# Regulatory agility through use of performance-based regulations

SEAN BELYEA

Canadian Nuclear Safety Commission

Ottawa, Canada

Email: sean.belyea@cnsc-ccsn.gc.ca

**Abstract**

Performance-based regulation offers flexibility for modern and innovative technologies across many sectors, including nuclear. In Canada, like many other nations, nuclear regulatory frameworks evolved during the design and rollout of its first commercial reactors in the 1960’s to 1980’s. Canadian regulation at this time was heavily performance based, coupled with reliance on scientific judgement to make decisions for safety.

In the decades that followed, regulations and standards evolved to include more prescriptive-based elements. Informed by operating experience, industry teamed with regulators to codify best practices on how to achieve safety. This approach, when coupled with a common national nuclear technology CANada Deuterium Uranium (CANDU), led to excellent safety standards that were more prescriptive in nature.

In recent years, the CNSC has focused on the development of performance-based approaches in its Regulatory Framework to be in a better position to regulate new nuclear technologies that differ from its current CANDU fleet. The CNSC is also fortunate in that it embraces the use of a graded approach for regulation and allows the use of alternatives to meet regulatory requirements.

This paper examines the advantages of employing performance-based regulation using a graded approach for advanced reactor designs. It also explores how prescriptive regulations and standards developed for traditional nuclear technologies can be effectively integrated into the regulatory framework for novel technology and newer advanced designs.

## INTRODUCTION

In this paper, it is assumed that a small modular reactor (SMR) is a lower powered (typically less than 300 MWe) nuclear reactor that tends to vary in design from conventional grid-connected reactors already in use such as boiling water or pressurized water reactor designs. For example, many SMRs are of a non-water-cooled design and even water-based SMR designs tend to employ some novel features that are not found in traditional reactors in-service today.

This paper references the Canadian Nuclear Safety Commission (CNSC), which regulates the development, production and use of nuclear energy and substances to protect the health, safety, security of persons and the environment; implements Canada's international commitments on the peaceful use of nuclear energy; and disseminates objective scientific and regulatory information to members

When the first nuclear reactors were designed and deployed in Canada in the 1960’s and onwards, the regulations and standards that were used to evaluate safety were a mix of high-level performance-based rules, along with significant amounts of engineering judgement. A key performance-based safety objective has always been to ensure nuclear reactors have the ability to ‘control, cool and contain’. This means that a reactor needs to be able to be in **control** of its reactivity, keep **cool** enough to prevent fuel damage, and be able to **contain** radionuclides to prevent unwanted releases. As nuclear reactors were designed, constructed and operated in Canada and throughout the world, regulations and standards were written to help ensure that reactors could be operated safely and maintain this high-level safety objective. As operational experience was gained, regulations and standards were changed, added and evolved to better articulate rules and best practices that enable safe operation. While many of the rules in place today for nuclear reactors are prescriptive in nature, the high-level objectives they help achieve go back to the key elements of ‘control, cool and contain’.

While there are many broad categories of nuclear reactor technology (e.g., water cooled, molten salt, high temperature gas, and liquid metal reactors), most reactors that have been built and operated in Canada and around the world are water cooled. The major categories of water-cooled reactors are boiling water reactors (BWR) and pressurised water reactors (PWR), which also include pressurised heavy water reactors like the CANada Deuterium Uranium (CANDU) design used in Canada. Because the majority of reactors in the world utilize water-cooled designs, many of the regulations and standards that have been written to ensure safety are written in a way that make them more applicable, or in some cases solely applicable, to water-based designs. The IAEA also recognizes this in the document *Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Small Modular Reactors* [1]:

“*In the case of nuclear power plants (NPPs), much of this experience relates to large, land-based water cooled reactors (WCRs) that are dedicated to electricity generation. Although safety standards aim to be technology neutral, their content does sometimes reflect the current dominance of this type of NPP*.”

