ROYAL MILITARY COLLEGE of CANADA
SLOWPOKE-2 FACILITY

NON-POWER OPERATING LICENCE RENEWAL APPLICATION

23 February 2022

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EXECUTIVE SUMMARY

The purpose of this application to the Canadian Nuclear Safety Commission (CNSC) is to request the renewal of the non-power reactor operating licence for the SLOWPOKE-2 Facility located at the Royal Military College of Canada/Collège militaire royal du Canada (RMC), Kingston, Ontario. Furthermore, the request is for a ten-year license valid from 01 July 2023 to 30 June 2033. This reactor became critical in September 1985 and has operated successfully with the original 1985 fuel charge and now continues to operate successfully with the second fuel charge installed in September 2021.

The SLOWPOKE-2 Facility falls into CNSC's Class 1A Facilities because the SLOWPOKE-2 reactor is a fission reactor. Thus, the SLOWPOKE-2 Facility must comply with the regulator's requirements for a Class 1A Facility.

The primary purposes of operating this research reactor at RMC is to provide an intense neutron source used for the education of the military and civilian students registered in the undergraduate and graduate programs of the university, for education and training Canadian Armed Forces personnel, and for research to support the Department of National Defence (DND), various other federal government departments including Health Canada, Crown Corporations, research activities at other universities and Canadian industry. It also serves as a tool for the education of interested individuals in the general public about matters dealing with nuclear reactors and radioactivity. Civilian students graduated from the nuclear program are mostly employed by the nuclear industry.

The following document contains the details of the historic and current operations of the reactor at RMC. No changes documented in the current submission will impact the safe operation of the SLOWPOKE-2 reactor.

The SLOWPOKE-2 reactor has safely and successfully operated for 37 years and continues to be a resourceful tool for elemental analysis and research into the understanding of nuclear matters. The reactor is a testament to its excellent design for small research reactors. DND and RMC feel privileged to have had the opportunity to work with this Canadian-designed reactor and hope to continue the experience with the sixth relicensing authorized by the CNSC.

1.0 INTRODUCTION

1.1 Background

The activity to be licensed is the operation of the non-power research reactor denoted SLOWPOKE-2 Reactor designed and built by the Atomic Energy of Canada Ltd. and located in the Sawyer Science and Engineering Building Module 5 at RMC within the City of Kingston, Ontario. RMC acknowledges that the land on which the RMC campus is situated is the traditional territory of the Haudenosaunee, Anishinaabe and Huron-Wendat peoples, where RMC is proud to deliver the successful Aboriginal Leadership Opportunity Year (ALOY) program.

RMC is a federal institution situated on Point Frederick near the demarcation line where Lake Ontario ends, and the St. Lawrence River begins its journey to the Atlantic Ocean. The property and the reactor belong to the Crown and are administered by DND in the name of the Commandant of RMC.

RMC has a Public Information Officer who is in charge of appropriately publicizing information about activities and features of RMC to the general public and to the media. The Director of the SLOWPOKE-2 Facility established a Public Information Programme [1] which manifests itself in a website accessible to the general public to keep the public informed of activities at the Facility. The Facility provides tours to high school students who are considering becoming cadets at RMC, to graduate students from other teaching institutions, to NATO officers and selected military attachés from embassies in Ottawa, and to visiting dignitaries from within Canada and from abroad. The SLOWPOKE-2 Facility participates in community events such as the highly attended, very successful, annual Science Rendezvous held in the spring in Kingston. The Facility responds to questions of interest from the general public and media.

1.2 Identification and Contact Information

The Licensee Identification is as follows:

Applicant Name: The Royal Military College of Canada/Collège militaire royal du Canada

RMC is situated on the traditional lands of the Haudenosaunee, Anishinaabe and Huron-Wendat peoples. RMC acknowledges the significance of these lands to the Indigenous peoples and RMC expresses its gratitude to be able to live and learn here [2].

Licensee Address:	The Office of the Commandant The Royal Military College of Canada P.O. Box 17000, Stn. Forces Kingston, ON K7K 7B4
Physical Location:	SLOWPOKE-2 Facility at RMC/CMR Department of Chemistry & Chemical Engineering, Sawyer Building Module 5 11 General Crerar Crescent

The Royal Military College of Canada
P.O. Box 17000, Stn. Forces
Kingston, ON
K7K 7B4

Licence Holder, Commandant RMC	Commodore Josée Kurtz e-mail: Josee.Kurtz@forces.gc.ca
Manager, SPOC, SLOWPOKE-2 Facility	Dr. Paul Chan e-mail: paul.chan@rmc.ca
Director, SLOWPOKE-2 Facility	Dr. Pavel Samuleev e-mail: pavel.samuleev@rmc.ca

1.3 Facility and Activities to be Licensed

The overall purpose of the application, submission date 01 March 2022, is to renew the SLOWPOKE-2 non-power reactor operating licence at RMC in order to permit the Commandant and RMC staff to continue providing and expanding general knowledge about reactors, radioactivity, and effects of such on the environment through teaching and research. The request is for a licence renewal of ten years, which is an identical period as for the current operating licence, which will expire in June 2023.

The SLOWPOKE-2 Reactor at RMC went critical in September 1985 when the first licence was issued for the period 1985-88. The reactor has operated for 37 years using the original Low Enriched Uranium (LEU) fuel. Five licence renewals were issued by the former Atomic Energy Control Board and now CNSC over the 37 years of operation with the periods as follows: 1988-93, 1993-2003, 2003-2013 and 2013-2023. This application for another ten-year operating licence would be the first licence issued to the Facility with a new LEU fuel charge (September 2021). The new core meets its design intent and has been operated successfully with no leakage of fission products. It is our expectation that the SLOWPOKE-2 reactor will operate for another 35 or more years.

Since the last review of aging management in 2013, improvements to the Facility have been incorporated at a steady pace in accordance with a plan [3] for improvements and changes to the Facility that currently extends to 2028. This plan is updated annually by the Director of the Facility. In this plan, the steps and associated costs are detailed to address aging equipment, to make improvements with respect to routine maintenance in the Facility and to have physical and digital upgrades made to improve the functioning of the Facility.

The most important upgrades are focussed on electrical improvements for operation of the reactor. The upgrades include lowering voltages wherever possible, separating and shielding low voltage cables from high voltage cables, and other means of lowering any electrical noise that interferes with the transmission of the current from the self-powered neutron flux detector to the receiving Keithley picoammeter. Extensive work by replacement with improved parts was done to the 1985, AECL "service box" to greatly improve access to parts of the service box, now called the "Headspace and Sample Air Control" panel. Digital neutron tomography is a new capability of the Facility. Further improvements will follow the plan as presented to the SLOWPOKE-2 Committee in 2021 [3].

CNSC staff performed a compliance inspection of the RMC SLOWPOKE-2 Reactor refuelling project on August 28 and September 3, 2021. The inspection covered eleven safety and control areas and the Public Information Program. RMC was found compliant with all CNSC criteria. CNSC staff further noted the high level of professionalism, expertise and attention to safety that the refuelling team displayed during the project [4]. RMC will continue to maintain and improve the operational safety of the SLOWPOKE-2 Facility.

2.0 SAFETY AND CONTROL AREAS

2.1 Management System

2.1.1 General Considerations

The management system for the SLOWPOKE-2 Facility is defined, planned and controlled in accordance with CNSC Regulatory Documents REGDOC-2.1.1 "Management System" [5] and REGDOC-2.1.2 "Safety Culture" [6] and adheres to the principles in the Canadian Standards Association (CSA) N286-12 [7].

The ADM-3: Management System Document for the SLOWPOKE-2 Facility at RMC [8] defines the responsibilities for and purpose of the SLOWPOKE-2 Facility. ADM-3 helps to:

i. provide a detailed requirements for the SLOWPOKE-2 Facility;
ii. identify objectives to achieve the requirements;
iii. identify risks and control risks to the objectives;
iv. establish plans, measures and targets; and
v. establish monitoring procedure to ensure planned results are achieved.

The Management System Document describes the management positions at the SLOWPOKE-2 Facility at RMC and contains the organizational chart for the management structure.

The Quality Assurance Manual [9] describes the program, which ensures compliance with Facility policies and documents covering Personal and Environmental Health and Safety, Radiation Protection, and Fire and Workplace Hazardous Materials Training. The impact on the environment of the operation of a SLOWPOKE-2 research reactor is required information by the CNSC, and compliance by the Facility is reported to the CNSC annually.

The advisory committee for the management of the Facility is the SLOWPOKE-2 Committee, which meets annually. However, during the continuing disruption of normal business due to COVID-19 and its variants, the CNSC has been informed by the Manager of the SLOWPOKE-2 Facility that information will be communicated via email as a year-end report. Copies of those reports were sent to the CNSC.

Inspections by organizations external to the Facility itself such as: the CNSC, the DND Fire Marshall's Department, CFB Kingston's fire inspection unit, the internal inspections done by the Department of Chemistry and Chemical Engineering (CCE) and RMC's Academic Wing Workplace Health and Safety Committee all contribute to the Facility adhering to and improving on policies for safety.

2.1.2 Management System

The Facility has a written Management System Document [8], which follows the principles in (CSA) N286-12 [7]. The ADM-3: Management System Document for the SLOWPOKE-2 Facility at RMC [8] defines the responsibilities for and purpose of the SLOWPOKE-2 Facility, identifies regulatory requirements and measures to meet them, and establishes monitoring procedures to ensure achievement of planned results.

2.1.3 Organization

The organization structure for the SLOWPOKE-2 Facility at RMC is shown on

Figure 1. The official Point-of-Contact to the CNSC at RMC has been delegated by the Commandant to the Manager of the SLOWPOKE-2 Facility at RMC.

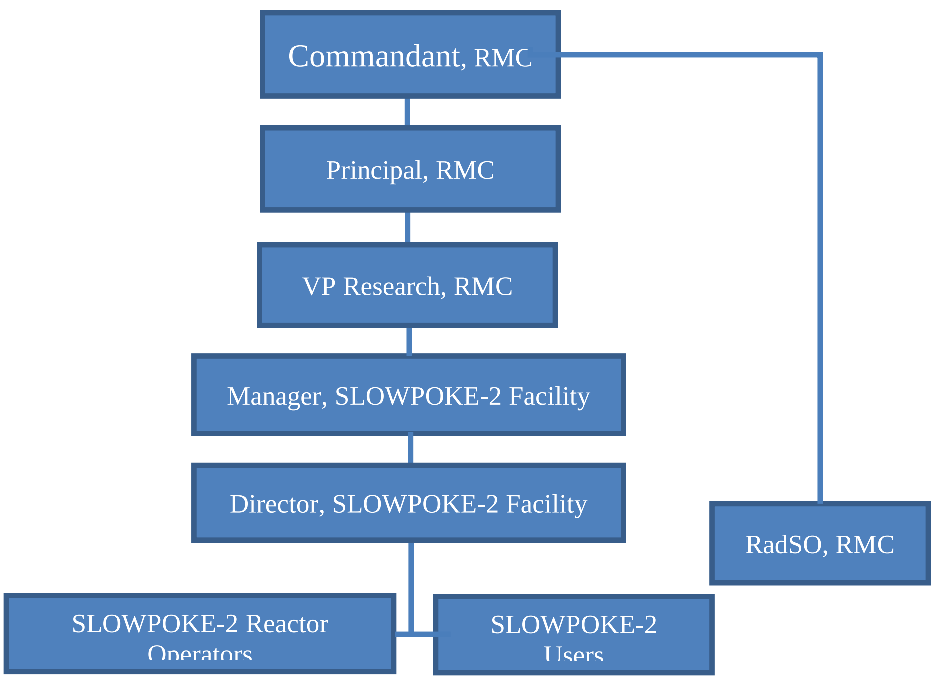


Figure 1. Organizational Structure at the SLOWPOKE-2 Facility at RMC.

2.1.4 Performance Assessment, Improvement and Management Review

Performance assessment, improvement and management review are performed and documented in records kept by the Director of the SLOWPOKE-2 Facility.

Individual Process Assessment

Individual process assessment is performed periodically as SLOWPOKE-2 Facility staff carry out their daily duties, during analytical investigations and reactor maintenance. When the Facility realizes a problem, the staff member consults an appropriate authority such as another analyst, Reactor Operator, the Radiation Safety Officer, the Manager and/or the Director of the Facility. Weaknesses are identified and corrections suggested. Subsequent action is approved and initiated by the Director.

