Bringing safety performance of older plants on par with advanced reactor designs

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Abstract

The Canadian regulatory philosophy calls for continuous improvement in safety, to meet the changing expectations of the society. It is acknowledged that there are economic and physical limits to such improvements for existing facilities. Nevertheless, the advances in science, accumulation of experimental evidence, more powerful computational methods, proven design features of advanced reactor designs and better understanding of key risks arising from nuclear facilities - all this allow enhancing safety of facilities built to earlier standards.

The paper elaborates on recent developments influencing safety performance of Canadian nuclear power plants.

1. INTRODUCTION

Ours is a fast-paced world with every aspect of life incessantly changing, sometimes at a neck-breaking speed. The nuclear industry is not immune to this. The technology of safety, the societal expectations towards demonstration of safety and regulatory frameworks are different today from what they used to be thirty, twenty and even ten years ago.

In Canada, continuous improvement in safety performance is an accepted paradigm, in fact, a recognized strength of the regulatory and operational practices. Let us dwell first on the cornerstones of the Canadian regulatory philosophy prior to diving into the question how the continuous improvement is pursued and attained.

Under the Nuclear Safety and Control Act licensees are directly responsible for managing the regulated activities in a manner that protects health, safety, and the environment, while respecting Canada's international obligations. In other words, an organization operating a nuclear power plant bears primary responsibility for its safety. The regulator, Canadian Nuclear Safety Commission or CNSC, regulates the development, production and use of nuclear energy in order to prevent unreasonable risk to the environment, to the health and safety of persons, and to national security. The CNSC is answerable to Canadians for ensuring that the licensees properly discharge their responsibilities. This is achieved through [1]
1. Setting regulatory requirements and assuring compliance
2. Basing regulatory requirements and actions on the level of risk
3. Making independent, objective and informed decisions, and
4. Serving the public interest.

The very high level regulatory requirements are set in the law (the Nuclear Safety and Control Act), and Regulations under it and are relatively stable. Such, the Nuclear Safety and Control Act stipulates the following:

- §24 (4). Conditions for Licence issuance
  No licence shall be issued, renewed, amended or replaced unless, in the opinion of the Commission, the applicant
  a) is qualified ...; and
  b) will make adequate provision for the protection of the environment, the health and safety of persons and the maintenance of national security and measures required to implement international obligations to which Canada has agreed.

The specific oversight requirements are spelled in regulatory documents and national standards which are significantly more agile. These documents can be and are periodically revised to reflect the best modern practices and in order to serve the public interest. The regulatory documents spell out attributes of a qualified applicant for a licence, and what constitutes adequate provisions for assuring nuclear safety. The development and update of regulatory documents is under the control of the CNSC and is flexible enough to respond to the changing realities and expectations. We, the Canadian regulator, have also arrived at what we believe is a balanced approach for incorporation of new or revised regulatory documents into the compliance oversight (or, in other words, making them requirements) while recognizing the benefits of regulatory stability.

2. SAFETY AND CONTROL AREA FRAMEWORK

To promote consistency in compliance oversight across all regulated activities, CNSC staff developed a set of Safety and Control Areas (SCA) consisting of 14 subjects or themes. These Safety and Control Areas are used in planning and conduct of inspections, technical reviews, regulatory research and public reporting. They are also used to lend a structure to the regulatory framework across all types of nuclear facilities and activities. These 14 Safety and Control Areas are listed in Table 1; the corresponding regulatory documents can be found at http://nuclearsafety.gc.ca/eng/acts-and-regulations/regulatory-documents/index.cfm

<table>
<thead>
<tr>
<th>Management system</th>
<th>Conventional health and safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human performance management</td>
<td>Environmental protection</td>
</tr>
<tr>
<td>Operating performance</td>
<td>Emergency management and fire protection</td>
</tr>
</tbody>
</table>
In the last decade, CNSC has been formalizing regulatory expectations (simultaneously bringing them in closer alignment with the IAEA guidance) as regulatory documents at a relatively fast pace adding several new or revised documents every year. We found however, that making all these new documents part of the compliance activities in an ad-hoc, piece-wise manner is burdensome for both the regulator and the regulated organizations. The preferred approach is to add the new requirements at the time of Periodic Safety Review (PSR) or relicensing\(^1\) (nevertheless, when justified, new requirements can be implemented faster). The PSR itself is a relatively new practice in Canada but which has now become a formal requirement. Objectives of a PSR are seen as helping determine [2]:

1. The extent to which the facility conforms to modern codes, standards and practices
2. The extent to which the licensing basis remains valid for the next licensing period
3. The adequacy and effectiveness of the programs and the structures, systems and components (SSCs) in place to ensure plant safety until the next PSR or, where appropriate, until the end of commercial operation
4. The improvements to be implemented to resolve any gaps identified in the review and timelines for their implementation. Such improvements then become part of the licensing requirements.

