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NON-PROLIFERATION AND THE NUCLEAR REVIVAL

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Abstract

Canada has played a leading role for 80 years in founding, upholding, and strengthening the global non-proliferation regime. In Canada and elsewhere, a resurgence of new development throughout the nuclear fuel cycle will potentially challenge the efficiency of this regime, leading to unexpected deployment costs and delays if not mitigated. This risk arises because advanced reactor concepts, fuel designs and processes, and waste management schemes (short-term, intermediate and long-term) will all require the development of new safeguards approaches by the International Atomic Energy Agency (IAEA), including possibly new verification technologies - and, in some scenarios, verification paradigms. Additional challenges are posed by the scale and remoteness of some deployment scenarios, the difficulty of access for some facilities – from the very small (microreactors) to the very big (geologic repositories), the bulk-flow nature of some fuel designs (e.g., molten salt and pebble bed), and the implications of transnational, factory-sealed supply chains. Mitigation of this risk starts with early awareness by key stakeholders (designers, end users, regulators), and voluntary collaboration with the IAEA to adapt designs and processes, develop verification tools, and optimize safeguards approaches – long before the obligatory onset of safeguards once a new-build project is initiated. This process is known as 'safeguards by design'. The paper provides a brief history of the global non-proliferation regime and Canada's role, surveys the safeguards challenges related to emerging technologies across the nuclear fuel cycle, and summarizes how safeguards can be collaboratively prepared to ensure that these technologies are deployed in a timely manner while meeting non-proliferation obligations.

1. Introduction

Since the end of World War II the global expansion of civilian nuclear energy has been predicated upon increasingly robust international controls on nuclear weapons proliferation. As a founding nation in nuclear energy development, Canada played a leading role in the evolution of this global non-proliferation regime as it adapted to meet evolving challenges. These challenges stemmed not just from the growing depth and breadth of the civilian fuel cycle, but from increasingly more complex (and sometimes successful) attempts to circumvent the non-proliferation regime or test its boundaries. While the primary objective of the regime has not changed, the logistics and complexity necessary to meet this objective have increased enormously – creating an additional challenge of adequate resources as international funding of the verification infrastructure (primarily represented by the International Atomic Energy Agency, IAEA) has not increased proportionately.

Non-proliferation verification is the grand bargain of civilian nuclear energy. Since coming into force in 1970 the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) has divided the world into those with nuclear weapons and those without, and prohibited proliferation of nuclear-weapons know-how between them. Acceptance of this prohibition, and the necessary international safeguards that verify its implementation, opens the door to civilian nuclear commerce.

The NPT hands the responsibility of administering, implementing and reporting on these safeguards to the IAEA. Nuclear safeguards are a set of technical measures applied to nuclear material and activities, through which the IAEA seeks to independently verify that nuclear facilities are not misused, and nuclear material not diverted from peaceful uses. Countries accept these measures through the conclusion of safeguards agreements with the IAEA, the most common being a Comprehensive Safeguards Agreement (CSA) [1], concluded by Non-Nuclear Weapon States (NNWS) under Article 3 of the NPT. Under a CSA, an NNWS accepts IAEA safeguards on all nuclear material in all peaceful nuclear activities within its territory, under its jurisdiction, or carried out under its control anywhere. Most countries have also concluded an Additional Protocol to their CSA, which provides the IAEA with enhanced information about the country's nuclear-related capabilities, activities, and plans [2].

Nuclear safeguards thus facilitate an independent assessment of both the correctness and completeness of a country's declarations related to nuclear material and activities. Verification measures include on-site inspections, complemented by containment and surveillance (C/S) techniques (e.g., seals, cameras) and information gathered through open-source and third-party sources. All safeguards-relevant information is evaluated for consistency, leading to an annual safeguards assessment for each facility and the country as a whole.

IAEA safeguards have evolved as technology has allowed more efficient and more effective verification, largely allowing the global non-proliferation regime to meet its objective despite increasing numbers of facilities. Fortunately, with few exceptions, the nature of these facilities has not changed much in the last 80 years – at least in the sense that familiar measures can continue to be applied to familiar layouts and technology.

