Canadian SMR Roadmap

Waste Working Group Report

July 2018

V0.0

Contents

1.0 Introduction

The purpose of this report is to present the output of SMR Waste Working Group (WWG) activities in support of the Pan-Canadian Small Modular Reactor (SMR) Roadmap project. Key activities include:

- Analysis of waste categories against Canadian SMR technologies that best align to end-user requirements
- Identification of key gaps in research and development for waste categories
- Identification of potential work that could address the key gaps

This report contains the results of the analysis, and a summary of key findings, high level recommendations and actions for consideration by the SMR Roadmap Steering Committee. The work was undertaken by the members of the Waste Working Group, as listed in Table 1.

CNSC has endeavored to support the SMR Roadmap initiative as primarily an observer providing regulatory clarifications. Contributions by CNSC to working groups are from the perspective of the mandate of the CNSC as the Canadian Nuclear Regulator.

Table 1: Waste Working Group Members

Organization	Single Point of Contact (SPOC)
Atomic Energy of Canada Limited (AECL)	SPOC: Paul McClelland
Nuclear Waste Management Organization (NWMO	SPOC: Mihaela Ion SUPPORT: Derek Wilson
Canadian Nuclear Laboratories (CNL)	SPOC: Mark Chapman
Canadian Nuclear Safety Commission (CNSC)	SPOC: Karine Glenn SUPPORT: Laura Andrews
New Brunswick Power (NPB)	SPOC: Mike Hare
Natural Resources Canada (NRCan)	SPOC: Catherine Badke
Ontario Power Generation	SPOC: Lise Morton
Province of Ontario Ministry of Energy	SPOC: Dhil Thiru

2.0 Used Fuel Disposal

In Canada, the Nuclear Waste Management Organization (NWMO) is responsible to develop a safe, long-term disposal solution for Canada's used nuclear fuel as per the federal Nuclear Fuel Waste Act (NFWA). The NWMO is implementing Adaptive Phase Management (APM), which at its end-point is safe isolation of used nuclear fuel in a deep geological repository (DGR) in a willing host community.

The NFWA, and NWMO's development of APM, considered the potential for new waste forms through new technologies or new-nuclear projects. As such, fuel waste from SMRs would be within NWMO's mandate for long-term disposal.

For emerging technologies, the NWMO would provide a fee for service at fair and reasonable costs to determine the long-term management requirements and associated costs for the resulting fuel wastes. If a new technology is deployed and there is a new fuel waste owner, the NWMO would work with the fuel waste owners to determine the long-term costs and develop the appropriate funding mechanism for accommodating these wastes. This would also include the recovery of costs expended by NWMO for the implementation of APM up to the date of SMR fuel waste production, proportional to the volume of SMR waste, as well as, any additional costs required to manage the new fuel waste form.

As with the considerations for waste characterization and interim storage, the large variety of SMR technologies and potential applications (e.g. on-grid versus off-grid remote) present a challenge in assessing the requirements for long-term disposal. The current disposal concept is designed to manage used CANDU fuel. In the absence of information on the fuel type, size, composition, characterization, etc., it is not possible to determine the potential impacts to the current disposal concept, safety case, or costs.

2.1 Identified Gaps

- Waste properties and characterization information may not be available to support the assessment of long-term disposal requirements or potential impacts to the current conceptual design.

- Some waste forms may require further processing to meet the waste acceptance criteria for the used fuel DGR. The details of such processing are unknown.

- In the absence of information on the fuel type, size, composition, characterization, etc., it is not possible to determine the potential costs associated with activities related to long-term management of SMR used fuel.

2.2 Proposed Actions to Address Identified Gaps

- Further work is required to understand the potential form and characteristics of the fuel waste to be considered for transportation, potential processing and/or reprocessing, and subsequent disposal.

- The NWMO to continue implementing APM in a manner that is consistent with the NFWA, which considers the long-term management of SMR fuel waste. The NWMO would work with the proponent to determine the long-term costs and the appropriate funding mechanism for accommodating these fuel wastes.

3.0 Used Fuel Interim Storage

Currently, used nuclear fuel in Canada continues to be safely stored in both wet and dry storage configurations by the waste producers as has been for decades. With the exception of research fuels, approximately 99% of the used fuel is CANDU fuel from nuclear reactors in Ontario, Quebec and New Brunswick. There is a robust regulatory and licensing framework for interim storage of used fuel.

