confirm whether the SSR-2/1 standards could be applied to SMRs. As a first step, a number of vendors and design-related organizations were asked to review and comment on the requirements in SSR-2/1 for one of two particular SMR designs: light water and high-temperature gas SMRs. Participants were given a list of requirements and asked to provide comments on their interpretations, expected applicability and suggested modifications.

The CNSC participant for this project was a technical specialist in the Assessment Integration Division, who made comments on topics such as defence in depth and containment conditions for the high-temperature gas SMR design. This work culminated in a consultancy meeting at the IAEA headquarters in Vienna, Austria in February 2017, where the compiled comments were reviewed by all participants to come to a common understanding of the current applicability of each requirement to the two SMR designs. Additional IAEA working meetings for this project were scheduled for June and September 2017 to further discuss the challenges identified and the final disposition for each requirement.



**Did you know?** CNSC staff, under the vendor design review process, are reviewing SMR designs that range from 3 MWe to as large as 200 MWe. Smaller designs are being developed by vendors to provide enough energy to heat and power small villages that currently have no access to an electrical grid. Slightly larger designs are being developed to provide heat and power for northern mining projects. Larger SMRs are being developed by vendors to replace older fossil-fuel plants on grids that cannot accommodate a large, traditional nuclear power plant.

More information about pre-licensing vendor design reviews as well as the reviews currently being conducted can be found in the [Reactors section on the CNSC website](#).

### **CNSC discussion paper on requirements and guidance for SMRs**

One of the key issues nuclear regulators such as the CNSC must address with vendors and other stakeholders involves the regulatory and licensing implications presented by SMRs. Regarding the regulations and licensing process in Canada, it is the CNSC's view that existing regulations under the *Nuclear Safety and Control Act* are already suitable for regulating activities involving the use of SMR technologies, the licensing process is risk informed and independent of reactor technology or size (but the CNSC is interested in understanding where enhancements can be made), and licence applications for specific activities and project phases can be reviewed in series or in parallel depending on the needs and the readiness of the applicant.

Even with the CNSC's flexible licensing approach, the innovative features found in new reactor technologies may present challenges to both the interpretation and application of regulatory requirements. Over the past several years, CNSC staff have examined key areas where challenges could exist around emerging technologies such as SMRs. In 2016, the CNSC produced a discussion paper to provide an overview of potential issues associated with SMRs. In some cases, the CNSC confirmed that the existing requirements remain valid and useful. In others, it was determined that further examination will be needed to confirm whether additional requirements or guidance are necessary to support those that already exist. For these issues, specific items to be addressed in future work – in some instances using existing regulatory tools and processes – were identified.

The information from the discussion paper was used to engage with stakeholders and technology forums to provide regulatory clarity where necessary. The document was posted for public comment on the CNSC website for 120 days, with more than 430 comments submitted by organizations such as Ontario Power Generation, Bruce Power, StarCore Nuclear, Moltex Energy, the Ontario Ministry of Energy and the Canadian Nuclear Association. Commenters were then invited to the CNSC headquarters in Ottawa for a follow-up workshop in September 2016 to clear up any remaining questions from industry and public stakeholders.

Refer to the CNSC website for the final report: [DIS-16-04, \*Small Modular Reactors: Regulatory Strategy, Approaches and Challenges.\*](#)

**Did you know?** While SMRs are newly emerging technologies, they are already being built in countries such as China, Argentina and Russia. The Russian KLT-40S reactor, for example, has been outfitted into a new floating power plant design and is designed to provide 35 MWe to a shore-based project and up to 35 MW of heat for desalination and district heating. This facility is currently awaiting an operating licence in Russia.



The Russian KLT-40S reactor plant unit being loaded onto a floating nuclear power plant.

#### 4th International Technical Meeting on Small Reactors

Since 2010, the CNSC, in cooperation with Chalk River Laboratories, has hosted four International Technical Meetings on Small Reactors, with the most recent taking place in November 2016 in Ottawa. These meetings bring together a diverse group of stakeholders from industry, regulators and policy bodies to learn about and debate important issues on areas pertinent to the development and use of new reactor technologies.

At this 2016 meeting, CNSC staff made several presentations on areas of regulatory interest. A presentation from Marcel de Vos of the New Major Facilities Licensing Division described how applicants for licences that refer to SMR technologies can use the CNSC's regulatory framework to ensure that their designs meet the regulatory requirements for all safety and control areas. Kevin Lee of the Regulatory Policy Analysis Division presented on the Canadian regulatory approach and also provided information on the contents of the CNSC-produced SMR discussion paper. Finally, former Vice-President of the Technical Service Branch Terry Jamieson presented on and discussed the CNSC's approach to reviewing the research and development programs used to support the regulatory review of SMRs.

Attendance at the meeting also allowed CNSC staff the opportunity to view other organizations' presentations, examining topics such as non-water-cooled small reactors, underground and off-grid installations, passive and inherent safety, accident tolerant fuels, and licensing of prototype and demonstration SMRs.

#### Did you know?



The power generated by a nuclear power plant is usually described either in terms of its megawatt electrical (MWe) or thermal (MWth) output. MWe refers to the electricity generation of a plant, while MWth refers to the heat energy produced by a system before it is converted to electricity.



## International commitments

A crucial aspect of the process of optimizing safety in the nuclear field is ensuring the collaboration and exchange of information between the CNSC and other energy regulators and researchers around the world. Maintaining cooperation between the CNSC and bodies such as the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), the Organisation for Economic Co-operation and Development (OECD) and France's Alternative Energies and Atomic Energy Commission (CEA) ensures that the CNSC has access to a strong international support network.