In Canada and elsewhere however, a resurgence of innovative development throughout the nuclear fuel cycle will potentially challenge the efficiency of the non-proliferation regime, leading to unexpected deployment costs and delays if not mitigated. This risk arises because advanced reactor concepts, fuel designs, processes, and waste management schemes (short-term, intermediate and long-term) will all require the development of new safeguards approaches by the IAEA, including possibly new verification technologies – and, in some scenarios, verification paradigms. Additional challenges are posed by the scale and remoteness of some deployment scenarios, the difficulty of access for some facilities – from the very small (microreactors) to the very big (geologic repositories), the bulk-flow nature of some fuel designs (e.g., molten salt and pebble bed), and the implications of transnational, factory-sealed supply chains.

Mitigation of this risk starts with early awareness by key stakeholders (designers, end users, regulators), and voluntary collaboration with the IAEA to adapt designs and processes, develop verification tools, and optimize safeguards approaches – long before the obligatory onset of safeguards once a new-build project is initiated. This process is known as 'safeguards by design'.

The following sections provide a brief history of the global non-proliferation regime and Canada's role within it, a survey of the emerging technologies and safeguards challenges across the nuclear fuel cycle, and a summary of how safeguards can be collaboratively prepared to ensure that these technologies are deployed in a timely manner while meeting non-proliferation obligations.

2. Brief history of the non-proliferation regime, and Canada's role

Recognition of the parallel but somewhat paradoxical needs to (a) prevent proliferation of nuclear weapons, while (b) allowing proliferation of peaceful nuclear science and technology, began immediately after the end of WWII and the nuclear explosions at Hiroshima and Nagasaki. In November 1945 a joint statement by Canada, the United States, and the United Kingdom (at that time the three nations possessing the "knowledge essential to the use of atomic energy"), made it clear that while fundamental nuclear science should henceforth be removed from its wartime cloak and shared with reciprocating nations, applications of nuclear energy should not be shared until adequate safeguards against its misuse were in place [3].

Attempts to define these safeguards over the next decade faltered, and meanwhile nuclear weapons capability spread to both the USSR (1949) and the UK (1952). The clearly insufficient US policy of secrecy and denial of nuclear weapons knowledge led ultimately to US President Eisenhower's "Atoms for Peace" speech to the United Nations in 1953, laying the groundwork for the NPT and IAEA, and finally embracing in earnest the parallel and paradoxical proliferation needs of nuclear energy [4].

By 1957 "Atoms for Peace" was embodied in the newly-minted International Atomic Energy Agency of the UN. Canada at this time was already an elder statesman of "Atoms for Peace", emerging from WWII with the world's largest peaceful nuclear program and leveraging this almost immediately to pioneer medical and industrial radioisotopes (including the first cobalt cancer therapy by 1951). In 1957 it had started building the first university-based research reactor in the British Commonwealth at McMaster University, and the first heavy-water, natural-uranium power reactor at Rolphton, Ontario. At Chalk River Laboratories, Canada's leadership in nuclear science was about to be cemented with the start-up of the massive NRU research reactor (November 1957), while its dominance in uranium supply had been established since the early days of the war.

It was thus natural that Canada assumed a leadership role from the outset on the Board of Governors of the IAEA, including its vital mission of international safeguards. The IAEA's first application of safeguards covered the transfer of three tonnes of uranium from Canada to Japan in 1959. Through the 1960s Canada's experience with bilateral nuclear safeguards helped hone the IAEA's Safeguards System [5] [6], and the negotiation of the NPT.