For SMRs, given there is a large variety of technologies and potential applications (e.g. on-grid versus off-grid remote), the requirements for interim storage, and potentially reprocessing, need to be further considered. It is expected that an on-grid application, within an existing operator's facility, would be managed in a similar fashion to today's interim fuel storage. However, for off-grid and remote applications, extended on-site storage may be required for the fuel to meet handling and transportation requirements for future long-term storage or further processing.

3.1 Identified Gaps

- Waste properties and characterization information may not be available to support the assessment of interim storage requirements.

- Interim storage durations (i.e. before the waste is transportable for further processing or final disposal) may be in excess of the time the SMR may be operational at a site. This could result in additional post-operations security and safeguarding requirements.

- The form of the waste for interim storage may not be in a form for which there is existing operating experience in Canada (e.g. entire core versus fuel elements). There may be a need to re-package fuel waste to meet interim storage requirements.

3.2 Proposed Actions to Address Identified Gaps

- Further work is required to understand the potential form and characteristics of the fuel waste to be considered for interim storage, and subsequent transportation.

- Consideration should be given to the regulatory framework for remote applications and/or the need for extended on-site interim storage.

4.0 Low and Intermediate Level Waste Disposal

A current generic gap for all radioactive waste producers in Canada is no disposal route currently exists for any low and intermediate level radioactive waste (LILW). There are two projects currently in the regulatory decision process that have been launched by the two organizations that own the vast majority of low and intermediate radioactive wastes in Canada. While technical requirements are well elaborated, uncertainty in what it takes to get a repository approved in Canada with respect to the impact assessment and associated processes will be reduced once one or both of these projects have been approved.

Other waste producers do not have planned disposal paths. There is currently no industry-wide integrated planning process that will co-ordinate the efforts of the various radioactive waste producers and result in disposal routes that will ensure all producers of radioactive wastes will have access to disposal. In this climate, if the landscape does not change, SMR owners/operators will be responsible for developing their own disposal routes for their low and intermediate level radioactive wastes. For SMRs, the situation is further complicated by the fact that SMR technologies are anticipated to generate much smaller volumes of low and intermediate level radioactive wastes than traditional nuclear power plants or nuclear research facilities, such that the low volumes from these producers are unlikely large enough to economically justify development of dedicated disposal facilities.

Note that various options for disposal of small volumes of low and intermediate level radioactive wastes have been and continue to be explored world-wide. To date there has not been much effort in this area within Canada as there has not been the market for it. All producers to date have either been generators of very large volumes of radioactive wastes (traditional nuclear power plants or national research facilities), or generators of insignificantly small volumes (hospitals and universities) that have been accommodated by AECL under existing agreements.

4.1 Identified Gaps

- SMR owners/operators have no access to disposal for low and intermediate level wastes.

4.2 Proposed Actions to Address Identified Gaps

- If various producers of radioactive wastes in Canada and other stakeholders organize and develop a national plan for the management of low and intermediate level radioactive wastes, then the path to disposal for SMR owners/operators would spring from this plan.

- If there remains no national plan for the management of low and intermediate level radioactive wastes, then SMR owners/operators will need to develop their own solutions for disposal of low and intermediate level wastes, either individually or in partnerships with other radioactive waste producers.

5.0 Low and Intermediate Level Waste Storage

The interim storage of low and intermediate level (LILW) waste in Canada by nuclear operators (i.e., nuclear waste owners) has been in practice, safely, for over 40 years. All waste owners currently store their LILW on-site and/or at centralized facilities (e.g., Ontario Power Generation's Western Waste Management Facility). Canada's current policy on LILW is based on the "polluter pays" principle whereby owners of LILW are responsible for funding their LILW storage and disposal, including determining their own method for storage and disposal.

For SMR owners, the costs of LILW storage during the full lifecycle of the plant until final disposal options become available must be considered. SMR developers should also consider the waste streams that may be generated by their designs to aid in early identification of any unique issues, and consider both the front-end and back-end of the lifecycle for their designs. Understanding the volume and waste characteristics is important for assessing storage options. The option to choose centralized or decentralized storage for interim LILW should also be considered, though these options should also take into account the location of the SMR (e.g., availability of transportation routes).