Assessment of Reactor Operators

An internal assessment taken in 2017 provided the opportunity for the reactor operators to describe any changes and weaknesses that could improve their duties. In turn, this assessment provided the Director with the opportunity to assess the reactor operators' understanding of their responsibilities.

The Annual Compliance Report informs the CNSC that the reactor operators have fulfilled their annual responsibilities as described in the Licence Conditions Handbook [10], Appendix D: Section 3: Continuing Training Requirements, subsection 3.1.3.

Assessment of the weekly reactor maintenance done by a certified Reactor Operator is performed by the Director of the SLOWPOKE Facility after that certified Reactor Operator has completed his/her required reactor maintenance routine in accordance with Standard Operating Procedures (SOPs) [11]. The Director checks that the Maintenance Logs [12] have been correctly filled in by the Reactor Operator who performed the maintenance that week, and that any problems identified during the maintenance process have been tagged for resolution or have been resolved. Mistakes and oversights in procedures used to do reactor maintenance are identified by the Director and brought to the attention of the responsible Reactor Operator. The Director shows the Reactor Operator the correction required and, if helpful, suggests documents or references that can be read for more information or for further self-education. The Director of the SLOWPOKE-2 Facility has sufficient authority and organizational freedom to carry out the required duties.

It is the responsibility of the Director to ensure that employees are qualified to undertake the activities assigned to them by providing adequate supervision and documentation of training for new staff, Officer Cadets, graduate students, research associates, technical staff, teaching staff, contractors and sub-contractors. Safety considerations are emphasized throughout their training.

2.1.5 Operating Experience

The Director of the SLOWPOKE-2 Facility reviews and evaluates work done in the Facility. The Director has the responsibility and authority to issue corrective actions. Documentation is done through signatures on appropriate documents. This includes internal work orders, reports submitted to the SLOWPOKE-2 Committee and to the CNSC. Actions that are employed to resolve problems are reviewed for effectiveness and accepted by the Director.

Data on the reactor and some ancillary equipment are recorded daily, and also weekly during reactor maintenance. If something unusual was noticed, the observation would be written up in the Issues and Maintenance Database [13]. The Director of the Facility is responsible for initiating and implementing analysis of the occurrence, responsible for initiating and implementing correction of the problem, and for taking follow-up action. The Director may delegate certain parts of the investigation and solution of the deficiency to an appropriate staff member. On a daily basis the Director is responsible for ensuring the safe operation of the Facility.

Feedback from operating experience is an invaluable tool for the Facility management to assess and fix problems that have arisen in the operation of the Facility, and also to foresee future problems that may arise. Present and former Directors of Canadian and Jamaican SLOWPOKE reactors, readily share their operating experience even though many of their SLOWPOKEs have been decommissioned and staff retired. This interaction within the SLOWPOKE community is very helpful.

Through a project supported by the IAEA, the RMC SLOWPOKE-2 Facility participated in meetings and email exchanges with the Miniature Neutron Source Reactors in Kenya, Pakistan, and Ghana. The descriptions of their facilities, neutron detectors, fuel conversions from High Enriched Uranium (HEU) fuel to LEU fuel and problems accessing parts are most interesting and informative. An IAEA report with RMC's contribution is to be published in 2022.

The Manager of the SLOWPOKE-2 Facility at RMC is a member of the COG/ CNSC Regulatory Feedback Team. Industry meetings have been attended on a regular basis to understand the requirements of new REGDOCs on power and non-power reactor facilities.

2.1.6 Change Management

Prior to any changes being made to a procedural process, work, design or product, the changes will be subjected to the same level of review and approval as was done/accepted for the original situation in accordance with Quality Assurance Program-5 (QAP-5): Change Control Procedure [14]. Changes are reviewed by persons with knowledge of the original intent and requirements. Documents are to be accepted by the Director before implementation.

An integral part of the Change Control Procedure is the Change Control Form [14]. This form identifies the person(s) initiating, justifying, reviewing, and approving the change(s) and associated requirements, and initiating work action and completion. The persons filling out this form are identified by date, signature, name and workplace title.

2.1.7 Safety Culture

The Management System document seeks to foster a healthy safety culture through assigning individual responsibilities so that the lines of authority are transparent, promoting communication, fostering commitment to practising safety and reinforcing positive attitudes.

Safety culture is a regular item listed as an agenda item for the SLOWPOKE-2 Committee so that a discussion on if and how safety objectives are being achieved at the Facility.

The safety performance has been satisfactory for all of the non-power operating licences issued by the CNSC to the SLOWPOKE-2 Facility at RMC. There has been no damage to equipment, no accidents involving personnel, and no worker at the Facility has ever reached the public limit for the annual public radiation dose. There have been no reportable events to the CNSC since the reactor was first commissioned in 1985.

2.1.8 Configuration Management

The Facility strives to maintain all aspects of the Facility in a desirable, safe operating condition by making repairs as quickly as possible and having up-to-date diagrams showing the changes in the configurations of hardware and software. The principles of configuration management are “like replaces like” or “equivalency” under normal operating conditions such that there is no negative impact to nuclear and conventional safety.

The Facility modernizes its hardware, software drawings and procedures continually. The most recent electronics upgrades to reduce electrical noise were evaluated and accepted by the Electrical Safety Authority Field Evaluation (ESAFE).

2.1.9 Records Management

Manuals, guidelines, records, and drawings are maintained by the Director of the SLOWPOKE-2 Facility in accordance with ADM-2: SLOWPOKE-2 Facility Document Management System [15]. Procedures for maintaining these documents include the following:

- indexing and uniquely numbering each document and drawing;
- reviewing and approving documents and drawings;
- distribution (a controlled procedure) of approved documents and drawings; and
- updating documents and drawings.

Documents are classified into one of the following three classes:

a. **Public:** External and could be made available on the RMC web site;

b. **Internal:** Made available to persons affiliated with RMC and working in the SLOWPOKE-2 Facility, and outside the SLOWPOKE-2 Facility on an as needed basis to support operational requirements; and
c. **Confidential:** Containing information confidential to the SLOWPOKE-2 Facility or a related third party.

A distribution list for confidential documents is retained in the document files. Modifications to the distribution list are subject to permission by an authority, usually the Director. Personnel and user information is identified as confidential. The information is protected under the Personal Information Protection and Electronic Documents Act [16]. The person with the authority to approve a specific document and/or procedure can choose into which category the document fits.

The SLOWPOKE-2 Facility keeps a record of all the personnel files with respect to training, experience, security clearance, dosimetry and compliance with regulations both internal and external to the Facility. This includes the identification of confidential information and legal requirements for the management of personnel information. Records will be kept as per regulatory requirements.

The digital regulating system for the SLOWPOKE reactor and additional documentation and drawings are kept in a separate electronic repository with access control. These SLOWPOKE-2 Integrated Reactor Control and Instrumentation System (SIRCIS) documents are stored in an electronic and restricted access format.

Analytical data is protected. Access to the data is through the Director. In addition, analytical data are copied to backup files. Paper copies of analytical reports are kept for seven years. Data pertaining to the operation of the SLOWPOKE-2 Facility are to be kept indefinitely. If no longer relevant for corporate knowledge or for historical interest, the data shall be declared not relevant, and listed as obsolete.

Certain logs such as the log for the weekly reactor maintenance of the SLOWPOKE-2 reactor and logs for auxiliary equipment are kept conveniently close to the relevant equipment or close to where the equipment is controlled. Irradiation logs are kept beside irradiation controllers. The log for the performance of neutron radioscopy and tomography is kept in the Reactor Control Room. Archived logs are kept in the SLOWPOKE-2 Facility Office.

Backup copies of all up-to-date documents and drawings will be made and stored in separate locations. The backup copies will be electronic, stored on portable hard drives.

2.1.10 Business Continuity

Natural Disasters:

The area around the City of Kingston, including RMC, experienced a small earthquake in June 2010. Sawyer Building Module 5 in which the SLOWPOKE-2 Facility is housed was upgraded substantially with added construction beams to comply with the seismic standards for 2012. These seismic standards and improvements were acknowledged by the CNSC.

Sabotage:

The digital operating system, SIRCIS, for the SLOWPOKE-2 reactor is not connected to the internet, and therefore cannot be held hostage to a ransomware attack. However, all the rest of the computer network at RMC was hit by a ransomware attack in June 2020. To limit possibility of similar attacks in the future, Shared Services Canada has severely restricted how the RMC computers connected to the Internet are now used.

Labour Actions:

Over the years there have been pickets by different groups of workers who have blocked access to RMC. The appropriate labour unions and the Commandant of RMC had signed agreements to allow the Manager, the Director and the Radiation Safety Officer (RadSO) access through the picket lines.

Power and Energy Disruptions:

In the case of a main power disruption, the Facility is backed up by uninterruptible power supplies (UPS) and a gas-powered generator. This generator, located exterior to Sawyer Mod 5, is purposely elevated above the ground to mitigate flooding.

Communication, Transport, Safety and Service Sector Failure:

Because RMC is part of DND, disruptions in the above-mentioned sectors would be taken over by the Canadian Armed Forces (CFB Kingston) until normal channels were restored.

Health-Related Epidemic or Pandemic Events:

RMC itself follows the most stringent measures dictated by federal, provincial and local public health guidelines, partially through providing materials such as hand sanitizers, face masks, limiting the use of bathrooms to only one person occupancy and emailing updates to the RMC community on recent health events. RMC has a Unit General Safety and Environmental Officer (UGSEO) who on his website provides written precautions and advice when health conditions become a very serious problem.

RMC has demonstrated that it could and does maintain its purpose of educating students and facilitating faculty research requirements through first, a ransomware attack in 2019, and then continuously through the COVID-19 pandemic.

External contractors are required to follow the DND's guidelines and requirements.

Environmental Events:

There are hazardous material spill kits available on the two floors on which the Facility resides. There are showers and eyewash stations in hallways. SLOWPOKE itself releases neither hazardous materials nor significant radiological materials to the environment.

2.2 Human Performance Management

2.2.1 General Considerations

RMC maintains processes and procedures to support human performance in its operation by meeting the regulations in REGDOCs-2.2.2 "Personnel Training" [17], 2.2.3 "Personnel Certification" [18, 19], 2.2.4 "Fitness for Duty" [20, 21] and 2.2.5 "Minimum Staff Complement" [22].

RMC ensures that an appropriate number of trained and certified staff are working at the SLOWPOKE-2 Facility. In general, positions within the Facility require a person with a science degree bestowed by a college or university that is recognized by educators and administrators in Canada. New technicians are trained by an experienced technician to perform a specific procedure. There is a documented Training Record for the teaching, learning, and targets of accomplishment. Refresher training/requalification can be done as needed, usually after the observation of a supervisor on a person's work or as a result of the outcome of an examination.

2.2.2 Human Performance Program

The Reactor Manual for the SLOWPOKE-2 Facility at RMC [23] states that the Facility Management will ensure that there are always a minimum of two Reactor Operators certified by the CNSC to run the reactor in automatic mode. In addition, RMC has a Radiation Safety Officer whose responsibility is to ensure that radiation fields inside and outside the Facility are below the limit for a Nuclear Energy Worked (NEW) and for the general public, respectively.

Personnel can request the time to take a course either to upgrade their workplace skills or to learn a new skill. Similarly, supervisors can recommend to the staff that certain courses or retraining should be taken. There is a List of Procedures [24] for tasks within the SLOWPOKE-2 Facility and also a separate Users' Guide for the Neutron Radiology System [25]. Employees must be able to read and comprehend the material in manuals for operation and maintenance of equipment. Appropriate courses taken to upgrade knowledge and skills and the guidance from Facility manuals help reduce human error, provide support for safe work activities and allow for continuous improvement of human performance.

All work done in the Facility is directly supervised by a Facility staff member, often the Director, or by the Radiation Safety Officer, all of whom are required to be vigilant that workers are carrying out their jobs safely with respect to themselves, their colleagues and to equipment located in the Facility. This is a verification process by witness of the work while it is being done.

A "normal" working day at the Facility consists of a 7.5-hour day with a half hour break for lunch. A co-worker or the Director of the Facility is on hand to notice when fatigue sets in and would recommend a break or resumption of duties to the next day.