The NPT's entry into force in 1970 precipitated the drafting of the model Comprehensive Safeguards Agreement [1] which Canada became the second nation to sign (shortly after Finland) in February 1972. The era of full-scope nuclear safeguards had begun: no longer was it the prerogative of nations to decide which materials and facilities would be placed under safeguards; a nation signing the NPT as a Non-nuclear Weapon State (per NPT definition, any country that hadn't already tested a weapon by January 1, 1967 – i.e., countries other than the US, UK, France, USSR, or China) committed to accepting IAEA safeguards on all peaceful nuclear activities and material on its territory or otherwise under its control.

The corollary here was the need to declare all such activities and material, and the consequent need for the IAEA to verify that such declarations were not just correct, but complete (i.e., nothing covert): this second crucial aspect would require another 20 years to begin to be adequately addressed.

In the meantime, the nuclear nations set about understanding how and when full-scope safeguards would be triggered – the gravity of this mission demonstrated when India tested its first nuclear explosive device in May 1974, using material created in its Canadian-supplied CIRUS research reactor (based on the NRX reactor at Chalk River, with heavy water supplied by the US). The resulting Guidelines of the Nuclear Suppliers Group (NSG), first published in 1978, have since informed the IAEA's safeguards implementation [7].

The late 1970s also saw the establishment of the Canadian Safeguards Support Program (CSSP) under the then regulator, the Atomic Energy Control Board (AECB), continued today under the Canadian Nuclear Safety Commission (CNSC). This program of is part of a broader network of IAEA Member State Support Programs (MSSPs) through which nations provide in-kind and extra-budgetary financial support to the IAEA Department of Safeguards. A key aspect of Canada's support was the development of equipment for both containment and surveillance (C/S) and verification. A well-known example of this is the Cerenkov Viewing Device (CVD), for decades a workhorse tool of the IAEA that allows inspectors to verify spent fuel in storage bays.

Beginning in the early 1980s Canada worked with the IAEA to develop customized C/S solutions for CANDU reactors, addressing their unique challenges for safeguards due to both the inaccessibility of the fuel while in constant motion through the core, and the need to efficiently seal large volumes of spent fuel transferred to dry storage [8] [9]. These sealing systems and unattended monitoring systems (UMS) represented early examples of Safeguards by Design (early collaboration between a nuclear designer and the IAEA to incorporate more efficient safeguards), which has relevance today in ensuring that innovative reactor designs and related processes can be efficiently and effectively safeguarded (discussed in more detail in Section 3.5).

The 1990s saw several serious shortcomings of the non-proliferation regime brought to light, in particular through revelations in Iraq and North Korea, which led to the first substantial overhaul of the IAEA safeguards system. The aim was to strengthen the system's ability to detect and deter covert activities by greatly increasing the IAEA's knowledge of activities and materials in the state as a whole, and by integrating this knowledge with declared facility verification measures so that safeguards overall could be implemented both more effectively and efficiently. This retooling resulted in more focus on existing measures that had been under-utilized, and in an Additional Protocol that gave the IAEA enhanced rights of access to locations and information [2].

Here Canada again played a leadership role in supporting the development, testing, and adoption of the new measures, leveraging its capabilities as an advanced non-nuclear-weapons nation with a broad and complex fuel cycle. The strengthening and efficiency improvements continued into the new millennium as the IAEA refined its state-level concept of safeguards implementation: basing facility-level safeguards on a macroscopic assessment of each country's specific capabilities and potential acquisition paths to weapons-usable material.

Today the nascent global nuclear revival brings with it a new set of challenges for the non-proliferation regime, due to both the advanced nature of new facilities and processes under development, and the scale and timeliness with which these are proposed to be deployed. As in the past, it will be crucial for safeguards development to keep pace with the industry's developments if this deployment is to remain consistent with the grand bargain of civilian nuclear energy.

The next section looks at some of these emerging safeguards challenges.

3. Emerging safeguards challenges across the fuel cycle

3.1 Advanced reactors and fuel designs

Advanced reactors, including SMRs, microreactors and "Generation IV" systems, represent new and often innovative technology and deployment models, including associated fuel-cycle facilities (e.g., fuel-fabrication, reprocessing, spent-fuel storage). For the IAEA it is essential that the capability to implement efficient and effective safeguards is ready when required. For countries under a comprehensive safeguards agreement (CSA) with the IAEA, this requirement applies to any new project utilizing nuclear material, regardless of size, technology, prototype status, location, end use, or supplier country.