SMR designs are being developed that utilize both water and non-water-based technologies. While only a few SMR designs have been built worldwide to-date, many projects are at various stages of pre-licensing or licensing. At the time of writing (2024), there are currently 3 applications that have been submitted to the CNSC for licensing. The applications consist of a BWR, a high temperature gas reactor, and a sodium fast reactor. Even though the CNSC has been shifting its regulatory documents to be more performance-based over the last 10-15 years, many aspects of some regulatory documents are still focused on water-based reactor technologies. Consequently, some non-water based reactors may have challenges meeting some CNSC expectations.

As part of its effort to ensure readiness for new reactor technologies, the CNSC has done several pre-licensing vendor design reviews (VDRs) of reactors that have involved a wide range of power sizes and technologies. The VDR process has demonstrated both the fact that Canada’s regulatory framework contains many elements that are specific to water-based technology – and it has also demonstrated that Canada’s flexible approach to nuclear regulations has enabled its framework to be largely fit for purpose. This was recognized in *A Call to Action: A Canadian Roadmap for Small Modular Reactors [2]* where it was stated that:

“*Canada’s enabling framework is sound. Existing regulatory and legislative processes are ready for SMR deployment in Canada, although some refinements would improve efficiencies*”

and that

“*Existing regulatory and legislative processes are ready for SMR deployment in Canada.*”

It would be an ideal situation if regulatory requirements for SMRs were completely clear, unambiguous and even more ideal if nuclear regulations were standardized across all nations, which they are not. It is impossible for any regulatory framework to anticipate every conceivable type of proposal that might be made. While there are ongoing efforts to make requirements as technology neutral as possible, in some cases, technology specific requirements are necessary for existing operating facilities. The reality is that there will always be room for improvement. In order to use regulatory rules that for the most part are largely fit for purpose, regulators must have the ability to apply a graded approach in order to meet fundamental performance-based objectives.

Based on recent CNSC experience both domestically and internationally, this paper examines some advantages of employing performance-based regulation using a graded approach for reactor designs and how prescriptive regulations and standards developed for traditional nuclear technologies can be effectively integrated into the regulatory framework through the use of alternatives and a graded approach.

## CNSC and IAEA approaches to performance based regulation and the use of alternatives

The CNSC’s Regulatory Framework establishes requirements using a mix of regulatory approaches. While there are technology specific requirements within the Canadian Regulatory Framework, the CNSC aims to have its regulatory framework applicable to all reactor technologies. There are ongoing efforts worldwide to make nuclear regulatory requirements as technology‑neutral as possible but in some cases, technology-specific requirements are necessary for existing facilities.

*CNSC REGDOC-3.5.3 - Regulatory Fundamentals* [3] describes Canadian policies on Performance based approaches. The REGDOC also explains that in Canada, regulators are directed to “*seek to design performance-based regulations where appropriate*”.

CSNC REGDOC-3.5.3 - *Regulatory Fundamentals* [3] goes on to describe a performance-based approach by explaining that “*Under a performance-based regulatory approach, the regulator’s desired outcomes are the same as they would be under a prescriptive approach: ensuring health, safety, security and environmental protection. The difference is that the regulator sets out objectives that must be met in order to achieve the regulatory outcomes. Specifically, how or what measures may be taken to achieve these objectives is not set out in the regulatory requirements. Under this approach, regulatory requirements do not need to be amended as frequently to reflect changing technology or new knowledge because the desired outcomes remain constant.*”

Having performance based regulatory requirements is conducive to the use of alternative approaches to meet requirements. Many countries, including Canada have put in place rules and guidelines to allow for the proposal of alternative ways to meet requirements. The most notable statement in the CNSC Regulatory Framework for how alternative approaches can be applied is in CNSC REGDOC-2.5.2, *Design of Reactor Facilities [4],* where section 9 on alternative approaches states:

“*The requirements in this regulatory document are intended to be technology neutral for water-cooled reactor designs. It is recognized that specific technologies may use alternative approaches.*

*The CNSC will consider alternative approaches to the requirements in this document where:*