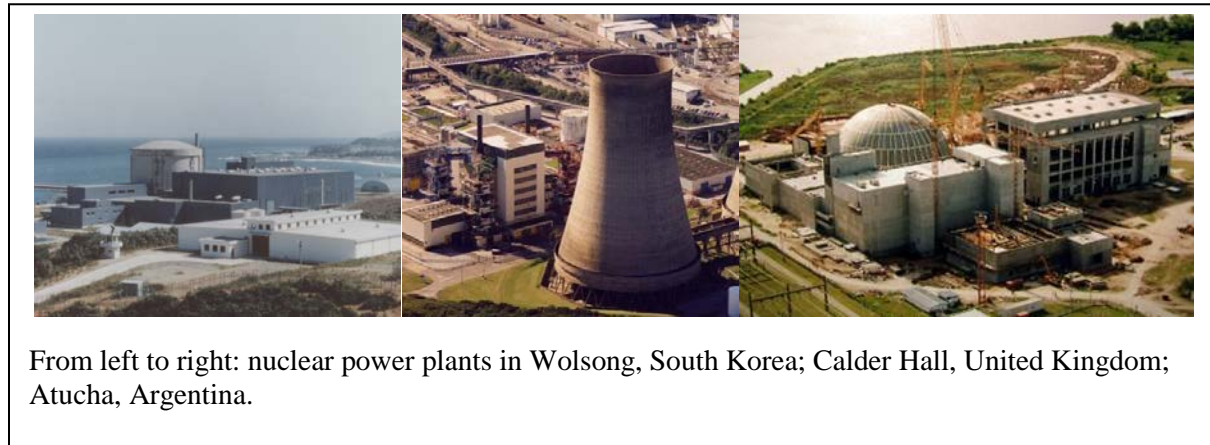


Photo taken during a May 2016 visit to the CNSC by the IAEA's Deputy Director General of Department of Safeguards. The meeting was hosted by the CNSC's Raoul Awad, Director General of the Directorate of Regulatory Improvement and Major Projects Management.

### Continued work with the European Commission

The European Commission's Horizon 2020 movement aims to promote scientific research by providing a single market, accessible to everyone, for the funding and support of research, knowledge and innovation. For the past two years, the CNSC has been involved in two Horizon 2020 projects: the Sustainable Network for Independent Technical Expertise (SITEX II) initiative and the FAST Nuclear Emergency Tools (FASTNET) project.

FASTNET is a four-year project that began in 2015 as an international collaboration of 21 nuclear organizations around the world, led by the Swedish Radiation Safety Authority and France's l'Institut de Radioprotection et Sûreté Nucléaire (IRSN). The results of the Nuclear Energy Agency's FASTRUN project (which was led by the CNSC) indicated that emergency response organizations struggled to assess consequences for unfamiliar reactor designs. In response, the FASTNET project looked to develop a common approach to assessing accidents. This would involve familiarizing the international community with a multi-tool common approach to diagnosing severe accident progressions and possible consequences for different reactor designs. The CNSC's participation in the FASTNET project this past fiscal year has included providing financial support as well as participants to workshops and administrative meetings. In November 2016, the FASTNET Steering Committee met in Bologna, Italy to review the status of the FASTNET work packages. This meeting was followed by a workshop for the FASTNET end-user group that focused on disseminating information on the different methodologies national organizations are using to assess the consequences of nuclear events. A follow-up meeting to this workshop took place in January 2017 in Stockholm, Sweden to review the status of a database being developed for the accident consequences of different reactor types (one of the FASTNET working group deliverables). CNSC staff were present for all three of these events.



From left to right: nuclear power plants in Wolsong, South Korea; Calder Hall, United Kingdom; Atucha, Argentina.

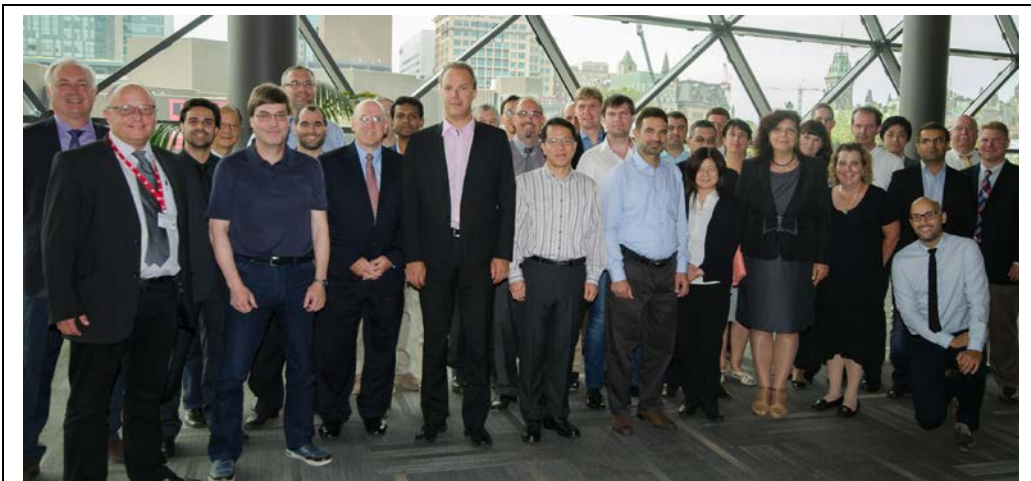
SITEX II is coordinated by the IRSN as a follow-up initiative to the first SITEX initiative. Composed mainly of nuclear regulators and technical support organizations, the group examines topics pertaining to the geological disposal of radioactive waste, including the safety case for this kind of waste disposal, regulatory expectations, stakeholder interactions and research. The CNSC's participation in SITEX II in 2016–17 included meetings with other project members to discuss the status of work packages. This included two plenary meetings in Brussels, Belgium in May and November, and a working meeting in Prague, Czech Republic preceding the first plenary meeting.

More information on both projects can be found on the [SITEX](#) and [FASTNET](#) websites.

### **International Generic Ageing Lessons Learned program**

With many commercial power reactors now reaching stages of operation surpassing the original lifetime estimates, the topic of aging management has become prevalent in the international nuclear industry. In 2013, the IAEA initiated the International Generic Ageing Lessons Learned (IGALL) program to serve as a global platform for regulators and utilities, providing an internationally recognized technical basis and practical guidance on managing the aging of the structures, systems and components of nuclear power plants. The CNSC and its licensees use the IGALL program to support the implementation of CNSC regulatory documents REGDOC-2.6.3, *Aging Management* and REGDOC-2.3.3, *Periodic Safety Review*.

The CNSC has provided ongoing financial support for the development of the IGALL program, which includes databases and collections of aging-management-related studies, mechanisms, environments and processes. This past fiscal year, the CNSC also participated in working group technical meetings pertaining to the third phase of the IGALL program. These meetings involved reviewing the status of the deliverables from the program's three working groups, each of which is focused on collecting and consolidating specific technical data relating to mechanical and electrical components and structures. The objectives of these meetings also often included updating and enhancing the correctness and completeness of the IGALL database.