While it is true that many advanced-reactor concepts and associated fuel-cycle processes proposed today have been discussed, tested, or even prototyped within the global nuclear R&D community for decades, few have had any significant level of international safeguards applied. The IAEA therefore has little practical safeguards experience with most of the novel concepts, and both time and resources will be needed to prepare – particularly where customized safeguards measures are needed.

The following innovative features of advanced reactors will require advance safeguards consideration:

- New fuels and fuel cycles, including those involving high-assay low-enriched uranium (HALEU), thorium, molten salts, pebble and prismatic graphite, and pyroprocessing;
- Longer refuelling cycles, on-load refuelling, and sealed cores;
- Smaller facility layouts, creating tighter, more complex spaces under containment and surveillance (C/S), with potentially significant radiation fields and other health and safety considerations relevant to in-field inspection and equipment maintenance;
- New deployment models, including factory-fuelled cores, transportable and floating nuclear power plants, transnational supply of sealed cores, and remote, distributed fleets of microreactors;
- New spent-fuel flow and storage configurations, including smaller items, and new physical forms (both item and bulk);
- Diverse operational end uses, including district heating, desalination, hydrogen production – possibly in combination with electricity production; and

- Non-traditional concepts of operations, including multi-unit operation with shared fresh and spent fuel management.

Accordingly, it is expected that the following aspects of safeguards implementation will be important considerations for the efficient and effective safeguarding of advanced reactors [10] [11]:

- Advanced and/or customized technology that make use of unattended operation and remote data transmission to the IAEA;
- Reliable, high-bandwidth, secure, remote digital connectivity;
- Containment and surveillance (e.g., seals), including the needs of factory-fuelled, transportable cores prior to shipping;
- Effective design verification, especially for complex layouts and transnational deployment;
- Multi-channel monitoring of reactor power, e.g., thermal/electric power for microreactors;
- Potential joint use of equipment, and monitoring of operator process data [10] [12];
- National-level concerns such as nuclear-material transfers, transnational supply arrangements, access to remotely-deployed facilities, enhancement of national fuel-cycle capabilities, and cyber infrastructure and security.
- Training for all stakeholders (IAEA, national authority, operator), including capacity-building needs for emerging national nuclear programs.

Many of these safeguards considerations have potential interactions (both synergies and conflicts) with security and safety considerations. Accordingly, it will be important to coordinate on such '3S' interfaces, and where possible seek a harmonized approach that leverages commonalities among similar technology types.

The IAEA is currently engaged with several SMR designers through Member State Support Programs such as Canada's, with the objective of developing preliminary assessments for safeguards implementation, including the identification (and if necessary, initiating) of any required development of new or modified technical measures.

3.2 Reprocessing

Several proposed fuel cycles incorporate some form of reprocessing of spent fuel in order to maximize resource efficiency and minimize the burden of final spent-fuel management. Any reprocessing activity is naturally challenging for safeguards as it involves nuclear material that is both highly radioactive and in bulk (non-item) form. The bulk nature usually implies statistical accounting techniques and management of process losses (in safeguards terms, 'material unaccounted for' or MUF) that must be sufficiently characterized to facilitate continuity of knowledge by the IAEA. The highly radioactive nature means that this must be achieved under difficult circumstances, typically necessitating remote handling or measurement.

Regardless of inherent challenges, the IAEA's objectives in safeguarding a reprocessing facility will be the same as with any nuclear facility: independent verification of nuclear-material accounting declarations, and continuity of knowledge. To achieve this, the IAEA will implement a number of measures including direct sampling, process monitoring (possibly utilizing shared operator data), design information verification, and containment and surveillance. The degree to which these measures are implemented will depend upon the complexity of the facility layout and chemical processes, and in general will be negotiated with the facility operator in order to minimize both the disruption to operations and the burden on the IAEA, while achieving the necessary safeguards objectives.