2.2.3 Personnel Training

A detailed description of the qualifications, knowledge, skills, and continuing training program for Reactor Operators is given in the Reactor Operator Training Program and Manual [26] written using the Systematic Approach to Training (SAT). This SAT document meets the requirements of REGDOC 2.2.2 "Personnel Training" [17]. A CNSC inspection on personnel training was performed in January 2022.

Persons involved with new Reactor Operators training are required by the CNSC to provide proof of appropriate qualification. Subject Matter Experts (SMEs) are so named, because of their knowledge and experience, and thus do not require specific instructions to assist in the training of new Reactor Operators.

Those persons who are not yet SMEs may enhance their knowledge and skills by taking appropriate courses during their employment. Specific skills are both taught and learned through taking courses and by being trained by a person qualified to perform that skill. Once a staff member has fulfilled the requirements for delivering on-the-job training and has passed the appropriate tests, then that person becomes qualified to become a trainer.

From 1985 to 2016, and then from 2016 to 2022, the Reactor Engineers and Reactor Technicians for the SLOWPOKE-2 Facility at RMC have been chosen and trained by Atomic Energy of Canada Limited (AECL) at the Chalk River Laboratories (CRL) and by the AECL contractor namely the Canadian Nuclear Laboratories (CNL). The SLOWPOKE-2 Facility receives a letter from AECL/CNL which states that an applicant has been trained as a Reactor Technician (RT) or a Reactor Engineer (RE) and has satisfactorily passed the academic and practical tests associated with the duties of an RT or an RE for working in a SLOWPOKE-2 Facility. This letter from AECL/CNL and a covering letter from the Director are forwarded to the CNSC for the certification of the RT and RE at RMC. A job description and the requisite qualifications for a Nuclear Maintainer are on file at AECL /CNL and accessible by the CNSC SLOWPOKE-2 Project Officer from AECL/CNL. This information can also be obtained through the Director of the Facility at RMC.

The required qualifications for staff members of the SLOWPOKE-2 Facility at RMC are described in the Reactor Manual [23].

Before working within the boundaries that define the SLOWPOKE-2 Facility, an individual is required to complete a Radiation Safety Training session conducted by the RMC Radiation Safety Officer. The Radiation Safety Officer maintains records of this training.

An external, independent auditor for the Canadian Association for Laboratory Accreditation (CALA) comes every two years for the external review of certain laboratory analysis procedures and documents. Documentation of the verification is through signatures on a report and/or signed actions resulting from the report issued by CALA. Response to action items on a report is dictated by the timelines set by the external organization. The CALA certification was renewed in 2021.

The verification process and Quality Assurance Manual for the SLOWPOKE-2 Facility at RMC are described in Reference [9].

2.2.4 Fitness for Duty

The Human Resources Department for DND has developed a fitness for duty program commensurate with risk. This program includes a policy on alcohol and drug use; access to assistance for employees with emotional and/or family stress, or substance abuse issues; and referral to medical assessment when appropriate (See the Standards of Civilian Conduct and Discipline [27], and the protocol to access Employment Assistance Program [28]). Staff performance evaluation by one's supervisor is performed on an annual basis.

Because the staff of the SLOWPOKE-2 Facility is few in number and a very limited number of technicians work inside the Facility, co-workers know each other very well. Consequently, it is fairly easy to identify persons feeling workplace stress and exhibiting unusual behaviour. No human performance issues have been identified at the Facility since COVID-19 pandemic started in 2020.

2.3 Operating Performance

2.3.1 General Considerations

RMC has processes and procedures in place to ensure that it operates in a safe manner and in compliance with its license conditions. An annual compliance report is submitted to the CNSC in accordance with REGDOC 3.1.2 [29].

Records from weekly reactor maintenance [11] and the daily operational data collected by SIRCIS govern the operation of the Facility. These practices normally identify areas or equipment that require attention to ensure compliance with the current licence requirements. See below sub-section 2.3.5, which discusses operating limits and conditions (OLC).

Only the fewer than ten Reactor Operators, the RadSO and two technicians have keys to the Control and Reactor rooms of the Facility. All visitors, contractors and students must have approval from the Director prior to be accompanied at all times by a RO or the RadSO while working within the Facility. Daily operation of the Facility is managed by the Director.

The SLOWPOKE-2 Committee for the RMC Facility is responsible for setting policies under which the Facility operates. The Commandant has the ultimate responsibility for the safe operation of the Facility. Under the Commandant's prerogative to designate authority, the Manager and Director of the SLOWPOKE-2 Facility are designated to maintain policies, make operating decisions, initiate maintenance, modify equipment, modify maintenance and operating procedures, and permit staff and all other categories of persons to enter the Facility. Experiments are reviewed and approved by the Director of the SLOWPOKE-2 Facility and the RadSO. The RadSO ensures compliance with CNSC, the Director General of Nuclear Safety (DGNS) and Transportation of Dangerous Goods (TDG) policies and the training and continuing training commitments within RMC. Policies pertaining to the review and audit of operations are defined within the SLOWPOKE-2 Quality Assurance (QA) program under the authority of the Commandant through the Manager and Director of the Facility. The Director is mandated to ensure that the policies pertaining to regulatory compliance and incident reporting are met.

2.3.2 Conduct of Licensed Activity

The policies, methods and procedures for carrying out the licenced activities of the Facility are described in the Reactor Manual for the Facility [23] and in the SIRCIS Operator Manual (pages 18 through 21) [30], where OLCs are stated. The regular checks described in SLOWPOKE standard operating procedures (SOPs) [24] serve to confirm the operational functions of the system, structures and components (SSC). If one of these procedures finds that an SSC is not functioning correctly, the system is tagged, the problem entered into the SLOWPOKE-2 Issues and Maintenance Database [13] for action and trending, and the Director would determine the steps needed to have that component fixed.

The Manager is ultimately responsible for ensuring that all documents and appropriate training of personnel exist to ensure that all practices carried out in the Facility have a strong component emphasizing safety. In practice, the Director and the RadSO oversee every work person in the Facility to make sure that licenced activities are carried out safely, ongoing upgrades and modifications are explained in writing and in person if requested, the plans scrutinized and approved by personnel with the appropriate authority, which is usually the Director of the Facility, and that the work is done with the proper equipment by appropriately trained personnel. A culture on safety first is practised at all times.

The RadSO is in charge of directing the handling, storage, and transport of nuclear material. Instructions and explanations are given in the Radiation Safety Manual [31].

2.3.3 Procedures

Current operating and maintenance procedures are described in the following documents:

a. OPN: List of Procedures by SLOWPOKE-2 Facility at RMC [24],
b. SIRCIS Operators' Manual by SLOWPOKE-2 Facility at RMC [30], and
c. CPSR-362: SLOWPOKE-2 Nuclear Reactor Operation and Routine Maintenance, Rev.2 by AECL [32].

Although the 1985 Manual, Nuclear Operation and Routine Maintenance [32] refers to the electromechanical operation of the SLOWPOKE-2 reactor, there are instructions for the maintenance of the reactor whether run electromechanically or digitally.

Daily maintenance checks of gamma radiation survey meter readouts on both floors of the Facility are noted, daily inspection of the SIRCIS GUI (Graphical Users Interface) is done, reactor temperatures noted and the Events and Alarms Window on the SIRCIS monitor is checked for unexpected statements, which may need immediate attention. Occupational health guidelines are followed daily. Radiation safety is practiced daily as each person inside the SLOWPOKE-2 Facility must sign into the SLOWPOKE Visitor and Dosimeter Log [33], and wear radiation recording devices.

The RadSO takes contamination swipes monthly and changes the Optically Stimulated Luminescence (OSLs) dosimeters and neutron badges quarterly. Procedures such as general reactor maintenance and attention to waste management are carried out weekly. Any malfunctions are recorded and action for repair initiated, usually by the Director. Packaging and arranging for transport of radioactive material according to TDG Class 7 instructions and CNSC transport regulations is done by the RadSO whenever radioactive material is being transported away from the Facility. Other maintenance procedures and checks such as vacuuming the reactor pool and testing the pool overflow valve are on a recorded schedule. A cursory visual inspection of the top of the reactor is done regularly by the Director of the SLOWPOKE-2 Facility.

2.3.4 Reporting and Trending

The SLOWPOKE-2 Facility at RMC provides all reports and notifications including annual compliance reports to CNSC in accordance with REGDOC-3.1.2 [29].

During weekly and monthly maintenance activities [24], Reactor Operators measure and record excess reactivity values, cleanness of water from the reactor pool and container, activity of the headspace gas, activity and capacity of the deionization resins to observe the trends and predict changes. The issue database [13] serves as a great tool to keep track of possible trends in other issues.

2.3.5 Operating Limits and Conditions

Certain operating limits and conditions are stated in the current operating licence, NPROL 20.00/2023 [34]. As previously mentioned, the SIRCIS Operator Manual [30] explains the OLCs for the SLOWPOKE-2 reactor located at RMC. These OLCs manifest themselves on the SIRCIS screen in the Control Room as five “Warnings”, which are the following:

a) Neutron Flux,
b) AC Power Failure,
c) Remote Shutdown,
d) Core Temperature, and
e) Pool Temperature.

If activated, the first four warnings cause the control rod to be inserted into the core to shut the reactor down. The fifth warning, namely “pool temperature” does not initiate any motion of the control rod.

a) A control rod shutdown due to a Neutron Flux warning serves three cases, which are if the maximum flux of 1.40×10^{12} n $cm^{-2}s^{-1}$ is exceeded for more than 55 seconds, if reactor is operated at neutron flux level exceeding 1.05×10^{12} n cm^{-2} s^{-1} at a steady state operating conditions, and if it takes more than 200 seconds for the flux to reach a preset value. The last case warns of a possible defect in or communication problem with the self-powered neutron flux detector.

b) If both the UPS and the backup generator fail to supply power to the reactor, there would be a guaranteed shutdown of the reactor.

c) The Remote Shutdown is activated manually by a reactor operator or an MP. The reactor cannot be started if the Remote Shutdown notification is in red.

d) If the outlet core temperature exceeds 58 °C, SIRCIS is programmed to shut the reactor down. This warning is to prevent a possible excursion.

Other operating limits, such as maximum allowed number of finished fuel elements as well as total amount of uranium-235 in the reactor and maximum excess reactivity, are executed by appointing Canadian Nuclear Laboratories personnel as Reactor Engineers and Reactor Technicians. Thus, RMC staff does not have access to the reactor container, fuel, and beryllium shims which eliminates possibility to adjust excess reactivity or fuel content.

2.4 Safety Analysis

2.4.1 General Considerations

The Safety Analysis for the RMC SLOWPOKE-2 Reactor is documented in a site-specific "Safety Assessment and Operating Envelope for the SLOWPOKE-2 Reactor at RMC [35]". This document updates the generic document from Atomic Energy of Canada (Commercial Products Report, CPR 26 [36]). This updated and site-specific assessment acts as the report that further demonstrates the safe operation and inherent safety of the SLOWPOKE-2 reactor. A Reactor Manual [23], a Fire Protection Document [37], a Quality Assurance Document [9], a Training Program [26], and a document on safety analysis, CPR 77 [38], provides the description and safety analysis for the SLOWPOKE-2 reactor with low enriched uranium (LEU) fuel. These documents support the safe operation of the RMC SLOWPOKE-2 Facility and contain the technical detailed information that meets REGDOC 2.4.1 "Deterministic Safety Analysis" [39].

The design of the SLOWPOKE-2 reactor provides for an inherently safe reactor that meets the requirements of REDOC-2.4.3 [40]. The negative temperature coefficient contributes greatly to the inherently safe characteristics of the SLOWPOKE-2 reactor. In addition, the reactor container is physically sealed and not permitted to be opened by RMC personnel. The excess reactivity is measured weekly during the reactor maintenance procedures [11, 41]. The core is cooled by natural convection, which means that the Facility does not have to rely on installed pumps for cooling. For personnel working in the Facility, the 4.4 meters of water above the reactor core provides sufficient shielding from the radioactivity of the core. The addition of the Radioscopy System in the pool results in some neutron activity in the Reactor Room when the Neutron Beam Tube is in use. To shield people from these neutrons, borated polyethylene has been added at strategic locations inside the Facility. During the 2012-2013 renovations to Mod 5 additional 2.4 m × 3.6 m, 2.54 cm thick sheets of borated polyethylene were attached to the ceiling of the Reactor Room.