The Periodic Safety Review offers a systematic and comprehensive approach for identifying safety improvements, in many cases bringing the facility in compliance with the letter or at least the intent of the modern requirements, standards and codes. Identified gaps are assessed to find a practicable resolution which may be either through design changes of modification of operational practices. Not every gap against the current requirements may be bridged in a cost effective manner. Nevertheless, the advances in science, accumulation of experimental evidence, sharing of best practices among peers, more powerful computational methods, proven design features of advanced reactor designs and better understanding of key risks arising from nuclear facilities – all these are used to find ways for improving safety of the facilities build to the earlier standards. At the completion of a PSR, a licensee operating a NPP identifies a set of concrete and practicable safety improvements, often in response to gaps against the up-to-date safety requirements.

These two fundamental attributes of the Canadian regulatory regime, namely, a flexible regulatory framework and the periodic safety review process, allow implementation of safety enhancements in response to evolving societal expectations, regulatory priorities and technological progress.

\(^1\) In Canada, the nuclear power plants are relicensed at relatively short intervals, usually every five or ten years.
3. SAFETY IMPROVEMENTS OF OPERATING NPP

Now, let’s have a look at the operating nuclear power plants in Canada. All of the NPP are at least 24 years old; all of them either have undertaken a Periodic Safety Review or are in the process of completing one. The older units have all gone through a refurbishment. Refurbishment involves replacement of components that have reached the end of their operational life (major components may include pressure tubes of a CANDU reactor, steam generators, etc) and overhaul or upgrade of other systems where justified. Refurbishment of a reactor is undertaken during an extended outage and allows prolonging its operating life while at the same time implementing safety enhancements.

Table 2. Operating NPP in Canada

<table>
<thead>
<tr>
<th>Reactor</th>
<th>MWe net</th>
<th>First power</th>
<th>Refurbishment</th>
<th>Periodic Safety Review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pickering A1</td>
<td>515</td>
<td>1971</td>
<td>2005</td>
<td>PSR#2 in progress</td>
</tr>
<tr>
<td>Pickering A4</td>
<td>515</td>
<td>1972</td>
<td>2003</td>
<td>PSR#2 in progress</td>
</tr>
<tr>
<td>Pickering B5</td>
<td>516</td>
<td>1982</td>
<td></td>
<td>PSR#2 in progress</td>
</tr>
<tr>
<td>Pickering B6</td>
<td>516</td>
<td>1983</td>
<td></td>
<td>PSR#2 in progress</td>
</tr>
<tr>
<td>Pickering B7</td>
<td>516</td>
<td>1984</td>
<td></td>
<td>PSR#2 in progress</td>
</tr>
<tr>
<td>Pickering B8</td>
<td>516</td>
<td>1986</td>
<td></td>
<td>PSR#2 in progress</td>
</tr>
<tr>
<td>Bruce A1</td>
<td>750</td>
<td>1977</td>
<td>2012</td>
<td>Completed</td>
</tr>
<tr>
<td>Bruce A2</td>
<td>750</td>
<td>1976</td>
<td>2012</td>
<td>Completed</td>
</tr>
<tr>
<td>Bruce A3</td>
<td>750</td>
<td>1977</td>
<td>2004</td>
<td>Completed</td>
</tr>
<tr>
<td>Bruce A4</td>
<td>750</td>
<td>1978</td>
<td>2004</td>
<td>Completed</td>
</tr>
<tr>
<td>Bruce B5</td>
<td>825</td>
<td>1984</td>
<td>Planned</td>
<td>In progress</td>
</tr>
<tr>
<td>Bruce B6</td>
<td>825</td>
<td>1984</td>
<td>Planned</td>
<td>In progress</td>
</tr>
<tr>
<td>Bruce B7</td>
<td>825</td>
<td>1986</td>
<td>Planned</td>
<td>In progress</td>
</tr>
<tr>
<td>Bruce B8</td>
<td>825</td>
<td>1987</td>
<td>Planned</td>
<td>In progress</td>
</tr>
<tr>
<td>Darlington 1</td>
<td>881</td>
<td>1990</td>
<td>Planned</td>
<td>Completed</td>
</tr>
<tr>
<td>Darlington 2</td>
<td>881</td>
<td>1990</td>
<td>In progress</td>
<td>Completed</td>
</tr>
<tr>
<td>Darlington 3</td>
<td>881</td>
<td>1992</td>
<td>Planned</td>
<td>Completed</td>
</tr>
<tr>
<td>Darlington 4</td>
<td>881</td>
<td>1993</td>
<td>Planned</td>
<td>Completed</td>
</tr>
<tr>
<td>Point Lepreau</td>
<td>635</td>
<td>1982</td>
<td>2012</td>
<td>Completed</td>
</tr>
</tbody>
</table>