1. *the alternative approach would result in an equivalent or superior level of safety*
2. *the application of the requirements in this document conflicts with other rules or requirements*
3. *the application of the requirements in this document would not serve the underlying purpose, or is not necessary to achieve the underlying purpose*

*Any alternative approach shall demonstrate equivalence to the outcomes associated with the use of the requirements set out in this regulatory document*”

IAEA Safety Guide SSR-2/1, *Safety of Nuclear Power Plants: Design [5]* contains a short statement that supports a similar idea of alterative measures being allowed as follows:

*“Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures).”*

One of the objectives of most regulatory bodies is that regulatory requirements should not stifle innovation. In keeping with this objective, while also noting that a principle of any nuclear regulatory framework is safety, it is important to allow alternative approaches to meet regulatory requirements. Allowing safety objectives to be met in a flexible manner helps to allow innovation without impacting safety.

## Examples of where alternatives will likely be PROPOSED

In the subsections below, a couple of examples of key nuclear systems are discussed, along with how alternative approaches can be used to help meet high level safety principles.

### Emergency Core cooling

The CNSC defines an emergency core cooling system (ECCS) in REGDOC-3.6, *Glossary of CNSC Terminology*[6] as

“*A safety system that transfers heat from a reactor core, following a loss of reactor coolant or certain other accidents that exceed makeup capability*.”

Section 6.5 of REGDOC-2.5.2, *Design of Reactor Facilities* [4] sets out requirements and guidance for Emergency core cooling systems and states that

“*Nuclear reactor facilities shall be equipped with an emergency core cooling system (ECCS). The function of this safety system is to transfer heat from the reactor core following a loss of reactor coolant that exceeds makeup capability.*”

In Canada, existing CANDU plants utilize an emergency core cooling system (water) to remove heat from the core during certain loss of coolant accidents. CNSC requirements in this area do attempt to be technology neutral, but some requirements do assume that water is being used for both ECCS and as a coolant, for example in the REGDOC-2.5.2[4] requirement that

“*The design shall take into account the effect on core reactivity of the mixing of ECCS water with reactor coolant water, including possible mixing due to in-leakage.”*

Using water to cool some SMR designs would be inherently dangerous. For example, using water in a sodium cooled reactor would result in a water-sodium reaction that would do nothing to keep the reactor safe – and can in fact be very dangerous. Alternative ways to using water to ensure heat removal for various accident scenarios must be considered for sodium cooled reactors.

Another reactor technology where alternatives will likely be used to achieve the function of emergency core cooling is high temperature gas reactors (HTGRs). HTGRs typically use TRi-structural ISOtropic (TRISO) particles for fuel and Helium as a coolant. HTGRs are known for having a strong negative reactivity with temperature coefficient which is sometimes proposed as a means of shutdown.

When an HTGR has an occurrence which would require the reactor to be shut down, the helium coolant circulation is typically stopped. This causes the temperature in the reactor core to increase, which then causes the reactivity in the core to decrease. An HTGR would typically use neutron absorbing rods to shutdown or control reactivity at this point. Even in the situation where rods were not used (or were unavailable), an HTGR would typically shut down on its own due to the decrease in reactivity with an increase in temperature. Heat could then be removed by passively dissipating it from the core to outside the reactor pressure vessel. In this example removing heat too quickly from an HTGR reactor core may be detrimental to safety in some cases, as it can increase core reactivity when the core temperature cools. Natural heat dissipation properties of a properly designed HTGR core would allow removal of heat to prevent fuel damage, while ensuring that heat is not removed so quickly that core reactivity is increased due to rapid cooling.

It is expected that many HTGR designs will employ an alternative approach for emergency core cooling by demonstrating that the reactor is designed in a way that allows for appropriate heat dissipation from the core in accident scenarios – quite possibly without the need for an ECCS. As water introduced to a very high temperature gas reactor core would likely result in steam explosions and fuel damage, even if an ECCS was utilized, it would not likely be one that uses water.