The IAEA has some experience with safeguarding reprocessing facilities, despite these being mainly located in nuclear-weapon states and not under international safeguards. The most significant example is the Rokkasho Reprocessing Plant in Japan, under full IAEA safeguards that were developed starting in the late 1980s with the extensive support of the developer prior to operation. This level of early engagement was essential for the efficient implementation of safeguards at this complex facility [13].

This will be no less true for advanced fuel cycles involving reprocessing, whether envisaged as an integral process within the reactor facility, or as a stand-alone facility – and particularly where advanced techniques are employed (e.g., pyroprocessing) for which there is little or no safeguards experience. The IAEA has published general guidance (including best practices) for the efficient safeguarding of reprocessing facilities [20], which will be an important starting point for technology-specific discussions – ideally initiated at the earliest possible stage of development.

3.3 Transfers to dry storage

The nuclear revival, regardless of its eventual pace, will see increased used of dry storage for spent fuel. The transfer of spent fuel from wet to dry storage facilities, typically co-located with a nuclear power plant (NPP), is a sound strategy for reducing the resources needed for maintaining safe and secure storage of spent fuel, while freeing up space in the wet storage needed for continued operation. The lack of a practical option for the long-term management of spent fuel in most countries today makes this intermediate storage step a necessity.

Spent fuel that is under safeguards in wet storage will continue to be subject to safeguards during transfer, emplacement, and subsequent storage in dry container facilities. Due to the increased difficulty of access to the spent fuel in dry storage however, the IAEA's toolbox includes a special 'Difficult-to-Access' (DtA) designation, applied solely at its discretion, that reduces the ongoing verification requirements for this nuclear material by strengthening the containment and surveillance measures (usually doubling up on the number of independent measures required; e.g., seals, cameras). Prior to transfer to dry storage under this designation, the spent fuel would typically be verified by the IAEA at a higher level than during routine inspections, as this would likely represent the last time that the material can be accessed without considerable effort and inconvenience to both the IAEA and facility operator.

The entire process of dry storage, from preparation of the spent fuel in the wet storage bays through its transfer, emplacement and ongoing storage, involves safeguards measures and activities (and corresponding operator responsibilities) that, for an operator undertaking this process for the first time, will be new and largely unlike the safeguards implemented for years at the wet storages. Early discussion and planning can therefore be effective in facilitating a smooth transition to this phase of spent-fuel management by raising awareness of new requirements, incorporating them into the planning process, and potentially facilitating the development of advanced measures that can reduce the burden on operations, the national safeguards authority, and the IAEA.

For the facility operator these aspects may include:

- Integration of the additional verification activities of the IAEA into the facility procedures to be followed in preparing spent-fuel items for transfer (including requirements for regulatory and national safeguards-authority oversight);

- Working with the IAEA and other authorities to optimize the IAEA's approach for maintaining continuity of knowledge of the spent fuel during transfer, emplacement and storage. This can include the use of seals, on-board cameras and/or radiation monitors during transfer, unattended monitoring systems and remote data transmission, radiation characterization for reverification purposes, and in general verification strategies based upon near-real-time inspections and random selection;

- Following Canada's example, procurement of dry-storage containers that facilitate the efficient application of IAEA seals, including an 'immobilization seal' or other measure that provides continuity of knowledge of each container's movement history – or, less ideally (in lieu of earlier safeguards planning), working in advance with the IAEA to retrofit these safeguards accommodations into existing container designs;

3.4 Deep geological repositories

The end goal for spent fuel in many national nuclear programs, including Canada's, is emplacement and long-term disposal within a Deep Geological Repository (DGR). Under current IAEA policy, both the pre-closure and post-closure phases of a DGR are subject to safeguards, due to the large volume of nuclear material involved and the fact that it cannot be considered 'practicably irretrievable' by the host country (i.e., the condition for termination of safeguards, per most countries' safeguards agreements).