Even if a national plan for the disposal of LILW were present, SMR operators would still require interim storage as it can be assumed that immediate or "just in time" transport of wastes, as they are generated, may not be feasible or economical as the quantities of the generated wastes would be small.

5.1 Identified Gaps

- In the absence of a national plan for LILW storage, SMR owners will have to determine their own solutions for the interim storage of their LILW until a final disposal option is available.

- Potential new SMR sites in remote communities will require specific safety, security and safeguards considerations that may differ from those of well-established nuclear sites without compromising safety, security and protection of the environment.

5.2 Proposed Actions to Address Identified Gaps

- If a final disposal plan (i.e., national plan) for LILW is developed, SMR operators would likely be able to accurately determine the extent and costs associated with their interim storage needs (i.e., volume and duration of stored LILW, including the frequency of LILW transportation).

- Ensuring the safety and security of personnel and the environment at a new LILW storage facility would require regulatory oversights and operator training with a focus on the safety culture currently found at large nuclear power plants and research reactors.

6.0 Transportation of Fuel from Small Modular Reactors

The two key legal instruments that govern the transportation of any radioactive material in Canada are: the Transport of Dangerous Goods (TDG) Regulations; and, the Packaging and Transport of Nuclear Substances (PTNS) Regulations, which are overseen and enforced by Transport Canada and the CNSC respectively. The TDG Regulations set out the general requirements for shipment of hazardous materials, with radioactive substances being defined as Class 7 materials. The TDG Regulations state that the requirements for the transport of nuclear material are specified within the PTNS Regulations, which cover the entire transport activity from the initial packaging of the material through to arrival at the intended destination. The PTNS Regulations specify the classification of material and packages, as well as requirements for licensing, packaging, and certification.

The IAEA Regulations for the Safe Transport of Radioactive Material provide an international framework for transport legislation that is reviewed and updated regularly. While the IAEA regulations are used as the basis for the Canadian regulatory documents, they do not supersede the TDG or PTNS Regulations. For any transport activity, it is necessary to ensure that the legally-binding requirements of the TDG and PTNS Regulations are met. Under these regulations, material such as irradiated conventional power reactor fuel must be transported within a Type B or Fissile Material package.

Conventional power reactor cores are composed of multiple individual fuel assemblies that can each be removed from the reactor core. Transportation of those fuel assemblies cannot occur until several years of cooling under water in a fuel bay. Once the fuel assemblies meet the transportation package licence requirements, a specified quantity is placed in a safe geometry and loaded into a transportation package. It is likely that the current regulatory framework and many existing packages would be applicable to SMR core designs that utilize conventional fuel types and cores that can be disassembled into individual fuel assemblies.

However, transportation of an irradiated sealed SMR fuel core could create unique challenges. While existing transportation packages may have sufficient capacity for Very Small Modular Reactor (VSMR) cores, they would still require relicensing for the unique characteristics of that VSMR fuel core. The transport of larger sealed SMR fuel cores could be fundamentally different from conventional fuel transportation and require the development of new transport packages. Depending on the size and burn-up of the core, the required shielding could result in proposed transport packages that exceed weight limits for many transportation routes. The characteristics of sealed SMR cores pose unique challenges to fuel transportation that should be evaluated early and factored into the SMR design process and site selection.

6.1 Identified Gaps

- Projected post-irradiation fuel characteristics are required in order to support a comprehensive evaluation of SMR fuel transportation challenges. Key characteristics required include fuel configuration, fission product inventory, decay heat generation, physical and chemical form, and fissionable material content. These characteristics will drive the transportation assessment, including how the fuel may be transported while adhering to current regulatory requirements, if any existing fuel packages are viable options, how much decay time will be required at the SMR site prior to transport, and are there any pre-transport processing requirements.

- Fuel transportation packages have significant mass in order to provide the shielding and containment to meet transportation regulations. Therefore, irradiated fuel transportation typically requires modern transportation infrastructure such as highways, rail networks, or deep water ports. This infrastructure may not exist at remote SMR deployment sites, and alternate methods of transportation may require development. The non-divisible nature of sealed SMR cores could require significantly larger and heavier transportation packages than those currently in use, which could challenge weight limits for existing transportation routes.