Section 6.5, *Emergency core cooling system* of REDOC-2.5.2 [4] sets out additional requirements and guidance for emergency core cooling that may not completely applicable to all reactor designs. When evaluating a design’s emergency core cooling strategy against the additional requirements and guidance in REGDOC-2.5.2 [4], the high-level objective to “*transfer heat from the reactor core following a loss of reactor coolant*” should be kept in mind. If an alternative approach to emergency core cooling was being proposed by a proponent, section 9 of REGDOC-2.5.2 [4] on alternatives would be used as part of the evaluation of the proposed approach.

Requirement 52 of IAEA document SSR-2/1 [5] sets out requirements for Emergency cooling of the reactor core as follows:

*“Means of cooling the reactor core shall be provided to restore and maintain cooling of the fuel under accident conditions at the nuclear power plant, even if the integrity of the pressure boundary of the primary coolant system is not maintained.*

*6.18. The means provided for cooling of the reactor core shall be such as to ensure that:*

1. *The limiting parameters for the cladding or for integrity of the fuel (such as temperature) will not be exceeded;*
2. *Possible chemical reactions are kept to an acceptable level;*
3. *The effectiveness of the means of cooling of the reactor core compensates for possible changes in the fuel and in the internal geometry of the reactor core;*
4. *Cooling of the reactor core will be ensured for a sufficient time.”*

The above performance-based requirements could likely be met by most SMR designs (including Sodium cooled reactors and HTGRs) without the need for an alternative approach. The performance-based guidelines in IAEA SSR-2/1 [5] requirement 52 contain less information than is contained in section 6.5 of REGDOC-2.5.2 [4] on the same subject. While only stating performance based high level objectives can be more applicable for all reactor types, a disadvantage of this approach is that additional guidance may not be included that would be of benefit for some technologies and approaches to emergency core cooling.

Regardless of the approach or reactor type, all reactors must demonstrate they can meet the high-level safety objective of removing heat from the reactor core to maintain cooling of the fuel under accident conditions. Having regulatory flexibility helps regulators accommodate different approaches to achieving regulatory equivalency to a dedicated emergency core cooling system that is in use in existing water-based nuclear power plants.

### Containment

Traditional requirements and guidance for containment have focussed on a containment structure which surrounds the reactor core to help (amongst other things) limit radioactive releases, protect against external events, and provide radiation shielding. Many SMR designs are proposing alternatives to traditional containment structures and methodologies. Some examples include using the fission product retention properties of fuel for the confinement of radionuclides (i.e. TRISO particles and molten salt fuels) and the use of non-leak tight structures or subterranean installations to protect against external events and provide radiation shielding. The current requirements and guidance provided by both the CNSC and IAEA focus on the use of a leak tight containment structure to achieve these requirements.

For the CNSC, Section 6.6, *Containment and means of confinement* of CNSC REGDOC-2.5.2 [4] contains many requirements for containment structures. The first statement in this section states that

“*Each nuclear reactor facility shall be installed within a containment structure, so as to minimize the release of radioactive materials to the environment during operational states and DBAs.*”.

Section 6.6 of REGDOC-2.5.2 [4] goes on to set out requirements around:

* Strength to withstand “potential internal overpressures, underpressures, temperatures, dynamic effects such as missile generation, and reaction-forces anticipated to result in the event of DBAs”,
* Leakage rates and the ability to test those leakage rates,
* Penetrations through the containment structure,
* Ability to isolate containment,
* Ability to control atmosphere within the containment structure ,
* Prevent hydrogen build up.

From IAEA SSR-2/1 [5], requirement 54 sets out that:

***“A containment system shall be provided to ensure, or to contribute to, the***

***fulfilment of the following safety functions at the nuclear power plant:***

***(i) confinement of radioactive substances in operational states and in accident***

***conditions; (ii) protection of the reactor against natural external events and***

***human induced events; and (iii) radiation shielding in operational states and***

***in accident conditions.”***

Requirements 55-58 further set out requirements around:

* Control of radioactive releases from the containment,
* Penetrations through containment,
* Containment isolation,
* Access to containment,
* Atmosphere within containment.