From the safeguards standpoint, a DGR represents a very large and complex version of a dry-storage facility as discussed is Section 3.3. Thus, the safeguards approach for a DGR will be conceptually similar to that of a conventional dry-storage facility:

- Spent fuel may have additional IAEA verification requirements prior to transfer;

- Spent-fuel transfers (from wet/dry storage to encapsulation plant, and from encapsulation plant to emplacement) will require continuity of knowledge by the IAEA;

- Viewed as a very large spent-fuel storage container, a DGR will require multiple containment and surveillance (C/S) measures applied to all credible diversion routes (e.g., surface access points), and the integrity of the containment verified (in this case, the 'geological containment' represented by the rock encompassing the active emplacement zone);

- Design information verification will be important in ensuring continuity of knowledge, updated as the DGR is constructed and operated.

Practically speaking, safeguarding a DGR will likely be one of the most challenging tasks assumed by the IAEA under its mandate. A DGR is a very large single facility (on the order of kilometres in all dimensions), most of which exists deep underground. During a DGR's extensive pre-closure phase of a century or longer, it is both an operational facility and a construction site, with dirty and dangerous conditions that are not conducive to independent inspection.

It is in every stakeholder's interest, therefore, that safeguards implementation at a DGR (and its associated encapsulation and final verification stages) be as simple and efficient as possible, while meeting the obligations of the host nation per its safeguards agreement. As with reprocessing, the IAEA has accordingly published guidance on this topic [21]. Also as with reprocessing, global safeguards experience is very limited; however, much has been learned from the IAEA's interactions with the stakeholders for Finland's Onkalo DGR (including the host national authority, the European Union safeguards authority, utility operator, and the designer/operator), which has been under development for two decades and is soon expected to begin accepting spent fuel.

3.5 Safeguards by design

In the preceding sections frequent references have been made to the need for early engagement on safeguards planning as a strategy for avoiding delays and additional costs in the nuclear revival. This strategy is known as Safeguards by Design (SBD).

SBD is fundamentally a process of raising awareness about safeguards obligations early in the design stage of any new nuclear technology development (contrary to the traditional timeline for such discussions), and optimizing these end-user needs with safety, security, and other design considerations. The relevant design processes are any that arise during the lifecycle of a facility, from initial design through decommissioning, and can involve either new facilities or modification of existing facilities (e.g., addition of dry storage as discussed in Section 3.3).

For the designer, SBD is a voluntary process that begins with knowledge of international safeguards and their implementation at relevant facility types. For this the IAEA's guidance documents provide a good starting point with respect to spent-fuel management [14-22]. A recommended practice is to involve a safeguards subject-matter expert (SME) in the design process, directly or as a review resource. Safeguards SMEs, if not available internally, can often be found in national nuclear labs, nuclear consultant companies, the national nuclear regulator, and of course through consultation with the IAEA.

For the technology recipient (e.g., host country, operator), SBD is also a voluntary process that can optionally be initiated through the procurement process – for example as a specification for consideration of international safeguards and their interfaces (potential conflicts/synergies) with safety and security design requirements.

The SBD process itself is a graded design review involving, at minimum, design experts and a safeguards SME – the level of detail generally dependent upon the technical-readiness level (TRL) of the technology. At any TRL the IAEA (Department of Safeguards) is available to engage in such discussions, which can range from informal discussion to detailed assessment. At the early stage of development of a project this engagement would typically not constitute a design declaration under a country's safeguards agreement, but rather take the form of a voluntary technical consultation at the discretion of the designer and/or technology recipient.

For high-TRL technology under consideration for implementation at an existing facility (e.g., procurement of a dry-storage facility at an operating NPP), SBD interaction with the IAEA will likely be initiated through the country's normal channels of communication for safeguards implementation – i.e., via the IAEA Department of Safeguards' personnel associated with a specific country and facility. For technology under development and not necessarily involving a specific technology recipient, the designer would typically interact with the technical support side of the IAEA Department of Safeguards, the main point of contact likely being the Division for Concepts and Planning (SGCP).