IGALL members at the September 2016 meeting in Ottawa. This was one of several IGALL meetings held during that year.

**Did you know?** There are reactors within the CANDU fleet that are now entering periods of extended operation. These facilities undergo a higher frequency of compliance testing to ensure that all systems remain within safety margins. Additionally, a large amount of research goes into topics such as life assessment, aging strategies and emergency mitigation to investigate new issues that may be encountered and how they can be prevented or addressed.



### **OECD High Energy Arcing Fault Events project**

High-energy arcing fault (HEAF) events, generally defined as massive electrical discharges occurring in power plant switching components, have been an identified phenomenon in nuclear power plants worldwide. As a significant source of energy release, these discharges can lead to major equipment failures and potentially act as an ignition source for fires in other plant components. Of the 415 worldwide plant fire events between 1979 and 2012 documented in the OECD FIRE Database, 48 were HEAF-induced. Additionally, these incidents have been occurring with increasing frequency in recent years, possibly as a result of aging infrastructure and increasing energy demands.

In response to these findings, the HEAF Events project was organized by the Nuclear Energy Agency (an agency within the OECD) as a collaborative international project involving 13 member countries and 19 organizations, including the CNSC representing Canada. The overall purpose of this work is to investigate and characterize a HEAF phenomenon through experimentally obtained scientific fire data. This information will then provide the basis for a technical definition of a HEAF phenomenon, as well as the development of simple models and deterministic criteria to predict and analyze potential HEAF scenarios.



Members of the FIRE and HEAF projects meeting in Yuseong, Daejeon, Republic of Korea on October 13, 2016.

During the 2016–17 fiscal year, this project’s work focused on the analysis of experimental data obtained during the 2014–15 testing period. Testing primarily involved experimenting with switchgears and bussing components in HEAF scenarios, and included obtaining high-speed high-definition video recordings of these tests. The individual experiment analyses performed by HEAF project partners have been compiled into a draft report. International meetings also took place during 2016 in locations such as France and the Republic of Korea, giving member countries the chance to discuss the status of their HEAF activities and review the most recent report draft.

### **OECD PRISME projects on fire safety**

From 2006 to 2016, the OECD PRISME and PRISME 2 research projects studied heat and smoke propagation in different modes, such as through doors or ventilation ducts, to improve regulatory oversight related to fire safety. The projects were a joint collaboration of 12 member countries – including the CNSC representing Canada – organized through the Nuclear Energy Agency of the OECD, with a series of experiments conducted at the IRSN Centre de Cadarache in France.

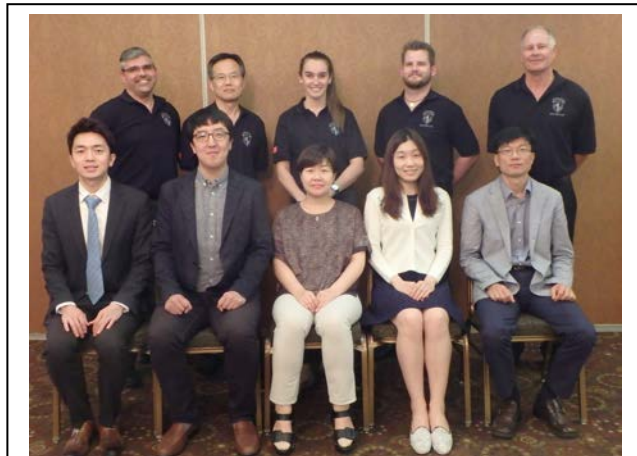
The experimental outcomes obtained by the PRISME projects have provided a stronger understanding of how fires develop and spread in confined and ventilated large-scale compartments of nuclear installations. The resulting database can be used to improve on the inherent limitations of existing fire-modelling capabilities and validate fire-simulation codes. Ultimately, this information provides critical knowledge on the impact of heat and smoke on safety critical systems to support the risk-informed regulatory oversight of fire safety.

**Did you know?** The IRSN Centre de Cadarache, located in France, is one of Europe’s largest research facilities for energy-focused technologies and development. It currently hosts many research projects for France’s Alternative Energies and Atomic Energy Commission, as well as the international joint fusion experiment known as ITER.

### **Korean delegation visit to Bruce Power**

A delegation from the Republic of Korea, including representatives from the Nuclear Safety and Security Commission (NSSC), the Korea Institute for Nuclear Non-Proliferation and Control (KINAC) and Korea Hydro & Nuclear Power (KHNP), visited Canada in June 2016 to hold several discussions with the CNSC. These discussions focused on the CNSC’s best practices in nuclear security and included an exchange of information with CNSC specialists and Bruce Power representatives on the development of a performance testing program.

Similar meetings between the CNSC and a delegation composed of representatives from the NSSC, KINAC, KHNP and the Korean Radiation Safety Foundation were also held in February and December 2016. At these meetings, informal discussions were held on topics such as post-Fukushima activities and underground low- and intermediate-level radioactive waste disposal facilities. Meetings such as this allow the CNSC and other organizations the opportunity to learn from the experiences and practices of one another, bringing the world closer to optimizing nuclear security.



The Korean delegation, accompanied by staff from the CNSC Nuclear Security Division, on a visit to Canada in June 2016.

### **International Commission on Radiological Protection**

The ICRP is an independent, international advisory body that aims to advance the science of radiological protection as it pertains to ionizing radiation and its biological effects. It provides recommendations and guidance on the development and implementation of radiation protection standards, legislation and practices. The ICRP's workforce is composed of more than 200 volunteers who are experts in different areas of radiological protection and recruited from around the world.

In addition to making financial contributions to the ICRP, the CNSC also provides office accommodations and administrative services for the ICRP Scientific Secretariat. Since 2012, the CNSC has also provided the ICRP Scientific Secretariat with full-time, fully funded intern students through the CNSC co-op program. This integrated support allows the Scientific Secretariat to work more effectively, while also providing valuable learning experiences to young professionals who may soon be entering the nuclear field.