The cadmium shut down capsules are used for the auxiliary shut down system [42] for the reactor should the cadmium control rod fail in some manner and/or the reactor room cannot be entered. Cadmium capsules are stored next to each irradiation controller and are checked regularly to ensure that the irradiation vials containing cadmium are in good condition for the next use of them.

It is evident that the radioactivity releases from the Facility during normal reactor operation are small, and there has been no effect on individuals nor on the environment [43].

2.4.2 Postulated Initiating Events

Postulated initiating events are documented in the Safety Analysis [35]. Under all postulated initiating events and should the reactor be on at full power, for example, and the control rod was unable to be inserted into the core for a shutdown, the Facility has an auxiliary shutdown system consisting of inserting an adequate number of known reactivity worth cadmium capsules into inner and outer irradiation sites which are located inside the reactor container [42]. The auxiliary shutdown system would thus avert the possibility of an excursion. This was again demonstrated during the refuelling of the reactor in September 2021 by CNL and RMC.

Should an unexpected reactor excursion occur, the decrease in density of the moderator, namely light water, would eventually, in cycles, bring the reactor down to a stable operating level at the heat removal capacity of the system. The self-limiting power excursion behaviour was demonstrably safe for reactivity additions of up to 0.65 % (6.5 mk). With the largest credible reactivity transient of magnitude 0.4 %, a delayed peak power is about 77 kW [44, 45].

Facility safety is amply described and explained in [44], which states the philosophy of the SLOWPOKE reactors supported by the deliberate design and engineering of the reactor. Additional safety aspects are discussed in the document, the Impact Assessment of SIRCIS Upgrades [46].

2.4.3 Hazard Analysis

Possible hazards affecting the Facility such as earthquakes, droughts, floods, high winds, tornadoes, abnormal surges in water levels, airplane crashes, ship collisions, chemical explosions, internal fires, internal floods, on-site transportation accidents, and releases of hazardous substances from on-site storage facilities, based on the experience of the previous 37 years, have a very low probability of occurring and are documented in the Safety Assessment and Operating Envelope [35]. Small earthquakes have occurred in the Kingston area, but, so far, no damage has resulted from an earthquake. The Reactor Manual [23] discusses the type of earthquake zone in which the RMC peninsula exists. Some of the other hazards could possibly occur and would be dealt with by trained emergency response teams.

2.4.4 Criticality Safety

The SLOWPOKE-2 Facility at RMC meets the requirements of REGDOC-2.4.3 [40]. From its inception the SLOWPOKE-2 philosophy has been to create the engineering design and operating procedures of a reactor exhibiting typical inherent safety characteristics, such that these inherent characteristics assure the reactor's safety during all conceivable conditions as described in [35]. The Facility should never experience a criticality incident because, except for the unobtainable core, the Facility has never held more than 20 g of fissionable material and has no expectation of doing so.

During the 2021 refuelling of the SLOWPOKE-2 reactor at RMC, a documented and signed criticality study was done by CNL [47]. The recommendations therein were followed for the storage at RMC of the 200 new, LEU uranium oxide fuel pins delivered to the Facility such that their proximity to the partially loaded new core would not cause a criticality event. Taken into account were the beryllium shims stored inside the Facility and any compounds containing uranium, which beforehand were removed to another location. The five new fuel pins that were not needed for the new reactor core were transported back to Chalk River. Associated transportation documentation was completed by CNL experts as per the refuelling contract stipulations.

2.5 Physical Design

2.5.1 General Considerations

"From its inception the SLOWPOKE philosophy has been to tailor the engineering design and operating procedures of a reactor exhibiting typical inherent safety characteristics, such that these inherent characteristics ensure the reactor's safety during all conceivable conditions" [44]. RMC manages changes to ensure that safety and physical design of the Facility are maintained in accordance with REGDOC-2.5.1 "General Design Consideration: Human Factors" [48].

To ensure that there are no unacceptable impacts on persons and on the environment, the Facility practices the concept of "As Low As Reasonably Achievable" (ALARA) [49-52] .To this end, the Radiation Safety Officer maintains a dose management and tracking program for the staff, contractors, and visitors of the SLOWPOKE-2 Facility at RMC. The impact on the environment due to the operation of a SLOWPOKE-2 research reactor has been demonstrated as negligible [43], and annual compliance with regulations is demonstrated through annual compliance reports and CNSC inspections.

2.5.2 Design Governance

Design governance is assured through oversight at the SLOWPOKE-2 Facility. The SLOWPOKE-2 Committee provides oversight of risk and control processes. The Management System [8] describes the ethics practiced at the Facility as well as the description of the roles and responsibilities of Facility staff and of RMC's upper administration. There have been no physical changes to the design of the SLOWPOKE-2 Reactor. AECL remains as the Design Authority of the SLOWPOKE-2 Reactor at RMC.

2.5.3 Site Characterization

The geological, seismological and hydrological information is described in the Reactor Manual [23].

The following aerial view of the site location (Figure 2) shows the proximity of the Peninsula on which the Facility sits with respect to the City of Kingston, the Portion of RMC which is on the mainland, and Fort Henry, a UNESCO Heritage site.

The City of Kingston lies to the west and north of RMC. The part of the City to the west of RMC has a mixture of small businesses and residential units. The northern part is mainly residential. Directly to the east of RMC lies Navy Bay and Fort Henry. Lake Ontario lies to the South of the peninsula on which RMC stands. To the west of RMC is the end of the St. Lawrence River.

The map of RMC's campus (Figure 3) shows Sawyer Building Module 5 in which the SLOWPOKE-2 Facility is located.

2.5.4 Facility Design

The rooms inside the Facility were designed with special use for each room in mind. For example, the Reactor Room and a room where radiochemistry would be practised and supported by a nearby shower were deliberately chosen with respect to location and function. As a consequence of their function, the SLOWPOKE-2 laboratories can be grouped according to the range of radiation expected in each room. Signs are posted upon entry to each room to warn personnel that they are entering a radiation zone as pointed out in the Radiation Safety Manual [31].

RMC - Classification of Rooms

All areas, rooms, and enclosures are classified according to Table 1. The SLOWPOKE laboratories fall under the Basic Level Laboratory Classification.

Table 1. Classification of Rooms

Room Classification	Description
Basic Level Laboratory	The quantity of unsealed nuclear substance used at a single time does not exceed 5 times its corresponding annual limit on intake (ALI).
Intermediate Level Laboratory	The quantity of unsealed nuclear substance used at a single time does not exceed 50 times its corresponding ALI.
High Level Laboratory	The quantity of unsealed nuclear substance used at a single time does not exceed 500 times its corresponding ALI.
Containment Level Laboratory	The quantity of unsealed nuclear substance used at a single time exceeds 500 times its corresponding ALI.
Nuclear Medicine	The nuclear substance is prepared for or administered to a person.

Royal Military College of Canada – Posting of Radiation Warning Signs

A warning sign shall be displayed wherever a source is being used or stored, bearing the radiation trefoil symbol and the words "RADIATION DANGER RAYONNEMENT" [31, 53]. Access by the general public is not permitted to any area where the exposure rate exceeds 2.5 μSv per hour. Any location determined to exceed this 2.5 μSv per hour limit must be cordoned off and posted with the radiation warning signage. Radioactive material will be stored behind sufficient shielding to ensure that exposure levels adjacent to the storage area do not exceed 2.5 μSv per hour.

Names, job titles and telephone numbers of individuals with the appropriate authority are posted on respective rooms for contact 24 hours a day in case of an emergency. These individuals include the Radiation Safety Officer and the Director of the SLOWPOKE.

In areas where nuclear sources and radiation devices items are stored, radiation surveys are conducted monthly. The values of the measured radiation fields are posted inside the Facility.

The general layout of the Facility is shown in Figure 4.

The Facility itself does not contain large quantities of chemicals because the majority of work done in the Facility is neutron activation analysis, which does not need the use of chemicals. A neutron beam tube (NBT) designed by AECL in the late 1990s is located inside the reactor pool with an upper section that protrudes into the reactor room. When in use for radioscopy, there are semi-conformable borated polyethylene "paddles" that surround the item to be radiographed, and thus shield/stop the majority of neutrons from entering the Reactor Room. Extra precaution is taken for personnel safety by magnetically locking [54] the three, inner doors into the reactor room while radioscopy is in progress. A restricted code is required to unlock these three doors.

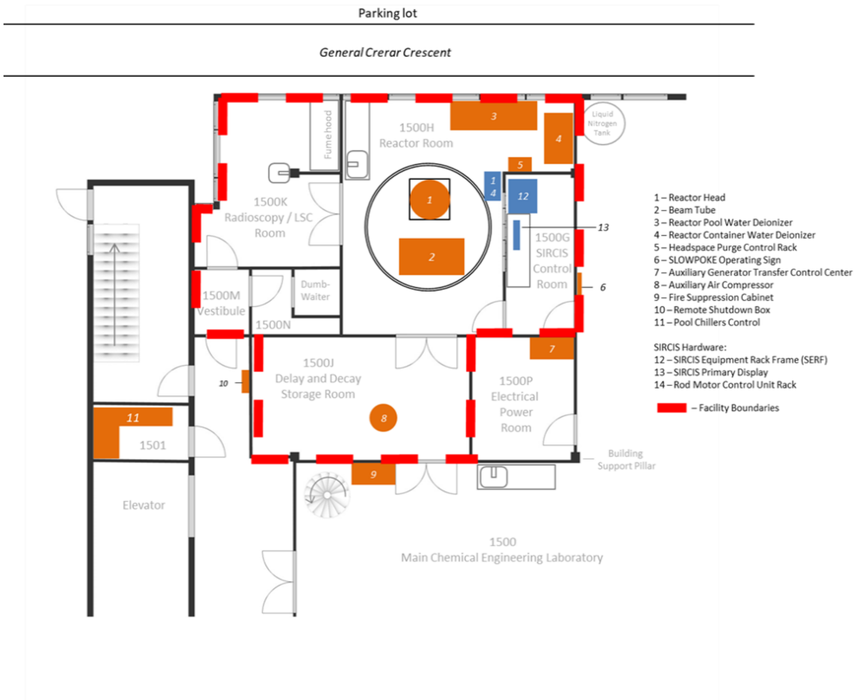
2.5.5 System and Component Design

There is no pressure-retaining system at the SLOWPOKE-2 Facility. The heating, ventilation and air conditioning systems for the Facility are controlled remotely from an engineering centre for the Sawyer Building. The portion of pipes, vents, etc. in Sawyer Mod 5 was entirely replaced in 2012/2013. As per the refuelling project completed in 2021, there is no reactor life-limiting degradation observed inside the pool and reactor container. Exterior to the reactor container itself, any system addition, design, modification or procurement is governed by the SLOWPOKE's Change Control process [14] under the Management System.

Figure 2. Aerial view of the RMC (Google Maps, 2021 CNES).

Figure 3. Site Plan of the RMC.

a)



b)

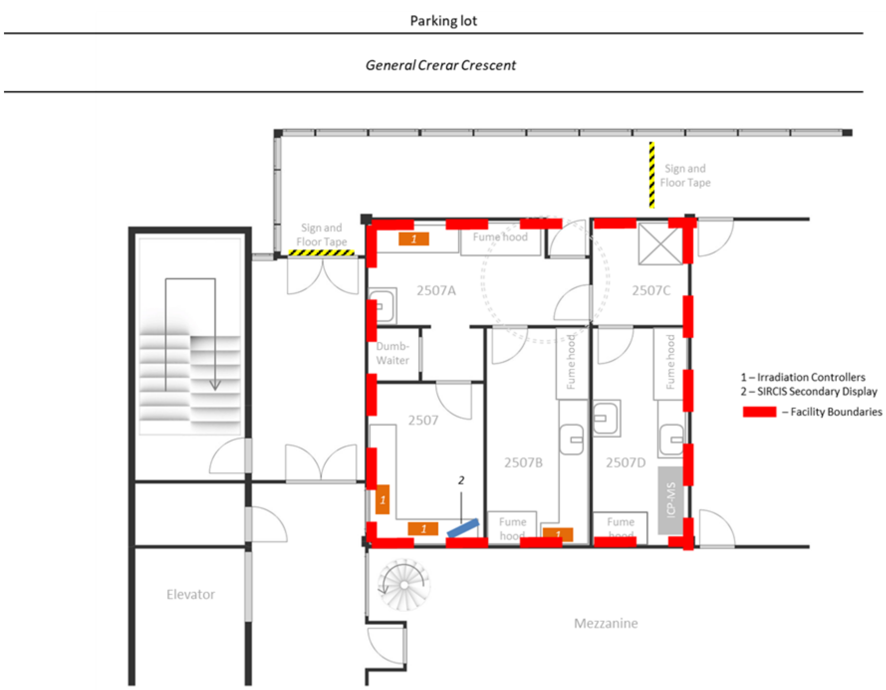


Figure 4. Plans of the first (a) and second (b) floors of the SLOWPOKE-2 Facility at RMC, 2022

2.5.6 Waste Treatment and Control

Waste minimization, storage, and eventual removal from RMC is described in the Radiation Safety Manual [31] (Section 14 on Management of Radioactive Waste and Section 15 on Ionizing Radiation Source Disposal). Waste management is also discussed in detail under the Waste Management section of this Application. The main strategy to waste management is waste minimization, delay and decay, and enforcing proper description of the waste so that information is available for the disposal event.