- Response to emergency situations or mechanical failures of transportation equipment may be significantly impeded in remote jurisdictions. This gap is common to waste transportation, but more acute for used fuel transportation due to the additional safeguards and security requirements for fissionable material. These challenges would be magnified in remote locations where the viable shipping window could be restricted to a month or two due to freeze-up of ports or thawing of ice roads. The uranium mining industry has experience on this topic that could be leveraged.

6.2 Proposed Actions to Address Identified Gaps

- Develop a matrix of fuel characteristics (pre- and post-irradiation) for the SMR technologies that will inform the SMR fuel transportation evaluation.

- Include fuel transportation considerations (including fuel package identification) in the overall SMR technology evaluation process.

- Identify alternative heavy lift and transport technologies that could be utilized to move fuel packages to/from SMR sites that have inadequate transportation infrastructure.

- Leveraging experience gained in the uranium mining industry, evaluate requirements for emergency response for transportation of irradiated fuel from remote locales.

7.0 Low and Intermediate Level Waste Transportation

Currently, for all radioactive waste producers in Canada there is no gap for the transportation of Low and Intermediate Level waste as this is an activity that has been occurring in this country for decades. The safety record for the transportation of low and intermediate level waste across the country is very strong and there is a wealth of operating experience and knowledge (this also applies to the transportation of used fuel). In addition, the program includes:

- a strong regulatory and licensing framework;
- a robust design basis for the transportation packages;
- availability and ready access to vehicles and transportation packages;
- a thorough emergency response plan and framework; and,
- experienced owners, carriers and shippers.

While transportation of low and intermediate level waste is done almost exclusively by road in Canada, there is extensive experience in Canada and internationally with transportation of radioactive materials by air, rail or water.

For SMRs, the need for transportation becomes a must if there is not availability on site for interim storage or disposal of wastes. If the SMR is located in an area accessible by road, then it is assumed that the required infrastructure will be developed to access the location and therefore current road transportation modes can be utilized. However, the timeliness of emergency response to a transportation event in a remote location needs to be considered.

For any SMRs which are not accessible by road, then transportation of low and intermediate level waste will be required by air, rail or water.

7.1 Identified Gaps

- Transportation Emergency Response infrastructure may not be available or effective in all areas of Canada and in particular, remote Northern locations, and the response time to reach the scene of an event may be long.

- While the technology, package design and operating experience exists domestically and internationally for radioactive material transportation by air, rail and water, there may be a need to address social license considerations regarding transportation of irradiated fuel and radioactive wastes.

7.2 Proposed Actions to Address Identified Gaps

- Rely on international experience to obtain transportation package designs, technology, available vendors and licensed carriers to support transportation by air, water or rail if required.

- Depending on SMR location, infrastructure will be required to enable transportation of low and intermediate level waste by different modes. For example, rail tracks or seaports may need to be established at the SMR location. Also, emergency response plans will need to be developed. Again, established international experience can be utilized in this development, as well as experience acquired through activities related to uranium mining.

8.0 Waste Characterization

Characterization of radioactive waste and used nuclear fuel provides key information on the properties of the wastes which are needed for the design and safety assessment of storage, transportation and disposal facilities. These properties include: physical characteristics (number, dimensions, mass), chemical composition, mechanical durability, irradiation history (e.g. reactor, burnup, discharge date), radionuclide inventory, radiation fields, heat output, fissile material content, chemical and long-term reactivity, especially in contact with water, release mechanisms and rates for radionuclides, in contact with air and with water.

The methods to obtain this information for radioactive waste and used nuclear fuel exist in Canada and worldwide. In particular, they have been applied to used CANDU fuel, which is the dominant used fuel waste in Canada.

The SMRs, including any potential reprocessing of their used fuels, are likely to create new waste forms. These SMR technology-generated wastes will likely have different characteristics from current used fuel and radioactive wastes in Canada. It will therefore be important to characterize them. Note that the waste form for long-term storage and disposal may be different from the waste form generated in the reactor. This storage and disposal waste form is the one that must be characterized. It will therefore also be important to determine what this final waste form is, such that it can be developed and characterized.