The CNSC has also supported ICRP-hosted conventions that bring together experts and organizations to discuss different topics within the field of radiological protection. For example, in 2017 the funding provided by the CNSC will go in part to the 4th bi-annual International Symposium on the System of Radiological Protection held in Paris, France. This conference will provide more than 600 professionals, experts and researchers from around the world the opportunity to convene and discuss their concerns, challenges and ways forward in advancing the field of radiological protection.



University of Ontario Institute of Technology co-op student Alex Komosa (pictured left) participating in a task group meeting pertaining to the Fukushima Daiichi accident during his rotation with the ICRP.

## Strengthening the next generation

One of the CNSC's core missions is to disseminate scientific, technical and regulatory information about its actions as well as the actions of every player in the nuclear industry. This may include information on radiological effects on the environment, health and safety of the public and workers, as well as information on the development, function, transportation or regulation of nuclear materials, technologies and applications. This dissemination is achieved through projects such as this report, the content posted on the CNSC website and through a great number of outreach programs. By working with various academic and non-profit organizations to provide co-op opportunities and implement programs such as Cool Science Saturday, the CNSC is able to have an impact on the nuclear literacy of students from elementary school to university – and play a huge role in the encouragement and development of the next generation of scientists, specialists and experts.



CNSC employees bringing the 2016 Cool Science Saturday event to the small community of Hornepayne in northwestern Ontario.



### **Annual UNENE student workshop and poster session**

The CNSC has been a long-time supporter of the University Network of Excellence in Nuclear Engineering (UNENE), which conducts nuclear research at Canada's universities and works to develop scientific expertise through post-graduate training. These have been the central goals of the UNENE partnership between Canadian universities, the nuclear industry, and regulatory and research bodies since its formation in 2002.

The funding provided by industry members and organizations such as the CNSC allows UNENE to offer its Industrial Research Chair positions, which are granted to university professors to help support their research in areas such as health physics and environmental safety, risk-based lifecycle management, advanced nuclear materials and more. This funding also enables UNENE's Collaborative Research and Development (CRD) grants. More than 25 targeted research grants have been awarded through the CRD program since 2005, with 13 of these still involving ongoing work.

A portion of the CNSC's funding also goes towards the annual student workshop and poster sessions held by UNENE. This event provides graduate students with the opportunity to conduct their own research and then present their findings to industry professionals. First-, second- and third-place winners are awarded at this session. The 2016 first-place winner was Mi Li from Western University, whose research focused on how radiation affects the kinematics of corrosion on metal welds composed of dissimilar metals.



Mi Li (right), first-place winner of the 2016 UNENE student workshop, with UNENE President Jerry Hopwood.

**Did you know?** Through its partnership with six Canadian universities, UNENE offers those already working in the nuclear industry the opportunity to earn a master's degree in engineering as well as a diploma specializing in nuclear engineering. The overall purpose of this program is to ensure the development of qualified nuclear scientists and professionals to sustain Canada's nuclear industry.



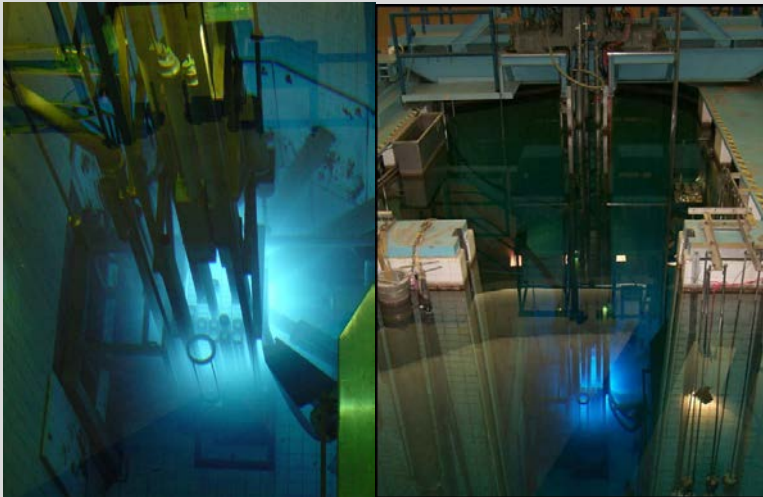
### McMaster University NEUDOSE project

Early in 2015, a group of 30 McMaster University students, led by recent graduate Dr. Andrei Hanu (who now works as a researcher at NASA's Goddard Space Flight Center), began working collaboratively to design, construct and launch a miniature satellite – the CubeSat – into orbit. The CubeSat will contain specialized equipment able to record and report on the ionizing radiation unique to a space environment. The purpose of this project, known as the Neutron Dosimetry and Exploration (NEUDOSE) mission, is to enable researchers to classify and characterize the radiological hazards present in a low earth orbit atmosphere. It also serves as a highly unique learning experience for McMaster students, who play an integral role in every step of the project from conception to launch to the studying of results. In 2016–17, the CNSC provided funding directly to this project in the interest of the research it will produce as well as the learning and experiences it affords to the students working on it.



CNSC President Michael Binder (left) with Erica Dao, a graduate student in radiation sciences at McMaster University and team member in the NEUDOSE mission. They are holding the CubeSat at the Canadian Nuclear Association Conference in February 2017.

**Did you know?** The open-pool style reactor housed at McMaster University was originally designed to be used as a research reactor. Today it is also the world leader in the production of the radioactive isotope iodine-125, which is used in the medical treatment of prostate cancer.



Two photos of the research reactor housed at McMaster University. The blue glow seen around the core of the reactor is the result of [Cherenkov radiation](#). In essence, it can be considered a “shockwave” of light that is the result of a flow of electrically charged particles moving through a medium (in this case, water) at a speed greater than the [phase velocity](#) of light in that medium.

### **Let's Talk Science**

Since 1993, the Let's Talk Science initiative has focused on educational development and outreach to youths and educational professionals in the STEM subjects (science, technology, engineering and math). In 2016 alone, Let's Talk Science reached more than 850,000 youths and 18,000 educators in 1,700 communities across Canada through its web- and classroom-based workshops and programs.

Over the past four years, the CNSC has provided financial and collaborative support to Let's Talk Science, with the shared goal of increasing student and teacher literacy in nuclear subject matter. To this end, an effort has been made to include nuclear learning modules in both the web-based CurioCity program and the community-based Let's Talk Science outreach program. As of 2016, five new nuclear-themed videos, articles and case studies have been posted to CurioCity, which all include links to relevant CNSC online learning resources. In the outreach program, opportunities for CNSC staff to volunteer have been provided to allow for more direct interaction with the public.