2.5.7 Control Facilities

The SLOWPOKE-2 reactor at RMC is controlled by the digital Integrated Reactor Control & Instrumentation System (SIRCIS), see Figure 5. Using SIRCIS, certified Reactor Operators can start-up and shut down reactor, control and monitor neutron flux in the automatic mode or control rod position in the manual mode, measure excess reactivity, and energize irradiation site controllers. SIRCIS also displays outlet, inlet, and pool water temperatures, water levels in the pool and reactor container, operational status of deionization systems, as well as provides information about system alarms and warnings.

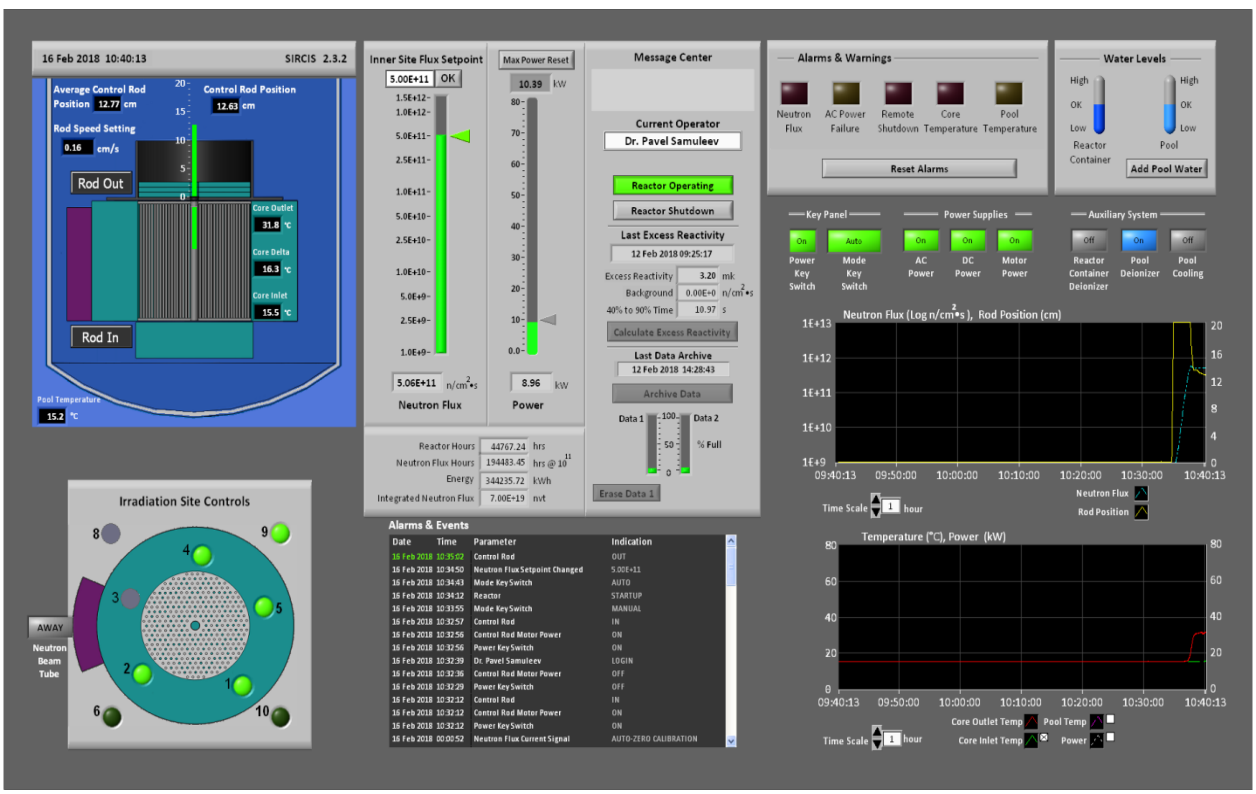


Figure 5. Screenshot of SIRCIS control system during reactor operation at half-power.

Should an unforeseen event occur, personnel would leave the area of concern and, if necessary, the reactor would be shut down. There are special sections/rooms on each floor where disabled personnel can wait for assistance to be evacuated from the building.

Figure 6. West wall of Sawyer Building Mod 5 at RMC showing seismic upgrades

2.5.8 Structure Design

Sawyer Building Module 5 in which the reactor facility is located rests upon caissons, which are described in the Reactor Manual [23]. Sawyer Mod 5 was seismically upgraded in 2012/2013 (Figure 6).

Essential services such as response from the Military Police for security concerns resides at CFB Kingston. Fire and paramedic services are located in the City of Kingston and would have to cross the LaSalle Causeway to reach the peninsula on which RMC resides. In early 2023 the completion of a bridge across the Cataraqui River will be another way to reach RMC from the City of Kingston.

2.6 Fitness for Service

2.6.1 General Considerations

With respect to Fitness for Service the reactor facility has continued to achieve the design intention and function of a SLOWPOKE. The SLOWPOKE-2 Facility at RMC addresses the maintenance requirements specified in REGDOC-2.6.3 [55].

Before and for the current operating licence, NPROL-20.00/2023 [34] for the SLOWPOKE-2 Reactor Facility at RMC [34], there have been no changes at the reactor facility that could negatively impact this Safety and Control Area (SCA). Maintenance on all parts and supporting devices for the reactor [24] have been carried out diligently on a recorded, regular, scheduled basis. Aging management concerns are viewed and reported to the Director in parallel with the Weekly Reactor Maintenance tasks and at shims when the certified Reactor Technician opens the reactor container inspection plate so that lights and a camera can be used to view the conditions inside the reactor container. Periodic inspections are done as the availability to perform an inspection arises such as at a shim event or a refuelling event. Testing and calibrations of equipment are done on a regular, scheduled basis or as required.

2.6.2 Maintenance

Maintenance associated with the conventional building services such as electricity, heat, water, air quality, and structural integrity is the responsibility of Construction Engineering (CE) located at CFB Kingston. There is an RMC–wide procedure for requesting maintenance services from CE.

Similarly, there is an RMC-wide procedure for requesting help from computer services for both technical assistance and repairs. Computer services are the responsibility of the Computing Services Department at RMC assisted by Shared Services Canada, which is a Government of Canada Department supporting information technology infrastructure.

Maintenance and preventative maintenance for the reactor and/or structures supporting the reactor and/or auxiliary equipment is done in parallel with a Weekly Maintenance Procedure [11] and a legacy document from CPSR-362, May 1985 [32]. At less frequent, but defined, intervals preventative maintenance and tests are done by SLOWPOKE-2 Facility staff, technicians in the Department of Chemistry and Chemical Engineering, CE or contractors. Maintenance details for the great majority of the SSCs in the Facility can be found in [11], which updates the legacy reference [32].

The Director of the SLOWPOKE-2 Facility maintains an electronic record of miscellaneous and unusual events that may occur during Weekly Reactor Maintenance and during operation of the reactor. This e-record is called an “Issue and Maintenance Database” [13]. The observation is dated and described in this database. If remedial action is required, a priority for the action will be assigned by the Director and communicated to the SLOWPOKE Reactor Operators.

The Director of the SLOWPOKE-2 Facility at RMC analyzes information received in order to initiate appropriate action to resolve a problem or answer a query. The problem and/or query may need the attention of the SLOWPOKE-2 Committee. The Director would so inform the Chair of the SLOWPOKE-2 Committee. The ensuing Committee meeting would produce archived minutes for future reference. In this way, the safe operation of the Facility should be maintained or improved, quality assurance applied, and the management process updated.

Weekly reactor maintenance is required to be performed at the Facility [32, 11]. If any of the systems checked during weekly maintenance do not perform as expected and the problem cannot be resolved immediately, then the reactor controls must be tagged with a date, instruction, and a brief statement of the problem so that inadvertent operation is prevented. The Director is to be informed when a problem occurs, so that appropriate action can be initated.

2.6.3 Aging Management

The Facility is compliant with REGDOC-2.6.3: Aging Management [55] through weekly reactor maintenance [11] and other maintenance procedures [24], Issues and Maintenance Database [13], and SLOWPOKE-2 Committee Meetings [3].

During the refuelling of the SLOWPOKE-2 reactor at RMC in August/September 2021, cameras were used to produce videos recording the detailed visual examination of the inside and outside of the reactor container, the walls and bottom of the reactor pool, and the exterior of the Neutron Beam Tube. These videos are archived at the Facility and are available for viewing. The Facility managed to conduct a detailed examination of major parts of the reactor infrastructure that would usually not be available because of inaccessibility and lack of appropriate equipment. These videos reinforce the fact that since the reactor was commissioned in 1985, there have been no aging issues relevant to the continued safe use of the systems, structures and components (SSC) of the reactor facility.

Aging and obsolescence issues are handled under the authority of the Director, who also creates a list of improvements to address lifecycle management of components, within the allocated annual budget accepted by the SLOWPOKE Committee for the reactor facility at RMC. The list is kept in a table titled Planned Lifecycle Management Updates of the SLOWPOKE-2 Facility in the SLOWPOKE-2 Committee Meeting Summary [3].

Obsolescence of the digital operating system, SIRCIS, and its supporting components are managed by having at least duplicate or even triplicate components/instruments/software stored at RMC. These commercial-off-the-shelf-components are calibrated annually or as needed to keep them immediately ready for use.

2.6.4 Periodic Inspection and Testing

Testing and calibrations on equipment are done on a regular, scheduled basis or as required as per instrument specifications such as: the annual calibration of gamma and neutron detectors, electronic personal dosimeters (EPDs), quarterly testing of chloride levels in the pool and reactor container waters, calibration of National Instruments modules, analysis of pool and reactor container water for radioactivity content, weekly check of the Remote Shutdown system, and resetting the SIRCIS program weekly. Periodic inspections are done as the availability to perform an inspection arises such as during a shim event or a refuelling event. The tests for assuring operational viability of some systems are done by contractors whose speciality applies to a specific system such as the Fire Flex Dual Fire Suppression System, the two water deionizer systems, the heat exchangers for the reactor pool, and the backup gas generator.

2.7 Radiation Protection

2.7.1 General Considerations

The SLOWPOKE-2 Facility requires that each employee in the vicinity of, or directly handling, radiation sources be instructed on the radiation safety procedures. The Radiation Safety Manual [31] clearly explains all aspects of Radiation Protection required and followed by the Facility.

Radiation protection measures are in place to minimize and control the potential for radiation exposure to both staff and public arising from the operation of SLOWPOKE-2 reactor at RMC. The Facility complies with the Radiation Protection Regulations, radiation protection orders of DND and REGDOC 2.7.1 "Radiation Protection" [56] through the RMC Radiation Safety Manual [31] and SEP-1: Radiation Safety for the SLOWPOKE-2 Facility document [57].

2.7.2 Application of ALARA

To minimise the possible adverse health effects of ionising radiation, as low as reasonably achievable (ALARA) principles are practised. The radiation dose received by individuals is measured [33, 52] by appropriate and calibrated radiation devices and recorded at RMC by the RadSO. The technicians, reactor operators, the Manager, and the Director of the Facility are Nuclear Energy Workers (NEWs).