These SMR wastes may also be different materials, and may include significant amounts of new radionuclides that are important to design and safety. This may lead to some requirement to develop new methods for characterizing them.

Characterization of the wastes is likely to take an extended effort and time.

8.1 Identified Gaps

- Waste characterization information may currently not be available and development work may be required to support the safety cases for waste management licence applications for transportation, storage or disposal of new waste forms.

- Development and validation of novel waste characterization methods for new waste forms created by SMR technologies, may take extended periods of time.

8.2 Proposed Actions to Address Identified Gaps

- In the near-term and before any demonstration SMR units are built, standard codes could be used to estimate the waste characteristics, which would be used as key inputs to the design and safety assessments supporting the management of the new waste.

- Collaboration of SMR owners with potential receivers of the SMR-generated wastes is encouraged at the early planning stages, to exchange technical information and to determine the requirements for short- and long-term management of the waste.
- Collaboration with Canadian and international laboratories is recommended also at early planning stages, to determine whether an adjustment of waste characterization methods currently in use can accommodate the new waste forms.

9.0 Decommissioning

Currently, there is no gap in the regulatory framework as it applies to decommissioning of SMRs. Class I nuclear facilities (including all reactors) are required to keep decommissioning plans up to date throughout the lifecycle of a licensed activity, in accordance with CNSC regulatory guide G-219, *Decommissioning Planning for Licensed Activities*. In addition, the CNSC requires that all licensees implement financial guarantees to cover the cost of decommissioning work resulting from the licensed activities.

The CNSC requires licensees to prepare a preliminary decommissioning plan (PDP) and a detailed decommissioning plan (DDP) for approval. The PDP must be filed with the CNSC as early as possible in the lifecycle of the activity or facility and must be reviewed and updated at a minimum every five years. As per the CNSC requirements and further documented in CSA standard N294.0 *Decommissioning of facilities containing nuclear substances*, applicants are required to consider decommissioning and dismantling activities in the design of new reactor facilities. Specific requirements for decommissioning planning applicable to SMRs are also set out in the CNSC regulations for Class I nuclear facilities.

The PDP documents the preferred decommissioning strategy along with objectives at the end of decommissioning. The plan should be sufficiently detailed to assure the proposed approach is technically and financially feasible, and must include proposed strategies for managing all waste. It must also be in the interests of health, safety, security and environmental protection. Proponents must propose their preferred strategy as part of their PDP and must support it with a safety case. Any proposed decommissioning strategy will be assessed by the CNSC against regulatory requirements to ensure the protection of health and safety of the public and the environment. Decommissioning strategies are not prescribed by the CNSC, however, in order to align with international best practice, in-situ confinement should not be considered for new reactor designs.

Strategies for management of waste resulting from decommissioning must consider and prioritize the recycling or reuse of equipment and materials to reduce the volume of radioactive waste. Minimizing radioactive waste is also a key principle in the CSA standard on the management of low- and intermediate-level radioactive waste which specifically refers to the development of a waste management program to reduce the overall volume of radioactive waste requiring long-term management.

9.1 Identified Gaps

- Wastes arising from decommissioning may be an issue, especially where proponents are proposing to dispose of the reactor vessel and used fuel all as one. This does not conform to the principle of waste minimization and volume reduction and could result in large volumes of intermediate waste being disposed in high level waste disposal facilities. Furthermore, the transportation of such waste may be complex.

- The current Canadian regulatory framework allows for four decommissioning strategies: prompt decommissioning, deferred decommissioning, in situ confinement or a combination of these.

However, in order to align with international best practice, in-situ confinement should not be considered for new reactor designs.

9.2 Proposed Actions to Address Identified Gaps

- Engagement with proponents is required in order to ensure that decommissioning plans include appropriate long term waste management considerations.
- Both the CNSC and CSA Group are in the process of revising the regulatory documents and standards that apply to decommissioning. These revisions will include text to clarify acceptable decommissioning strategy for new reactor designs.

10.0 Conclusions

For each analyzed topic, gaps have been identified and actions have been proposed to resolve the gap. The actions as presented in each section are not compared for overall prioritization. This section identifies key findings and the higher priority recommendations and actions for consideration by the Steering Committee.