In addition, Let's Talk Science hosts an annual event – the Let's Talk Science Challenge – where students from Grade 6 to Grade 8 participate in a day-long event that includes STEM-based quizzes and design challenges. Throughout the day, students earn points based on their knowledge as well as their creative and innovative thinking. Prior to the event, students are provided with study handbooks, which include a presentation of STEM-based topics ranging from uranium mining to biofuels to mathematical probability.

For more information, visit the [Let's Talk Science website](#).



Students from Grade 6 to Grade 8 attending the 2017 Let's Talk Science Challenge at Carleton University in Ottawa.

The Let's Talk Science Challenge is a free program hosted annually in April and May at participating outreach sites across Canada. The program allows participants to test their own abilities, build teamwork skills and meet with role models in STEM fields.

## Renewing the CNSC workforce

To support the growth and development of the next generation of nuclear industry employees, the CNSC continues to maintain its student co-op and new graduate programs. With many nuclear industry employees approaching the age of retirement, ensuring that an interested and well-equipped workforce exists to supplement the industry is crucial.

The CNSC offers as many as 50 or more student term positions each year, with placements available in all areas of the organization. While many of these placements happen during the summer, a 12 to 15-month rotation is available for a handful of students from universities such as the University of Ontario Institute of Technology (UOIT), McMaster University and the University of Saskatchewan. Once they graduate, these students have the opportunity to return to work on contract at the CNSC as new graduates. Through these initiatives, the CNSC is able to foster the development of future industry workers as well as benefit from the fresh perspectives, talents and energy of these young professionals.



Co-op student and author of this report, Nicole Allison visiting Canadian Nuclear Laboratories (CNL)



## CNSC co-op programs



The 2016-17 and 2017-18 CNSC technical co-op students. Present on the far left is Akira Tokuhiro, Dean of the Faculty of Energy Systems and Nuclear Science at UOIT. On the far right is Marie-Claude Valade, who manages the CNSC's 12- and 15-month co-op programs.

In 2016, the CNSC hired five undergraduate co-op students, followed by another seven undergraduate and two graduate co-op students in 2017. The graduate students work at the CNSC for a one-year period while the undergraduates stay for 15 months. 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 work term.

Since 2006, the CNSC has maintained a co-op program where undergraduate and graduate university students, often with backgrounds in nuclear engineering or radiation health sciences, are hired for 12- to 15-month periods. During the 15-month co-op term, students rotate through different divisions within the CNSC every four months, with the potential to work at the CNSC's headquarters in Ottawa, the CNSC laboratory, the office of the International Commission on Radiological Protection (ICRP) Scientific Secretariat and even at some CNSC site offices at nuclear power plants around Ontario. This opportunity provides students with valuable work experience as well as a unique learning experience that exposes them to the many facets of Canada's nuclear industry.

During these work terms, students also have the chance to participate in many activities that take place outside of the office or lab setting. This includes travelling for inspections of nuclear power plants or uranium mines, training sessions, technical meetings with licensees or contractors, and conferences held here in Canada and abroad.

In addition to the long-term co-op students hired by the CNSC, many students are also brought on for four-month summer terms. These students come from many different universities and fields of study, and are given the opportunity to work and gain experience while also learning more about nuclear power and the Canadian nuclear industry. It takes people of all talents and educational backgrounds to sustain an organization – and the CNSC is always looking for engaged, curious and innovative individuals.

**CNSC student participation in international travel to address remaining Fukushima-related issues**

In September and October 2016, co-op student Trent Peerla Proulx travelled to Japan for three weeks as part of his rotation with the ICRP Scientific Secretariat's office. While in Japan, he participated in meetings on Fukushima-related issues including the Fifth International Expert Symposium, where experts convened to discuss how lessons learned from Chernobyl may be used to address Fukushima's thyroid question. This session was then followed by a tour of the Fukushima-Daiichi nuclear power plant. Additionally, the ICRP hosted two symposiums to discuss current work on radiological protection of the environment as well as the research of the Radiation Effects Research Foundation. Additional meetings were held between the ICRP, the Japan Nuclear Utility Service, scientists from the Radiation Effects Research Foundation and inhabitants from villages affected by the Fukushima accident.



Co-op student Trent Peerla Proulx (right) with ICRP Scientific Secretariat Christopher Clement on a three-week trip to Japan in fall 2016.



## **Future research at the CNSC**

Research continues to play a major role in generating the knowledge and information needed by CNSC staff to support the organization's regulatory mission.

In the following years, the CNSC will continue to focus on research related to these safety and control areas: fitness for service, safety analysis and waste management. More specifically, much of this research will focus on extended operation reactor facilities and the development and assessment of aging management strategies. Additionally, research can be expected into the safety implications, design and preparation of potential future waste repositories. Extensive research will likely also be seen in the design, safety analysis, regulation and licensing of emerging technologies such as small modular reactors.

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. Hosting, organizing and participating in conferences and projects with organizations such as the International Atomic Energy Agency, Atomic Energy of Canada Limited and the Organisation for Economic Co-operation Development remain an important aspect of the CNSC's role in advancing nuclear safety. As well, continued work with the University Network of Excellence in Nuclear Engineering and other youth-focused initiatives will allow the CNSC to contribute to the development of the next generation of nuclear experts and workers.

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

## Glossary of terms

**Aging management program / aging management plan:** A set of policies, processes, procedures, arrangements and activities that provides direction for managing the aging of a nuclear power plant's structures, systems and components (SSCs). AM program refers to the overall integrated aging management program or framework for a nuclear facility, while AM plan refers to a plan that is SSC specific or mechanistic based. Also called lifecycle management plan.

**Alpha particle:** A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. **Note:** An alpha particle is identical to a helium nucleus, which has a mass number of 4 and an electrostatic charge of +2. An alpha particle has low penetrating power and a short range (a few centimetres in air). Alpha particles will generally fail to penetrate the dead layers of cells covering the skin and can be easily stopped by a sheet of paper. However, alpha-emitting isotopes are harmful if ingested.