Many SMR designs are proposing alternative approaches to meet containment requirements. Some examples include:

* Reactors that propose functional containment by using newer fuels such as molten salt or TRISO fuels are proposing that fission product retention is being achieved within the fuel itself,
* Subterranean installation is being used to help provide protection against external events and provide radiation protection,
* Non-leak tight structures are also being proposed for radiation protection as well as providing a barrier within which environments can be protected from dangers such us missiles or combustible gasses.

Alternatives for traditional containment structures are expected to be used for many new SMR designs being proposed. Once again, regulators must ensure that even if alternative approaches are used, fundamental principles including limiting radioactive releases, protection against external events, and providing radiation shielding are maintained. The CNSC has recently posted additional information on containment for Novel reactor designs at https://www.cnsc-ccsn.gc.ca/eng/reactors/smr/about/containment/

## How to evaluate alternative approaches:

As mentioned earlier in Section 2 of this paper, both the CNSC and IAEA allow the use of alternatives to meet the requirements in its regulatory framework. In general, and as seen in Section 3 of this paper, many requirements as written start out with high-level objectives, followed by more detailed requirements. When considering the use of an alternative approach, suitable evidence must be provided to the regulator demonstrate claims. If alternatives are being proposed, the high-level objectives of the requirements need to be understood, and the alternatives should be evaluated against those high level objectives using a combination of engineering judgement, OPEX, testing, existing research, etc.

Section 3.2 of CNSC REGDOC-1.1.5, *Supplemental Information for Small Modular Reactor Proponents*[7] notes that when evaluating alternatives, regulatory staff should evaluate:

“*if the alternatives:*

* *meet the objectives of the requirements*
* *meet high-level safety objectives*
* *meet fundamental safety functions of "control, cool, contain"*

*At the same time, the alternatives need to demonstrate:*

* *defence in depth*
* *safety margins in view of the uncertainties in the safety case and of specific hazards over the facility’s lifecycle”*

## The impacts of alternative approaches on Leveraging information

While using alternative approaches as part of a performance based regulatory framework when meeting regulatory requirements is helpful for new technologies, this type of regulatory agility can also be a helpful approach when leveraging information from one country to another. Current proposed SMR deployment models often mention the deployment of a common or similar design in multiple different countries. Almost always, there are regulatory differences in each nation which would apply to an SMR design. These differences can sometimes make it difficult for regulators to share information on how a nuclear reactor was evaluated or reach the same conclusion about different aspects of the design. Being able to use an alternative approach may in some instances allow a regulator to make better use of an evaluation performed against different regulatory frameworks for its own use. This type of regulatory agility can be a key enabler in allowing a regulator to consider an evaluation done by another regulatory body using different regulatory frameworks.

## Conclusion

Allowing the use of alternatives helps regulators remain flexible in their approach to licensing nuclear technology. Being flexible in regulatory approaches allows for innovation, leveraging and sharing of information between countries and continual improvement without impacting safety or the ability of a reactor design to ‘control, cool and contain’. It is important for regulators and proponents to ensure that high-level safety objectives are met. Understanding the objectives behind more prescriptive regulatory rules allows both regulators and proponents to ensure they are met as alternative approaches are used in SMR design and operation. Through activities including vendor design reviews, ongoing licensing and international engagement, the CNSC is demonstrating how regulatory flexibility can help better enable safety and design portability between countries – all without negatively impacting safety or requiring unnecessary design changes between states.

## Further information

### Author affiliation

Sean Belyea – Senior Project Officer

Advanced Reactor Licencing Division

Directorate of Advanced Reactor Technologies

Canadian Nuclear Safety Commission

[sean.belyea@cnsc-ccsn.gc.ca](mailto:sean.belyea@cnsc-ccsn.gc.ca)

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