It is highly unlikely that persons working in the SLOWPOKE-2 Facility will ever approach the limits set for Nuclear Energy Workers (NEW), but their dose received should still remain as low as reasonably achievable. Typically, an annual dose for the Facility personnel stays well below the annual public limit of 1 mSv. The CNSC prescribes for NEWs an average dose of 20 $mSv \cdot y^{-1}$, but up to 50 $mSv \cdot y^{-1}$ in one year for unusual circumstances. The statement in the NSCA [58] says that NEWs may receive a total of 100 mSv over a period of 5 years.

2.7.3 Worker Dose Control

The following Table **2** Table 2 shows the action levels in place at the Facility [23, 31].

Table 2. Occupational Radiation Exposure Action Levels

Type of Dose	**Action Level**
Effective Dose (non-NEWs & NEWs)	0.25 mSv · (3-month period)$^{-1}$
Finger Dose Level (non-NEWs & NEWs)	10 mSv · (3-month period)$^{-1}$
Personal Alarming Device (PAD) (non-NEWs & NEWs)	5 µSv·day^{-1}
Loose Surface Contamination[1]	0.05 Bq·cm^{-2} (averaged over an area ≤ 100 cm^{2})
Loose Surface Contamination[2]	0.5 Bq·cm^{-2} (averaged over an area ≤ 100 cm^{2})
Work Area Dose Rate[3]	≥ 25 µSv·h^{-1} for more than 10 seconds in the reactor room
Work Area Dose Rate[4]	0.2 µSv·h^{-1} in the reactor room on Monday morning
Freshly irradiated sample [5]	≥ 25 µSv·h^{-1} on the technician's EPD as the freshly irradiated source is removed from the lead receiver.

Notes:

1. Alpha contamination as detected on a liquid scintillation counter
2. Beta contamination as detected on a liquid scintillation counter
3. As measured by the area monitor on the ceiling of the reactor room
4. As measured by the area monitor on the ceiling of the reactor room
5. As measured by the calibrated EPD worn by persons inside the SLOWPOKE-2 Facility.

2.7.4 Radiation Protection Program Performance

The Radiation Protection Program is evaluated by the CNSC. The RadSO holds the consolidated licence [59]. The most recent and successful virtual inspection by Nuclear Substances and Radiation Devices (NSRD) section of the CNSC occurred in 2021. No items of non-compliance were observed.

2.7.5 Radiological Hazard Control

Each Department within RMC is responsible to the RadSO for control and enforcement of all radiation safety regulations within their area of responsibility. It is the responsibility of each individual to become familiar with these orders and to see that all specified safety precautions are followed by themselves and any personnel under their supervision. The RadSO will ensure that those authorized to use and/or store radioactive materials are aware of all internal licensing permit conditions.

Within the SLOWPOKE-2 Facility, two of the gamma probes in the Reactor Room are connected to the dispatcher at the military police building located at CFB Kingston. When the military dispatcher receives a radiation alarm, the Facility, usually the Director, must be notified immediately. When the dispatcher receives an intrusion alarm, the military patrol car is sent to the Facility immediately and, again, the Director will be contacted first.

An inventory of all radioactive holdings is performed annually. The RadSO performs regular leak tests on all sealed sources over 50 MBq. Other swipe tests are performed according to license and/or internal requirements.

Requests for acquiring radioactive materials to be stored and used at RMC must go through the RadSO. The RadSO will receive sources and supervise unpacking, perform contamination checks, retain copies of shipping documents, and adjust inventory records.

All storage, handling, and use of radioactive materials is in accordance with applicable license conditions and Radiation Safety protocol for the SLOWPOKE-2 Facility [57]. All sources and equipment containing sources shall be stored in areas approved by the RadSO and a permit will be issued allowing such storage.

Persons under the age of 18 years shall not have any duties or employment that could expose them to substantial ionising radiation. Pregnancy reduces the permitted maximum dose received level, and the exposure of a pregnant female is monitored more closely.

In order to monitor the personal dose received by an individual, those workers employed in a radiation area will wear passive, personal dosimeters as supplied by the RadSO. These will consist of optically stimulated luminescence (OSL) dosimeters for determining beta and gamma doses and if necessary, a CR39 neutron dosimeter. Both of these dosimeters are supplied and read by the National Dosimetry Services of Health Canada. During a potential exposure from a high radiation source, i.e., in the SLOWPOKE-2 Facility, an Electrical EPD is worn by all personnel for an immediate dose reading.

In the event of an accident involving radioactive material, the following measures will be taken:

a. The RadSO shall be contacted as soon as possible.
b. If sufficient contamination of the person is expected to have occurred, the person would be accepted at the Kingston General Hospital Emergency and treated. If possible, Emergency should be contacted by the RadSO to make hospital personnel aware that a person needs treatment for radiation contamination.
c. No one else shall enter or leave the area of suspected contamination without the authority of the RadSO, except to save lives.
d. Equipment shall not be removed from the area; and
e. Potentially exposed and/or contaminated personnel shall remain in the area but away from contamination until monitored and decontaminated if necessary.

When the RadSO arrives he/she will assume on-site control to see that the area is secured and to prevent the spread of radioactive contamination. The RadSO will determine the extent of the contamination. The RadSO will formulate and carry out a plan to decontaminate the area.

The RadSO will inform the CNSC as required in REGDOC-3.1.2 [29], investigate the causes of the incident, and forward reports to CNSC along with copies to the Command RadSO and the Commandant.

2.8 Conventional Health and Safety

2.8.1 General Considerations

The SLOWPOKE-2 Facility at RMC complies with REGDOC-2.8.1, Conventional Health and Safety [60] as well as with orders in the DND general safety program published in the DND General Safety Program-Policy and Program, Volumes 1, 2, & 3 [61]. In addition, RMC follows and conforms to the occupational health and safety rules and regulations stipulated by Part II of the Canada Labour Code [62] and to Canada's Occupational Health and Safety Regulations [63].

The Canadian Labour Code is an act of the Canadian Parliament, which applies to civilian employees in federally regulated workplaces and therefore to RMC.

The Vice Chief of the Defence Staff oversees general safety in DND through the Directorate of General Safety (D Safe G). D Safe G Orders and Directives, DAOD 2007-1 [61], state that each organization working for DND must establish:

a. A signed safety policy statement.
b. A safety organization and committee structure.
c. A continuing program of safety including Workplace Hazardous Management Information System (WHMIS) training.
d. A system of periodic safety inspections by qualified DND staff.
e. An awareness of the Canada Labour Code Part II.

2.8.2 Practices

The SLOWPOKE-2 Facility manages workplace safety hazards through programs applicable to all of RMC through DAOD 2007-0 [64], Safety, Defence Administrative Orders and Directives (DAOD) and also to programs developed at the CCE Department in which the SLOWPOKE-2 Facility is physically located.

RMC has a Unit General Safety and Environmental Officer (UGSEO) who, in part, sends out health and safety advisories to all of the community at RMC. These advisories are sent by email and posters are also put up in all the departments.

RMC has three health and safety sub-committees each of which is responsible to the RMC Safety Council. In particular, one sub-committee, the Academic Wing Workplace Health and Safety Committee (AWWHSC) performs periodic inspections of laboratories at RMC. Those inspections could result in a findings report to which the SLOWPOKE-2 Facility would have to respond in writing.

Newcomers who will become part of CCE or who will work in CCE on a temporary basis must attend an education and training session on WHMIS, safety, and introduction to radiation safety, pass an exam on the content of the training, and identify safety stations near their workplace. Examples of safety stations are fire extinguishers, fire alarms, eye wash stations, showers, first aid kits and emergency spill kits. The signed and dated checklist must be returned to the CCE Technical Officer with whom the checklist remains for the duration of a person's time in CCE even if the person is officially from another department at RMC.

In addition, the CCE technologists perform health and safety inspection of each laboratory in CCE twice a year and produce a report, which is given to the CCE Technical Officer. If action items are identified, the CCE Technical Officer informs the applicable laboratory manager and, finally, verifies that the action item has been satisfactorily addressed.

Examples of health and safety maintenance in CCE are flushing of the eye wash stations every 3-6 months, flushing of safety showers every 12-18 months, and inspection of fire extinguishers monthly.

The licensee manages workplace safety hazards within the SLOWPOKE-2 Facility [53]:

a. The workplace is maintained in a safe, clean, and orderly manner.
b. Hazards are evaluated, and eliminated or controlled, and the consequences of exposure to personnel are minimized.
c. Hazardous conditions are identified and, where practicable, physical barriers are installed.
d. Hazardous materials are labeled.

The licensee controls all chemicals, laboratory chemicals, corrosive agents, and cleaning agents to ensure proper storage, handling and use. The SLOWPOKE-2 Facility has lockable, flammable, liquid storage cabinets for flammable samples and chemicals. These cabinets comply with the American National Fire Protection (NFPA) Code 30 [65] under the American Occupational Safety and Health Administration (OSHA) for ignitable liquids. Radioactive samples and standards are kept inside lockable cabinets whose perimeter is lined with lead bricks.

RMC and thus the Facility follow DND's DAOD 4003-1 Hazardous Materials Management [66].

Non-radioactive hazardous substances are stored in accordance with WHMIS regulations. The Technical Officer in the CCE Department is most familiar with these regulations. For shipping and transportation of hazardous substances, the Technical Officer for CCE hires an authorized company that handles shipping and transportation and waste disposal of non-radioactive hazardous material.

In its 37 years of operation no SLOWPOKE-2 worktime has ever been lost due to a workplace health hazard or safety mishap.

2.9 Environmental Protection

2.9.1 General Considerations

The Facility complies with REGDOC-2.9.1 [67] and with all federal, provincial and municipal regulations with respect to the environment. Because RMC is a lodger unit of CFB Kingston, RMC and the Facility also comply with the environmental program run by the environmental officer for CFB

Kingston [68-80]. RMC also follows the orders and directives in DAOD 4003-0, Environmental Protection and Stewardship [81] to:

a. Conform to DND/CF environmental policy requirements that are outlined in [81].
b. Conform to ADM(HR-Mil) and CFB Kingston policies.
c. Maintain the Facility's activities while minimizing impact on the environment.

New stainless-steel weld-sealed exhaust ducts were installed on both floors of the SLOWPOKE-2 Facility during renovation in 2012. RMC performed an ERA [43] based on radioactivity values measured in the past. Argon-41 in the out air from irradiation sites is exhausted daily to the roof of the building. Using the average reactor operating hours from the last several years, the experimental gamma spectroscopic results and the argon-41 external dose coefficient for cloud shine, a dose rate to a worker on the roof of the N-W staircase of Sawyer Building Mod 5 of 0.052 µSv/year was calculated. The release amount of argon-41 to the roof has not changed during the past ten years because the number of hours of use of the reactor has not changed substantially as indicated in the Annual Compliance Reports. Similarly using measured gamma spectroscopic data, as reported from the Annual Compliance Report and the external dose coefficient for cloud shine for xenon-133, the dose to a worker on the roof during a weekly head space purge is 9.30×10^{-4} µSv/year. Argon-41 and xenon-133 constitute the major gases purged weekly. As summarized in Table 3, these doses are totally negligible compared to the 1 mSv yearly allowed dose for the general public.

There are no radioactive liquid releases from the Facility. After the new fuel core was installed in September 2021, a sample of water from the reactor container was analyzed for gamma ray activity on a high purity germanium detector. The sample contained less than 0.3 Bq/L of argon-41 and 5.7 Bq/L of xenon-133. Traces of cobalt-60, sodium-24, barium-140, and strontium-91 were found. These results indicate that there are no defective welds on the fuel pins. A minute amount of uranium contaminants is present on the fuel as a result of the fuel fabrication process. A sample of pool water was also analyzed and no radioactivity above background level was detected. Results from liquid scintillation analysis of reactor container water for alpha was less than 10 Bq per litre and beta activity 28,000 Bq per litre. These results are typical for the past ten years of operation as documented in the Annual Compliance Reports to the CNSC.

Table 3. Radionuclide and Hazardous Substances Discharged from the Facility

Discharge Path	**Typical Radionuclide**
Release through exhaust fan from the operating irradiation controllers	Argon-41: Less than 0.052 µSv/year*
Weekly headspace purge to the roof of Sawyer Building Mod. 5	Xenon-133: Less than 9.30×10^{-4} µSv/year*

* Conservative dose rate assessed for a person working on the roof of the Sawyer Building Module 5 at RMC [43].