**Alpha radiation:** Radiation consisting of alpha particles. See [alpha particle](#).

**American Association of State Highway and Transportation Officials (AASHTO):** A United States standards body that publishes regulations, protocols and guidelines on highway design and general construction.

**Balance-of-plant system:** The supporting/auxiliary components in a power generating system. In a nuclear power plant, these components would include the turbines, condenser and major electrical power systems.

**Beta particle:** A charged particle that is emitted from the nucleus of a radioactive element during radioactive decay of an unstable atom. Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body. Beta particles may be stopped by thin sheets of metal or plastic.

**Beta radiation:** See [beta particle](#).

**Calandria:** A large cylindrical tank that is the core of a nuclear reactor. It houses the reactor's fuel elements as well as the moderator/coolant substance.

**Cherenkov 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.

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

**Defence in depth:** A failure-mitigation strategy that relies on the hierarchical deployment of multiple, independent and redundant layers of protection to prevent accidents from occurring.

**Delayed hydride cracking:** A crack growth mechanism that occurs when certain hydride-forming materials are exposed to hydrogen. In the case of CANDU pressure tubes, the zirconium alloy of the pressure tubes is a susceptible material and is exposed to hydrogen in solution.

**Flow accelerated corrosion:** A corrosion mechanism where the flow of water across a material's surface provides the conditions necessary for an increased rate of corrosion to take place.

**Gamma radiation:** Penetrating electromagnetic radiation emitted from an atom's nucleus. Also called gamma rays.

**Hydride:** In chemistry, this may refer to free hydrogen anions (negatively charged ions). In compounds referred to as hydrides, a hydrogen anion is combined with another element.

**Inductively coupled plasma:** A plasma source where electric currents produced by electromagnetic induction are what supply energy to the source.

**In-plane and out-of-plane stresses:** Forces applied to a structure either parallel (in-plane) or perpendicular (out-of-plane) to a particular face of the structure.

**Ion:** An atom that has either too few or too many electrons. In stable form, an atom has an equal number of positively charged protons and negatively charged electrons, resulting in a neutral net charge. When ionized, an atom may have either a positive or a negative charge.

**Ionizing radiation:** For the purposes of radiation protection, radiation capable of producing ion pairs in biological material(s). **Note:** Ionizing radiation is constantly present in the environment and includes the radiation that comes from both natural and artificial sources, such as cosmic rays, terrestrial sources (radioactive elements in the soil), ambient air (radon), and internal sources (food and drink).

**Irradiated fuel bay:** A large pool of water where radioactive material (mainly fuel discharged from a nuclear reactor) is cooled and shielded until it is safe to remove to dry storage. It may also be referred to as the wet storage bay, spent fuel bay, storage bay, storage pool, or used fuel pool.

**Isotope:** A variation in the form of atoms, of the same chemical element, which are distinguished by the number of neutrons in the nucleus. The number of protons remains the same, but the number of neutrons differs. For example, uranium has 16 different isotopes.

**Laser ablation (in the context of LA-ICP-MS):** The process of using high energy laser beam to vaporize surface material from solid samples for analysis by atomic spectroscopy.

**Leak before break (LBB):** Leakage from a flaw in a pressurized component (such as a pipe) during normal operation of a nuclear reactor, detected early enough for the reactor to be shut down and depressurized before the flaw grows large enough to cause a rupture.

**Lifecycle management plan:** See [aging management program / aging management plan](#).

**Mass spectrometry:** An analytical process where ionized atoms or molecules are deflected by a magnetic field according to their mass and charge. By measuring this mass-to-charge ratio, the particles may be identified. This process is performed by a device called a mass spectrometer.

**Megawatts electric (MWe):** A unit describing the electrical energy output of a system.

**Megawatts thermal (MWth):** A unit describing the heat energy output of a system. In a nuclear power plant system, thermal energy is converted to electrical energy (with an accompanying loss of energy determined by the efficiency of the system).

**Neutron radiation:** Radiation that involves free neutrons (unstable subatomic particles with no electric charge) released from atoms during the nuclear fission or fusion process. When absorbed into a stable atom, the free neutrons make that atom unstable and more likely to produce ionizing radiation. Neutron radiation has a high penetrating capability.

**Nuclear gauges:** Devices that contain radiation sources and are used to quickly take routine measurements (such as material density, thickness or moisture level). They are typically used in construction and industrial settings.

**Organically bound tritium:** Tritium that is bound to carbon.

**Phase velocity:** The velocity of a wave motion, defined as the product of the wavelength and frequency of the wave.

**Phenomena and key parameter identification and ranking tables (PKPIRT):** 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.

**Primary-side:** A term to describe the fuel and coolant components in a nuclear power generating system. These components would include the calandria, steam generators, and heat transport pumps and piping system.

**Radiography camera:** A device that can examine the internal structure of an object through the controlled use of gamma radiation.

**Radiometric dating:** A process by which the age of rocks can be estimated through knowledge of the decay rates of radioactive elements within the rocks.

**Radionuclide:** A material with an unstable atomic nucleus that spontaneously decays or disintegrates, producing radiation. Nuclei are distinguished by their mass and atomic number.

**Radiosensitivity:** The relative susceptibility to damage from radiation for cells, tissues, organs and organisms.

**Resistivity:** A material property describing the resistive power of a particular substance to the flow of electricity.

**Stratigraphy:** The branch of geology concerned with the relative order and position of unique rock layers, particularly how they relate to a geographic time scale. This is often used in the study of sedimentary and volcanic rock.

**Thermalhydraulics:** The study of hydraulic flow in thermal fluids.

**Tritium:** A radioisotope (symbol T or  $^3\text{H}$ ) of the element hydrogen, composed of one proton and two neutrons.

**Tsetse:** A large, biting fly found in the tropical regions of Africa. They act as a vector of infections (such as sleeping sickness) in humans and domestic animals.

**Uranium ore concentrate (yellow cake):** A uranium compound in powder form that is an intermediate product in the processing of uranium from raw ore to nuclear fuel and requires further refinement before it is suitable for nuclear use. Uranium concentrate from a mill is upgraded by refining and converting it to uranium trioxide ( $\text{UO}_3$ ), and subsequently into uranium dioxide ( $\text{UO}_2$ ) (used in Canada) and uranium hexafluoride ( $\text{UF}_6$ ) (exported). Also called yellowcake.