For example, in the specific case of SMRs the IAEA Department of Safeguards initiated several years ago a dedicated Member State Support Program (MSSP) task that facilitates SBD engagement directly with reactor designers, with SGCP as the main point of contact but involving other internal experts as needed. The process is voluntary and initiated by the national authority (the CNSC in the case of Canada's involvement) and technology designer(s).

More information on the IAEA's safeguards-by-design activities (including links to online PDF versions of the SBD guidance documents [15]-[22]) can be found on its website at: www.iaea.org/topics/assistance-for-states/safegaurds-by-design.

4. Summary

The nuclear revival will need to proceed in lock step with enhancements to the non-proliferation regime if it is to succeed while remaining consistent with international legal obligations. In the past the evolution of the nuclear industry has proceeded at a slow enough pace that nuclear safeguards – the cornerstone of non-proliferation and therefore of civilian nuclear energy expansion – has generally been able to keep up with emerging implementation challenges. The safeguards challenges of the current nuclear revival however, based on the diversity of technologies and timeliness of proposed deployment, will be both significant and quickly evolving. There is a clear need, therefore, for early engagement so that safeguards solutions can be integrated within the design process and considered alongside safety and security requirements.

The good news is that, given sufficient early engagement, safeguards solutions exist and non-proliferation does not have to be an impediment to nuclear innovation (or put another way, nuclear innovation an impediment to global security). Quite the contrary, as embodied in the tenets of the NPT, non-proliferation can rightfully assume its role as an enabler and cornerstone of nuclear innovation: the NPT, it must be remembered, recognizes the "inalienable right" of nations to benefit from peaceful nuclear technology. For Canada this will possibly include a national debate over technologies such as reprocessing – a technology that it pioneered in the earliest years of its nuclear program but has generally avoided until very recently. For innovations such as this, there are clearly proliferation challenges but also non-proliferation solutions (largely in the form of adequate safeguards).

Safeguards by Design, the proactive practice of good engineering whereby an end user's international obligations are accounted for as early as possible, is also a concept pioneered by Canada. By continuing to accord due weight to this requirement, Canada is in a position to honour its legacy of leadership in global non-proliferation, and help ensure a sustainable nuclear revival.

5. References

[1] "The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons", INFCIRC/153 (Corrected), IAEA, June 1972. (Available online: https://www.iaea.org/sites/default/files/publications/documents/infcircs/1972/infcirc153.pdf)

[2] "Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards", INFCIRC/540 (Corrected), IAEA, October 1998. (Available online: https://www.iaea.org/sites/default/files/infcirc540c.pdf)

[3] "Three-Power Declaration on Atomic Energy", Nature, No.156, November 1945. (Available online: https://www.nature.com/articles/156615a0)

[4] "Atoms for Peace", address by U.S. President Dwight D. Eisenhower to the 470th Plenary Meeting of the United Nations General Assembly, 8 December 1953. (Available online: https://www.iaea.org/about/history/atoms-for-peace-speech)

[5] "The Agency's Safeguards", INFCIRC/26, IAEA, March 1961. Updated in April 1964 as INFCIRC/26/Add.1 (Available online: https://www.iaea.org/publications/documents/infcircs/agencys-safeguards)

[6] "The Agency's Safeguards System", INFCIRC/66, IAEA, December 1965. Updated in September 1967 as INFCIRC/66/Rev.1, and in September 1968 as INFCIRC/66/Rev.2 (Available online: https://www.iaea.org/publications/documents/infcircs/agencys-safeguards-system-1965)

[7] "Guidelines for Nuclear Transfers", INFCIRC/254/Rev.14/Part 1, October 2019 and "Guidelines for Transfers of Nuclear-Related Dual-Use Equipment, Materials, Software, and Related Technology", INFCIRC/254/Rev.12/Part 2, July 2022, Nuclear Suppliers Group (Available online: https://nuclearsuppliersgroup.org/index.php/en/guidelines/nsg-guidelines)