2.9.2 Effluent and Emissions Control

Each irradiation site and the head space purge is connected to HEPA filters, which stop any particulate material from being released to the environment during the travel of samples through irradiation system and during a head space purge. The most recent replacement of these filters occurred in 2019.

Before any gases are vented from the reactor container, the fission products (if any) are allowed to decay in the reactor headspace for a minimum of 48 hours over the weekend. The Facility uses numerous annually calibrated gamma probes and neutron detectors to take daily measurements. The gamma and neutron probe readouts are set internally to alarm at judicious activity levels. There have been no abnormal nor reportable events during the last 37 years of operation.

In situations when some of the deionised water from the reactor pool need to be discharged into the city sewer system, sample of the water is taken [82] and analyzed by gamma spectroscopy [83] and Liquid Scintillation Counting (LSC) [84] prior to discharge to ensure absence of radionuclides.

2.9.3 Environmental Management System

The environmental management system at RMC, which is followed by the SLOWPOKE-2 Facility consists of a “Commandant’s Environmental Policy Statement” [85] and the involvement of the RMC Safety and Environment Office which oversees an environmental program lead by the CFB Kingston Base Environmental Officer. RMC and CFB Kingston are also required to meet the requirements of the Canadian Armed Forces Environmental Management System (DAOD 4003-0) [81], which serves as policy guidance and references for the Base Standing Orders 16.00-16.12 [68-80].

2.9.4 Assessment and Monitoring

Assessment and Monitoring procedures are listed in [24]. The emissions monitoring system at the Facility consists of a headspace gas sample [86] withdrawn monthly and analyzed for the presence of radionuclides by gamma-spectroscopy [83]. The results are recorded and trended by the Director of the Facility and submitted to CNSC as part of the Annual Compliance Report.

During the Refuelling Project in 2021, CNL prepared an Environmental Effects Review [87] based on the physical works and activities that needed to be performed both at CNL and RMC. This review developed a Project-Environment Component Interaction Matrix, which includes atmospheric, hydrology, hydro geologic, aquatic, terrestrial, human health, socio-economic and waste impact. The environmental effects and their significance were assessed based on the mitigation measures (from reports such as the CNL Tooling and Shielding Plan [88]) and physical and procedural barriers established at RMC. The significance of the impact was determined to be negligible in all project phases and activities.

2.9.5 Protection of the Public

There are no radioactive liquid releases from the RMC facility. The Facility releases small quantities of Ar-41 and Ze-133 through weekly purges. Based on the average annual reactor operating hours over 2018, 2019, and 2020 (which is around 630 hours per year), the doses of Ar-41 and Xe-133 were calculated [43] for a worker standing beside the two, SLOWPOKE-2 exhaust fans, which are located at the top of the N-W staircase on the roof of Sawyer Building Module 5. The worst-case scenario defined by not including the dilution of vented gases through 10-foot stacks is stated here. The dose of Ar-41 to the worker would be 0.052 µSv for working beside the fans for 250 working days a year. Similarly, the decayed and then vented Xe-133 dose for the year (once every 52 weeks) is 9.30×10^{-4} µSv. The radioactivity from Ar-41 is by far the greatest contributor to the dose received. These doses represent less than 1/19,000 of the annual defined public dose of 1 $mSv.year^{-1}$, which is consistent with the typical doses associated with a SLOWPOKE-2 Facility. Also, argon and xenon are noble gases and are not alpha emitters, which means that their impact on the human body is minimal. A member of the public standing at the Sawyer's parking lot would receive almost zero of these doses based upon the dilution that would occur to the gases as the gases travelled from the roof of Sawyer Mod 5 to the ground beside Mod 5.

RMC implements an action level of a dose rate of 2.5 µSv/h anywhere outside the Facility such as in hallways, on the sidewalk outside the Reactor Room, and in labs which have a wall common to a SLOWPOKE-2 lab. The SLOWPOKE-2 Facility has measures in place to assure the protection of the public.

During the SLOWPOKE-2 reactor refuelling in 2021, when spent fuel was extracted from the reactor container and shipped to CNL the following measures were taken to reduce possible public exposure to radiation:

- defuelling took place in August before beginning of the academic year so that there were a limited number of cadets on the RMC grounds,
- defueling took place on the weekend so that there were a limited number of RMC employees on premises,
- area was cordoned off and monitored by MPs,
- all RMC employees and contractors were warned about parking, road and building access restrictions during the defueling activities.

Inside the Facility a member of the public would be given a EPD to wear [33]. If the EPD read over 4 µSv received during the time spent inside the Facility, the RadSO would investigate the cause of the action level dose received [52]. If the action level of 4 µSv recorded on the EPD were to occur for 250 working days, the total dose would reach 1 mSv, the public limit. It is highly unlikely that a member of the public would visit the Facility for the entire 250 working days.

No significant changes have occurred over the past 37 years because the 1985 Low Enriched Uranium (LEU) SLOWPOKE-2 fuel was clean, free from any leaky welds, and from measurable uranium contaminants. Similarly, the 2021 LEU fuel has demonstrated to be clean and meets the design requirements that there shall be no leak from the elements.

2.9.6 Environmental Risk Assessment

The Facility's Environmental Risk Assessment document [43] uses a graded approach allowed by REGDOC-2.9.1 [67] for Class 1 facilities as a guide to perform an Environmental Risk Assessment. This assessment approach is in Figure 7. Olive green indicates the possible outcomes from the screening process. Using the actual measured date and a conservative approach, this ERA confirms that SLOWPOKE has minimal environmental impact.

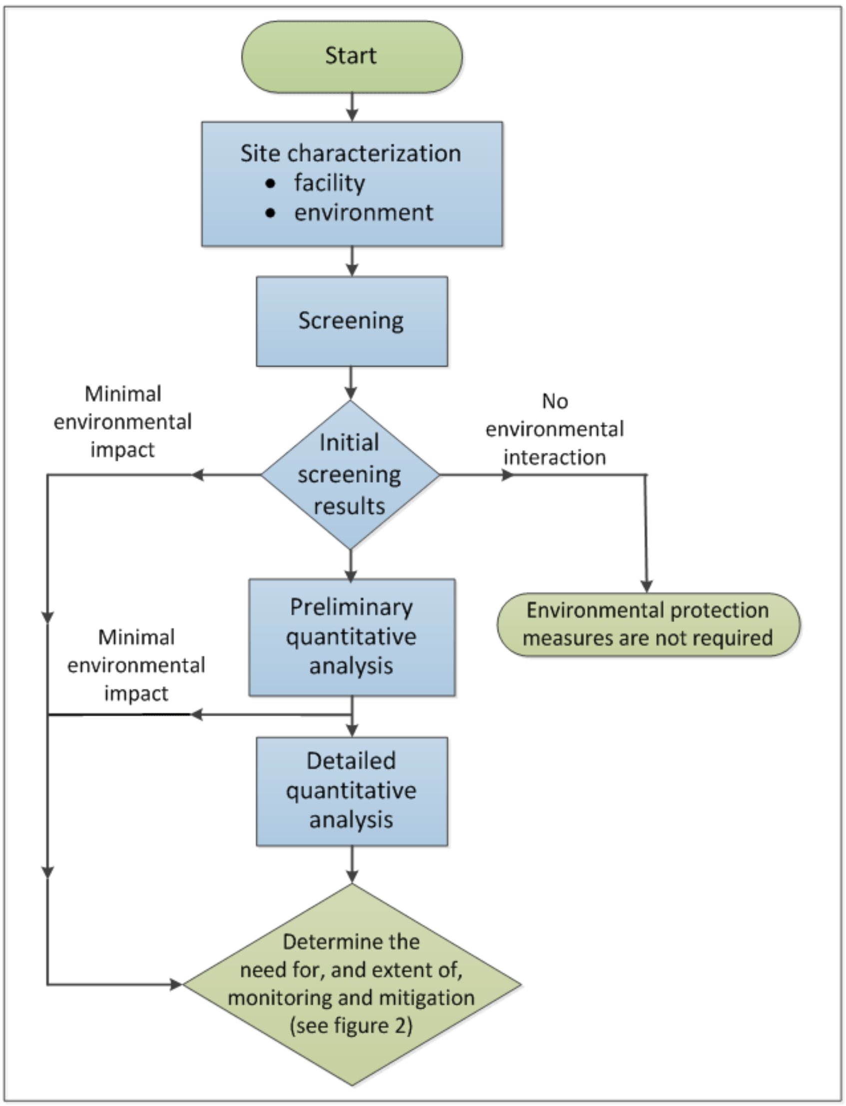


Figure 7. Tiered options for environmental risk assessments from REGDOC-2.9.1 (simplified from CSA N288.6).

2.10 Emergency Management and Fire Protection

2.10.1 General Considerations

The SLOWPOKE-2 Facility at RMC complies with the requirements of REGDOC 2.10.1 "Nuclear Emergency Preparedness and Response" [89] through the Emergency Procedures listed in the Facility Reactor Manual [23] and RMC's College Standing Orders (CSO) 2100-2 "Responding to Emergencies" [90], Fire Protection Program [37], and emergency exercises conducted by RMC.

A satellite image, Figure 2, showing the position of Sawyer Mod 5 to other buildings on the RMC Campus demonstrates that an emergency occurring at the reactor facility would be confined to Sawyer Science and Engineering Building Module 5. Sawyer Building Module 5 is the furthest building away from the majority of the other buildings on Campus. The building would be evacuated in the event of an emergency.

2.10.2 Nuclear Emergency and Conventional Emergency Preparedness and Response

RMC has an onsite emergency plan [90] in its Emergency Standard Procedures, which address the response groups with respect to the clear allocation of responsibilities, authorities, and arrangements for coordinating site activities and external response organizations throughout all phases of an emergency.

This site emergency plan provides:

a. Prompt recognition and classification of emergencies.
b. Timely notification and alerting of response personnel.
c. Safe emergency work practices that will be followed to support the safety of all persons and emergency workers.
d. Monitoring radioactive releases.
e. Information pertaining to the treatment and first aid of a limited number of contaminated and overexposed personnel/ persons on site.
f. Facility management and urgent mitigating repairs, control and other actions that are carried out at the Facility.

The Emergency Standard Procedures are explained in the Reactor Manual with the responses expected from the Commissionaires at RMC, the City of Kingston firefighters, CFB Kingston Military Police, and SLOWPOKE-2 reactor Licenced Operators under the two main headings of non-nuclear emergency and nuclear emergency.

As a result of a CNSC security inspection in October 2019, the Facility initiated a comprehensive and successful table-top exercise for response to security issues, including response to all non-routine conditions at the Facility. The persons and groups participating in the exercise and consequently updating their own emergency response procedures, which involve the SLOWPOKE-2 Facility itself, are the MP's Security Advisor to the Commandant, the Military Police training section, the City of Kingston firefighters training section, the J33 Operations Officer at RMC and J32 Security at RMC. These groups could not run a realtime physical exercise during the restrictions put in place to inhibit the spread of the COVID-19 virus. However, extensive communication between the participating groups familiarized everyone with the Facility and resulted in the alignment of interdepartmental Standard Operating Procedures (SOPs) between the CFB Kingston Military Police (MP), the City of Kingston Fire Department, and the SLOWPOKE-2 Facility.

An "After Action Report of the Incident Response Exercise for the SLOWPOKE-2 Facility at RMC" [91] was prepared and approved by the RMC Commandant in 2021. CNSC staff was informed of the successful completion of the virtual table-top exercise on the response of organizations to emergency situations arising at the Facility.

Another multi-jurisdictional emergency services training exercise called "Exercise WATCHDOG RESPONSE" was conducted, partly in Sawyer Mod 5 and involving the SLOWPOKE-2 Reactor, on October 2021. Those organizations participating in this exercise were the following: the 2 Military Police Regiment Detachment Kingston in conjunction with the Base Auxiliary Security Force (BASF), Her Majesty's Canadian Ship (HMCS) Cataraqui, the Royal Canadian Mounted Police's Marine Unit, Kingston Police Force, and Kingston Fire and Rescue.

2.10.3 Fire Emergency Preparedness and Response

The purpose of the Fire Protection Program (FPP) [37] is to reduce both the probability of occurrence and the consequences of fire at the SLOWPOKE-2 Facility.