**X-ray:** Electromagnetic radiation that consists of photons originating from outside an atom's nucleus.

## 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 2016–17.

Subject	Type	Event/publication	Date	Publisher or location delivered	Authors
<a href="#">Assessment of the effect of the advanced drift-flux model of ASSERT-PV on CHF, flow void fraction distribution</a>	Peer-reviewed journal article	<i>Annals of Nuclear Energy</i> , 94, 313–324 <i>Annals of Nuclear Energy</i> , 104, 197–213	April 2016 March 6, 2017	Elsevier	N. Hammouda Z. Cheng Y.F. Rao
<a href="#">Highlights of Canadian nuclear criticality safety standards, regulation and guidance</a>	Abstract of a technical presentation	<i>Nuclear Criticality Safety</i>	April 6, 2016	New Delhi, India	V. Khotylev
<a href="#">Coupled hydro-mechanical properties of Cobourg limestone with special reference to excavation damage zones</a>	Abstract of a technical presentation	European Geosciences Union General Assembly 2016	April 17–22, 2016	Vienna, Austria	M.H.B. Nasser M. Tibbo M. Sehzadeh S. Ye R.P. Young G. Su T.S. Nguyen
<a href="#">Modelling &amp; simulation and uncertainty qualification for safety analysis of nuclear power plants</a>	Abstract of a technical lecture	Xi'an Jiaotong University	April 25–29, 2016	Xi'an, China	W. Shen
<a href="#">Status of CAMP activities in Canada</a>	Abstract of a technical presentation	Spring 2016 CAMP Meeting	April 26–28, 2016	Abu Dhabi, United Arab Emirates	A. Delja
<a href="#">3D system-scale thermalhydraulic codes applications in Canada</a>	Abstract of a technical presentation	Meeting of the WGMA Task Group on the State-of-the-Art Report on the Simulation Capability	April 28–29, 2016	Boulogne, France	A. Delja
<a href="#">Development of a production MCNP CANDU 3D full-core model with practical remedies to the issues in deriving reliable tally results</a>	Abstract of a technical presentation	PHYSOR 2016: Unifying Theory and Experiments	May 1–5, 2016	Sun Valley, Idaho, U.S.	W. Shen J. Hu



<b>Subject</b>	<b>Type</b>	<b>Event/publication</b>	<b>Date</b>	<b>Publisher or location delivered</b>	<b>Authors</b>
<a href="#">Application of graded approach to safety standards of research reactors and sub-critical assemblies</a>	Abstract of a technical presentation	Expert Mission on the Use of a Graded Approach in Application of the Safety Standards to Sub-critical Assembly Project	May 2–6, 2016	Sidi Thabet, Tunisia	N. Mesmous J.E. Kowalski
<a href="#">Status of cyber security implementation in Canadian nuclear power plants</a>	Abstract of a technical presentation	2016 Korean Nuclear Society Conference	May 11–13, 2016	Jeju, South Korea	C.H. Jung
<a href="#">Mechanics of sedimentary rocks</a>	Abstract of a technical presentation	CNSC Technical Information Exchange Meeting with the Swiss Nuclear Safety Inspectorate	May 13, 2016	Brugg, Switzerland	T.S. Nguyen
<a href="#">Review of the long-term safety case for a deep geological repository</a>	Abstract of a technical presentation	CNSC Information Exchange Meeting with ENSI	May 13, 2016	Brugg, Switzerland	T.S. Nguyen
<a href="#">Managing structural integrity of key components for long-term operation of nuclear power plants</a>	Abstract of a technical presentation	2016 Annual Meeting of ICG-EAC	May 15–21, 2016	Qingdao, China	Y. Wang
<a href="#">Use of graded approach in the regulation of research reactors at the Canadian Nuclear Safety Commission</a>	Abstract of a technical presentation	IAEA Technical Meeting on the Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors	May 23–27, 2016	Vienna, Austria	J.E. Kowalski N. Mesmous
<a href="#">Laboratory and numerical investigation of the hydro-mechanical behaviour of the Cobourg limestone</a>	Abstract of a technical paper/presentation	DOPAS 2016 Seminar: Plugging and Sealing for Underground Applications	May 25–27, 2016	Turku, Finland	G. Su T.S. Nguyen Z. Li F. Nasser P. Young
<a href="#">The Canadian journey on seismic design and qualification of nuclear installations</a>	Proceedings report for CNSC-hosted workshop	CNSC Workshop on the Canadian Journey on Seismic Design and Qualification of Nuclear Installations	June 9–10, 2016	Ottawa, Ontario	Dr. T.S. Aziz
<a href="#">Canadian requirements for ensuring workers' competency in the field of nuclear energy</a>	Abstract of a technical presentation	IAEA Technical Working Group – Managing Human Resources	June 14–17, 2016	Vienna, Austria	C. Françoise

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<a href="#">Offsite and onsite power supplies at Canadian nuclear power plants</a>	Abstract of a technical presentation	24th International Conference on Nuclear Engineering	June 26–30, 2016	Charlotte, North Carolina, U.S.	J. Vucetic N. El Dabaghi
Overview of CNSC PHWR reactor physics benchmarking activities	Abstract of a technical paper/presentation	IAEA Technical Meeting on International Collaborative Standard Problems on a Numerical Benchmark Database for PHWR Transients	August 9–11, 2016	Ottawa, Ontario	D. Serghiuta
<a href="#">CANDU nuclear fuel safety criteria</a>	Abstract of a technical presentation	13th International Conference on CANDU Fuel	August 15–18, 2016	Kingston, Ontario	M. Couture
CANDU fuel thermohydraulic design	Abstract of a technical paper/presentation	13th International Conference on CANDU Fuel	August 15–18, 2016	Kingston, Ontario	Y. Guo
<a href="#">IFB loss-of-cooling severe accident</a>	Abstract of a technical paper/presentation	13th International Conference on CANDU Fuel	August 15–18, 2016	Kingston, Ontario	W. Grant
<a href="#">Fitness for duty: A Canadian nuclear regulatory perspective</a>	Abstract of a technical presentation	2nd International Conference on Physical Employment Standards	August 23–26, 2016	Canmore, Alberta	A.J. Derouin
<a href="#">What could be learnt from the development and qualification of Canadian reactor-physics codes</a>	Abstract of a technical presentation	16th Conference on Core Reactor Physics	August 23–26, 2016	Beijing, China	W. Shen
<a href="#">Early regulatory involvement in a deep geological repository initiative for the long-term management of Canada's used nuclear fuel</a>	Abstract of a technical paper	3rd Canadian Conference on Nuclear Waste Management, Decommissioning and Environmental Restoration	September 11–14, 2016	Ottawa, Ontario	J.L. Mecke K. Noble J.L. Brown
<a href="#">Reliability requirements and use of risk applications for the reliability program in Canadian nuclear power plants</a>	Abstract of a technical paper/presentation	European Safety and Reliability Conference 2016	September 25–29, 2016	Glasgow, Scotland	U. Menon C. Morin Y. Akl