[8] "Design Measures to Facilitate Implementation of Safeguards at Future Water Cooled Nuclear Power Plants", IAEA Technical Reports Series no. 392, Vienna, 1998. (Available

online: https://www.iaea.org/publications/5726/design-measures-to-facilitate-implementation-of-safeguards-at-future-water-cooled-nuclear-power-plants)

[9] J. Casterton, T. Ellacott, and M. Kent, "Safeguards-by-Design: The Canadian Experience", INMM Annual Meeting, Baltimore, July 2010.

[10] J.J. Whitlock and J. Sprinkle, "Proliferation Resistance Considerations for Remote SMRs", AECL Nucl. Rev., vol.1, 2, 2012. (Available online: http://www.nuclearfaq.ca/Whitlock-Sprinkle-AECL-Nucl-Rev-PR-Considerations-for-Remote-SMRs.pdf)

[11] J.J. Whitlock, "Safeguards by Design: Designing Nuclear Facilities with Safeguards in Mind", IAEA Bulletin, vol.63, 3, 2022. (Available online: https://www.iaea.org/bulletin/safeguards-by-design-designing-nuclear-facilities-with-safeguards-in-mind)

[12] J.J. Whitlock, D. Trask, "Operational Transparency: An Advanced Safeguards Strategy for Future On-load Refuelled Reactors", International Conference on Future of Heavy Water Reactors, Ottawa, 2011. (Available online: http://www.nuclearfaq.ca/Whitlock-Trask-FHWR2011.pdf)

[13] S.J. Johnson et al., "Development of the Safeguards Approach for the Rokkasho Reprocessing Plant", IAEA-SM-367/8/01, Symposium on International Safeguards Verification and Nuclear Material Security, Vienna, 2001. (Available online: http://www.nuclearfaq.ca/Development_of_the_Safeguards_Approach_for_the_Rokkasho_Reprocessing_Plant.pdf)

[14] "Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards", STR-360, IAEA, 2009.

[15] "International Safeguards in Nuclear Facility Design and Construction", NP-T-2.8, IAEA, 2013. (Available online: https://www.iaea.org/publications/10361/international-safeguards-in-nuclear-facility-design-and-construction)

[16] "International Safeguards in the Design of Uranium Conversion Plants", NF-T-4.8, IAEA, 2017. (Available online: https://www.iaea.org/publications/10759/international-safeguards-in-the-design-of-uranium-conversion-plants)

[17] "International Safeguards in the Design of Enrichment Plants", NF-T-4.10, IAEA, 2019. (Available online: https://www.iaea.org/publications/13452/international-safeguards-in-the-design-of-enrichment-plants)

[18] "International Safeguards in the Design of Fuel Fabrication Plants", NF-T-4.7, IAEA, 2017. (Available online: https://www.iaea.org/publications/10746/international-safeguards-in-the-design-of-fuel-fabrication-plants)

[19] "International Safeguards in the Design of Nuclear Reactors", NP-T-2.9, IAEA, 2014. (Available online: https://www.iaea.org/publications/10710/international-safeguards-in-the-design-of-nuclear-reactors)

[20] "International Safeguards in the Design of Reprocessing Plants", NF-T-3.2, IAEA, 2019. (Available online: https://www.iaea.org/publications/13454/international-safeguards-in-the-design-of-reprocessing-plants)

[21] "International Safeguards in the Design of Long Term Spent Fuel Management", NF-T-3.1, IAEA, 2018. (Available online: https://www.iaea.org/publications/10806/international-safeguards-in-the-design-of-facilities-for-long-term-spent-fuel-management)

[22] "International Safeguards in the Design of Radioactive Waste Management Programmes", NW-T-1.28, IAEA, 2025. (Available online: https://www.iaea.org/publications/15489/international-safeguards-in-the-design-of-radioactive-waste-management-programmes)