The list of operational and safety improvements generated by a PSR usually includes scores of items. Only a few of those may involve substantial design modifications. The significant design changes within the scope of PSR/refurbishment activities that were implemented in Canada include:

- installation of dedicated containment filtered venting system dedicated to design extension conditions
- provision of passive hydrogen recombiners inside the reactor building
- modifications to improve fire design
- installation of additional standby or emergency generators with increased seismic robustness
- replacement of computerized systems with modern digital assets
- installation of a post accident monitoring and sampling capabilities
- modification of instrumentation with increased measurement ranges and improved survivability
- implementation of additional systems to monitor and protect environment

In addition to design improvements, many other, programmatic, measures have been brought into the operational practices of the Canadian NPP as result of recent periodic safety reviews. No name just a few:

- incorporation of severe accident management guidelines
- verifying environmental qualification of equipment to the extended operational life duration
- verifying robustness against physical and cyber security threats, etc.

Of course, the other powerful impetus for safety improvements is arising from the operational experience, most visible recent examples of which are the Fukushima Daiichi accident in 2011, and the terrorist attacks in 2001. As a consequence of the latter, the physical security of nuclear facilities has been transformed in a very substantial way. Defining and assimilating lessons arising from the Fukushima event is still ongoing, but nowadays we pay much more attention and implement provisions to respond to the external hazards, multi-unit events, challenges to spent fuel safety, in particular to the events exceeding the original design basis.

In the aftermath of the Fukushima accident, operating Canadian nuclear power plants have implemented various physical and procedural enhancements, to meet the regulatory requirements and following the best peer examples. Such, the Canadian utilities added:

- capabilities to supply power to key safety systems in case of major accidents, including portable sources,
- capability to add coolant to plant primary and secondary circuits and the irradiated fuel bays, and
- provisions to support containment integrity through hydrogen (passive autocatalytic recombiners) and energy (air coolers and venting systems) managements’ equipment

These physical modifications were supplemented by procedural improvements (for example, updated accident management guidelines) and research results (such as support for demonstration on in-vessel corium retention). Results of updated Probabilistic Safety Assessments, which take credit of some but not all of the recent enhancements, indicate that

- Core Damage Frequency is reduced by a factor from 1.8 to 5.7
- Large Release Frequency is reduced by a factor from 1.8 to 13

The specific risk reduction value depends on the nature of hazard (fire, seismic events, high wind, etc) as well as particular set of safety improvements for a specific NPP. PSA methodology for such aspects as improved accident management guidance and training, or deployment of portable equipment, is not yet fully mature and these enhancements are not included in the quantitative risk evaluations.

It is necessary to acknowledge that there are economic and physical limits to the improvements for existing facilities that were designed to earlier standards and have a limited remaining operational life. Overall, it is easier to make changes to procedural/administrative elements, such as improved operational processes and personnel training. On the other hand, design modifications are costlier, require more time, and may be occasionally counterproductive, by introducing different vulnerabilities or complexities.

We also must take into consideration that there may be negative consequences to safety if the new requirements take away the resources from the safety sensitive activities. Generally, introduction of new, incremental requirements, detracts resources from other activities (which could be more safety significant) and introduce new administrative and operational burden, which may lead to errors, in particular during the transitional period. Application of cost-benefit and risk-informed arguments is seen as a useful tool for evaluation of the possible impacts and making informed decisions.

To summarize, in the recent years the operating Canadian nuclear power plants have implemented various physical and procedural enhancements, to meet the regulatory requirements and to follow the best peer examples. Some of these enhancements are expected to be standard features in operation of Generation III reactors. In particular, design extension conditions have been evaluated using systematic approaches and, where feasible, backfitting measures have been put in place. These measures have predominantly strengthened the fourth and fifth levels of defence in depth. Among other recent developments, the Canadian utilities added capabilities to supply power key safety systems in case of major accidents, and to add coolant to plant circuits and support containment integrity using both fixed and portable sources. At the same time, the regulatory framework has been reinforced to expand requirements for accident management, safety analysis (including a whole-site risk assessment), plant design, safety culture, management systems and periodic safety reviews.

4. REFERENCES

2. REGDOC-2.3.3: Periodic Safety Reviews. CNSC, 2015