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<a href="#">Geoscientific arguments in support of the safety case for a deep geological repository in Southern Ontario, Canada</a>	Conference presentation	DAEF Conference	October 2016	Cologne, Germany	T.S. Nguyen J. Brown M. Herod Z. Li
<a href="#">A regulator's role in research and development: Status of chemistry-related regulations and research in the Canadian nuclear power industry</a>	Abstract of a technical presentation	Nuclear Plant Chemistry Conference 2016	October 2–7, 2016	Brighton, England	R. Kameswaran M. Yacyshyn
<a href="#">Modification of the SPAR-H method to support HRA for Level 2 PSA</a>	Abstract of a technical paper	13th International Conference on Probabilistic Safety Assessment and Management	October 2–7, 2016	Seoul, South Korea	G. Banaseanu M. Xu Y. Akl S. St. Germain R. Boring
<a href="#">Regulatory review of CANDU fuel thermalhydraulic analysis and associated challenges</a>	Abstract of a technical paper/ presentation	5th International Workshop on Current CANDU Safety Issues and Resolutions for CANDU Safety and Sustainability	October 12–14, 2016	Gyeongju, South Korea	Y. Guo
<a href="#">Characterizing the mechanical behaviour of the Tournemire argillite</a>	Open-access peer-reviewed article	<i>The Geological Society</i> , Special Publications, 443	October 13, 2016	Geological Society of London	X. Su S. Nguyen
<a href="#">Presentation on CSA standard N290.12, Human factors in design for nuclear power plants</a>	Abstract of a technical presentation	1st CNSC–KINS Bilateral Technical Information Exchange Meeting	October 18, 2016	Daejeon, South Korea	A. Bouchard A. Salway
<a href="#">Development of a viscoelastoplastic model for a bedded argillaceous rock from laboratory triaxial tests</a>	Peer-reviewed journal article	<i>Canadian Geotechnical Journal</i> , 54(3), 359–372	October 18, 2016	NRC Research Press	T.S. Nguyen G. Su Z. Li D. Labrie J.D. Barnichon
<a href="#">Comparative modelling of laboratory experiments for the hydro-mechanical behaviour of a compacted bentonite–sand mixture</a>	Peer-reviewed journal article	<i>Environmental Earth Sciences</i> , 75, 1311	October 18, 2016	Springer Nature	A. Millard T.S. Nguyen et al.

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<a href="#">Preparing workers for the unexpected</a>	Abstract of a technical presentation	1st CNSC–NRA Bilateral Meeting	October 20–21, 2016	Tokyo, Japan	A. Bouchard A. Salway T. Hewitt
<a href="#">Regulatory oversight of safety culture</a>	Abstract of a technical presentation	1st CNSC–NRA Bilateral Meeting	October 20–21, 2016	Tokyo, Japan	A. Bouchard V. Goebel
<a href="#">Characterization of radionuclides in uranium mine tailings with synchrotron-based hard X-ray microprobe techniques</a>	Poster	II International Conference on Radioecological Concentration Processes	November 2016	Seville, Spain	S. Mihok K. Lange A. Lanzirrotti J. Brown
<a href="#">Overview of cyber security regulatory framework for nuclear power plants</a>	Abstract of a technical presentation	12th Annual UNENE Workshop on Nuclear I&C Systems	November 11, 2016	Mississauga, Ontario	C.H. Jung
<a href="#">Environmental qualification programs at Canadian nuclear power plants – A status report from the regulator’s perspective</a>	Abstract of a technical presentation	28th Annual Environmental Qualification Technical Meeting	November 16–18, 2016	Clearwater, Florida, U.S.	M. Vlatkovic
Comparative modelling approaches of hydro-mechanical processes in sealing experiments at the Tournemire URL	Peer-reviewed journal paper	<i>Environmental Earth Sciences</i> , 76, 78	December 2016	Springer Berlin Heidelberg	A. Millard T.S. Nguyen et al.
Modelling a heater experiment for radioactive waste disposal	Open-access peer-reviewed paper	<i>Environmental Geotechnics</i>	December 2016	Institution of Civil Engineers	T.S. Nguyen Z. Li B. Garitte J.D. Barnichon
Response to the criticism of the paper titled <i>Non-targeted effects and radiation-induced carcinogenesis: a review</i>	Open-access peer-reviewed scientific journal	<i>Journal of Radiological Protection</i> , 36, 1015–1016	December 2016	IOP Publishing	J. Burt P. Thompson R. Lafrenie
<a href="#">Leadership and management review</a>	Abstract of a technical presentation	14th IAEA-FORATOM Management System Workshop	December 12–15, 2016	Vienna, Austria	P. Lahaie

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<a href="#">Management systems and standards in the nuclear industry</a>	Abstract of a technical presentation	14th IAEA-FORATOM Management System Workshop	December 12–15, 2016	Vienna, Austria	P. Lahaie
Failure mode taxonomy for assessing the reliability of field programmable gate array-based instrumentation and control systems	Open-access peer-reviewed scientific journal	<i>Annals of Nuclear Energy</i> , 98, 198–228	2016	Elsevier	P. McNelles Z.C. Zeng G. Renganathan M. Chirila L. Lu
Radiation protection at uranium processing facilities in Canada	Workshop presentation	IAEA Workshop on Operational Radiation Protection and Waste Management for Nuclear Fuel Cycle Facilities (J7-TR-54794)	March 13–17, 2017	Vienna, Austria	C. Dodkin