10.1 Key Findings

- The disposal path for SMR used fuel will include the NWMO APM deep geological repository. R&D work will need to be undertaken to demonstrate the SMR waste form is safe for disposal in the APM DGR. Further work is required to determine the costs associated with the potential need to re-package and/or re-process SMR fuel wastes to meet acceptance criteria, and the potential implications to the current APM repository design.

- Industry does not yet have LILW disposal available. The two major projects in the regulatory decision process do not plan to receive wastes from small volume producers (including SMR). While technical requirements are well elaborated, uncertainty in what it takes to get a repository approved in Canada with respect to the impact assessment and associated processes will be reduced once one or both of these projects have been approved.

- There are potential logistical challenges with transportation of irradiated reactor cores and this will need to be explored, in particular for remote locations.

10.2 High Level Recommendations

- Acknowledging that the NWMO is the organization responsible for disposing of all used fuel in Canada, including that of SMRs, coordination between SMR developers and the NWMO is recommended at the early planning stages to exchange information and to establish the technical requirements for the long-term management of the SMR used fuel, including acceptable waste form. Similar coordination is recommended between the SMR developers and any potential receivers of the SMR used fuel for interim storage (if applicable). This would include waste characterization methods, handling and transportation considerations. Canadian Nuclear Laboratories has experience in this process for research reactor fuels.

- Recognizing that work and assessments to address waste characterization, interim storage, handling and transportation of the SMR used fuel could have long lead times, uncertainties as to the final costs of used fuel disposal could remain for SMR developers even as demonstration projects get underway. Such risk will have to be taken into account when establishing project cost estimates.

- Given the long-lead times associated with assessment of disposability of used fuel from SMRs, the potential of financial risk sharing regarding used fuel management with other stakeholders, including government, may be considered for SMR technologies nearing demonstration.

- Waste owners and other interested parties in Canada should work together towards an integrated plan for radioactive waste management in Canada, with particular focus on identification of disposal paths for low and intermediate level radioactive wastes from small volume producers, including from SMRs.

- Coordination between SMR developers and potential radioactive waste receivers is recommended in the early planning stages to exchange technical information and to determine the long-term management requirements for low and intermediate level radioactive wastes from SMR, and in particular interim storage capacity requirements.

- For off-grid and remote applications, extended on-site storage may be required for the fuel to meet handling and transportation requirements for future long-term storage or further processing. Preliminary assessments are therefore recommended to determine the need for any additional post-operations security and safeguarding requirements.

- The particular context of remote communities will have to be taken into account when establishing the safety case for responses to incidents (including for transportation).

10.3 High Priority Actions

- Working with waste owners, government could play a role in facilitating the development of an integrated plan for disposal of low and intermediate level radioactive waste generated in Canada that will identify viable disposal paths for radioactive wastes from small volume producers (including from SMRs).

- CNL, with appropriate funding from technology developers and/or government, could have a role in supporting technical and other enabling work that could be necessary for the management of used fuel and radioactive wastes from SMRs in Canada. This could include:
  - providing support to SMR developers in establishing the technical requirements for the management (including storage and disposal) of SMR used fuel and radioactive waste
  - starting to develop a strategic roadmap to identify the questions that would need to be answered for a candidate SMR technology for demonstration regarding management of SMR used fuel (including storage, transportation, disposal)

- The NWMO continue implementing APM in a manner that is consistent with the NFWA, which considers the long-term management of SMR fuel waste. The NWMO would work with the proponent to determine the long-term costs and the appropriate funding mechanism for accommodating these fuel wastes.

- CNL to continue discussions with NWMO to determine how AECL’s non-CANDU bundle used fuel can be accommodated in the APM deep geological repository. These discussions could inform what will be required to demonstrate disposability of SMR used fuel.

- Proponents of SMR technology for demonstration prepare to coordinate with NWMO in the sharing of technical information needed to demonstrate disposability of SMR used fuel.

- SMR developers and/or operators should start collecting a matrix of key properties of used fuel and radioactive wastes from the respective SMR technology, for sharing with potential receivers of the wastes.

- SMR developers and/or operators should start assessing interim storage requirements for used fuel and radioactive wastes from the respective SMR technology.

- Interested academic partners prepare to participate in collaboration between proponents of SMR technology for demonstration and NWMO in the sharing of technical information needed to demonstrate disposability of SMR used fuel.