The FPP explains the maintaining, implementation and control of activities related to fire safety, which are conducted by various departments (such as CCE within RMC and the CFB Kingston Base Fire Prevention Chief) with the following objectives:

1. Ensure that fires do not significantly increase the risk of radiological release to public.
2. Protect SLOWPOKE-2 personnel from the hazards of fires in accordance with RMC Fire Orders.
3. Minimize interruption of SLOWPOKE-2 operation due to fire.

Section 3 "Standards and Procedures" of the RMC FPP identifies procedures, processes and technical documents that define the SLOWPOKE-2 FPP. The FPP implemented for the SLOWPOKE-2 has ensured that personnel and equipment are protected from fire through the following good practices:

1. Control of sources of ignition.
2. Control of flammable and combustible material.
3. Mitigation of the consequences of fire through detection, suppression and response.
4. Conducting fire drills.
5. Maintaining the safety basis of the reactor.

Practices are based on widely recognized documents, such as but not limited to the following:

1. 2015 National Building Code of Canada [92].
2. 2015 National Fire Code of Canada [93].

3. NFPA 801 Annex B Standards for Fire Protection for Facilities Handling Radioactive Materials [94].

2.11 Waste Management

2.11.1 General Considerations

RMC maintains a waste management program that minimizes the generation of radioactive waste and is compliant with the requirements of REGDOC-2.11 "Framework for Radioactive Waste Management and Decommissioning in Canada" [95] and REGDOC-2.11.1, Waste Management, Volume I: Management of Radioactive Waste [96] The Radiation Safety Manual [31] sections 13, 14 and 15 contain the relevant information about RMC's waste management program.

All waste that is generated shall be appropriately handled and disposed to minimize the risk to staff, members of the public, and the environment up to the point when the waste is removed from the Facility. The RMC Radiation Safety Officer has the authority and responsibility for the management of the radioactive waste program. The 99% of radioactive material that the SLOWPOKE-2 Facility produces, and stores consists of low- and intermediate-level radioactive waste. The Radiation Safety Manual for RMC states that "all samples irradiated by Neutron Activation and their holding containers are considered to be radioactive". More than 80% of these samples are irradiated for fewer than 15 minutes [97] resulting in the presence of radioisotopes with half-lives of 11 seconds to 35 hours. Thus, these irradiated samples, after a period of delay-and-decay and gamma and beta survey taken before disposal, are treated as non-radioactive waste and can be treated as hazardous or non-hazardous depending on their chemical nature. Samples that are irradiated for periods of up to several hours will typically generate isotopes with longer half lives.

The only high-level radioactive waste in the Facility was from the 1985 LEU fuel charge, which was removed from the reactor container by CNL in August 2021 and sent to Chalk River for examination and storage. CNL is a licensed nuclear waste management facility for interim storage. As part of the RMC SLOWPOKE-2 Refuelling Project, CNL satisfied the requirements for approved external Waste Generators that produce waste to be shipped to CNL operating sites for processing/storage.

2.11.2 Waste Characterization

Each researcher, technician or other person producing radioactive material is responsible for its complete characterization before handing the material over to the RadSO. The more information forthcoming about the nature of the irradiated samples, the easier it is for the RadSO to characterize the waste and make an intelligent decision about how that waste should be handled for disposal (see section 14 in the Radiation Safety Manual [31]).

The RadSO must be informed if radioactive samples for storage and eventual disposal contain any hazardous chemicals or biological agents. (See section 15 in the Radiation Safety Manual).

2.11.3 Waste Minimization

It is the policy of the Facility to irradiate a minimum amount of sample for a minimum amount of time such that the information required from the irradiation is attained.

The Facility generates approximately $0.25m^3$ of neutron activated waste per annum. More than 80% of all generated radioactive waste decays to the background level within several months and can be safely disposed of as non-radioactive waste. Waste containing radioisotopes with long half-life is kept securely on site in the shielded containers until a suitable volume justifies disposal to the certified waste managing facility. The original 1985 LEU spent core was transported to Chalk River immediately after it was removed from the reactor container.

2.11.4 Waste Management Practices

The waste management practices followed by the Facility are explained in the Radiation Safety Manual [31].

The Facility and the RadSO are committed to protecting the health and safety of every worker in the Facility and to protecting co-workers who may need to occupy a lab in which there are radioactive samples and waste stored. Radiation fields are measured in public hallways, in labs adjacent to SLOWPOKE-2 rooms, and directly outside the Facility to make sure that the fields are consistent with the radioactive limits for public spaces.

2.11.5 Decommissioning Plans

In accordance with REGDOC-2.11.2, Decommissioning [98], the Facility has a comprehensive Preliminary Decommissioning Plan (PDP) [99] issued in 2022, which outlines in detail the radiological and non-radiological hazards associated with decommissioning the SLOWPOKE-2 Facility at RMC. The PDP was extensively updated using a cost estimate provided by CNL. This PDP will serve as a reference when a detailed decommissioning plan is required. The PDP has also included information associated with the decommissioning of the SLOWPOKE-2 Facility at the Saskatchewan Research Council in Saskatoon.

2.12 Security

2.12.1 General Considerations

The Facility benefits from the enhanced security that results from the Facility's location at RMC, and RMC being a lodger unit of CFB Kingston. RMC maintains a security program to control access to the SLOWPOKE-2 Reactor and to nuclear substances and to prescribe information. SLOWPOKE is compliant with REGDOCs 2.12.2 [100] and 2.12.3 [101].

Two main documents describe security measurements at the SLOWPOKE-2 Facility at RMC: Security Directives for the Facility [102] and a Site Security Plan [103]. Calian employees who work for/at SLOWPOKE-2 have a reliability clearance, as a minimum. Their security classification is valid when they are on-site at the Facility at RMC. The security clearance processes have recently changed at RMC. All upcoming SLOWPOKE contracts for civilian employees must have their fingerprints taken at the Kingston Police Centre.

The CNSC has proposed amendments to their Nuclear Security Regulations, which will impact Class 1A nuclear facilities administratively and financially. The SLOWPOKE-2 Facility is a Class 1 Facility. For the CNSC to estimate the financial impact of the proposed amendments, responses from the SLOWPOKE-2 Facility staff were submitted on schedule as per a CNSC request in 2021.

2.12.2 Response Arrangements

The Facility has an on-site response protocol, which begins with the Dispatcher for the CFB Kingston Military Police receiving an alarm and the subsequent arrival of MPs at the Facility as the physical deterrence and investigative personnel. The Director of the Facility and the RadSO for RMC annually offer a tour of the Facility to the MPs as well as a display and discussion of radioactive detector devices which are available at the Facility. The most recent tours took place in November 2021.

2.12.3 Security Practices

The Facility has a small amount of one Category III source, which according to Table 2: Security Levels and Security Objectives, REGDOC-2.12.3 [101] is a medium risk source based on the sources' radioactivity, which is 222 GBq. This source is protected by physical security and administrative measures in place at the Facility.

The Facility satisfies each one of the security and administrative measures listed in REGDOC-2.12.3 Part A, sections 3.2 and 3.3.

Further information about security of radioactive sources can be found in the 2021 Radiation Safety Manual [31], Section 9, Access Control and Security for Nuclear Sources and Radiation Devices.

2.12.4 Security Training and Qualification

RMC commissionaires monitor security cameras 24/7, which are inside and outside the Facility. They also visit and take note on the status of the Facility during non-working hours. Commissionaires are trained Non -Commissioned Members retired from the military. They are supervised by the RMC's Security Office.

The Facility has a very limited number of personnel with access to sensitive material held inside the Facility. These persons are given a code and keys to allow them to work inside the Facility rooms. The Director practices strict code and key control. It is only the Director who has the key to access to a secured safe within the Facility.

CNSC conducted a Type II security inspection in 2019. All recommendations made by the CNSC staff were implemented and the completed results communicated to CNSC staff in 2021.

2.12.5 Cyber Security

Because the computer program, SIRCIS, which "operates" the reactor is on a computer that is not connected to the internet, the Facility is protected from unauthorized operation by hacking of the reactor. As for data and other information stored on the computers belonging to the Manager and the Director, the Facility complies with the cyber security program devised and controlled by Shared Services Canada, a department in the federal government. The ransomware attack at RMC in 2019 has presented no security threat to the SLOWPOKE-2 reactor.

However, RMC office computers and computers in research labs had their hard drives removed, computers reconfigured, and strict new measures were put in place by RMC Computing Services and Shared Services Canada. For example, no memory sticks nor external hard drives can be plugged into computers at RMC now and all software to be installed on RMC computers shall to be approved by the Computer Information Services Department. Recovery from the ransomware attack at RMC is still in progress.

2.13 Safeguards and Non-Proliferation

2.13.1 General Considerations

The SLOWPOKE-2 Facility at RMC complies with the responsibilities for safeguards and non-proliferation of nuclear material according to Canada's agreement to comply with the international nuclear non-proliferation treaty, INFCIRC/164 [104].

The SLOWPOKE-2 safeguards program and procedures are prescribed information, subject to the requirements of the Nuclear Safety and Control Regulations.

RMC complies with the obligations from the Canada/IAEA safeguards agreements and all other measures arising from the Treaty. The SLOWPOKE-2 Facility at RMC complies with REGDOC 2.13.1 "Safeguards and Nuclear Materials Accountancy" [105] through the annual Physical Inventory Taking (PIT) as well as through the periodic Physical Inventory Verification (PIV) performed by IAEA inspectors. The most recent PIV took place on 1st of November 2019 and concluded that "all declared nuclear material has been accounted for and that there were no indications of the undeclared presence, production or processing of nuclear material" [106].

2.13.2 Nuclear Accountancy and Control

The Facilities' responsibilities for nuclear accountancy and control are in the form of communicating to the CNSC:

i) changes in an account of nuclear materials' holdings,
ii) the results of an annual Physical Inventory Taking,
iii) providing full access to the IAEA inspectors to perform Physical Inventory Verification, and
iv) keeping updated a Design Information Questionnaire [107], which is ultimately for the IAEA.

2.13.3 Access and Assistance to the IAEA

Each year either the Manager or the Director of the SLOWPOKE-2 Facility at RMC update as necessary a CNSC/IAEA document called the "Additional Protocol", which is related to complying to Canada's agreement to disclose all nuclear related activities, including research and development, to the CNSC. Through the CNSC, IAEA inspectors have visited and confirmed the physical inventory of fissile material at RMC on several occasions. Since 2013, no action has been raised.

2.13.4 Operational and Design Information

The Director of the Facility is responsible for keeping the inventory of safeguards material and the Design Information Questionnaire [107] up-to-date and available in response to a request from the CNSC. Except for the new LEU fuel inserted in September 2021, there have been minor inventory and no design changes at the Facility.

2.13.5 Safeguards Equipment, Containment and Surveillance

All of the regular, daily resources of the Facility are available for the inspectors from the CNSC and IAEA. Facility personnel are informed if new, sensitive equipment and/or material arrives at the Facility. They are reminded of the appropriate security precautions that must be followed.

The main source of the safeguarded material in the Facility is the SLOWPOKE-2 reactor fuel. It is safely secured under 6 meters of water in the reactor container with access sealed by CNL's Reactor Engineer. Any tampering of CNL seals is understood by Facility staff to be forbidden as are seals at the head of the reactor container and on the container with extra shims.

The rest of the safeguarded material is secured in the safe with combination known to the Facility Director and RMC RadSO only.

2.14 Packaging and Transport

2.14.1 General Considerations

The process of packaging and transporting radioactive material are conducted in accordance with safety standards and applicable regulations issued by Transport Canada and by the CNSC REGDOC-2.14.1 [108, 109]. The packaging and transport of radioactive material in the Facility complies with the regulatory programs through the Radiation Safety Manual [31], Transportation of Radioactive Material procedure [110], and SLOWPOKE-2 Facility Radiation Safety protocols [57].

The Radiation Safety Manual [31] contains sections on Packaging and Transport of Nuclear Substances and Radiation Devices, section 11, and gives an example of a shipper's declaration form, section 27.

RMC personnel that have the responsibility to conduct activities involving the packaging and transport of radioactive materials take a course that explains the applicable regulations in regulatory documents. In addition, these personnel have experience and knowledge in radiation safety and protection, handling of radioactive materials, use of radiation survey instrumentation as well as being certified in TDG Class 7 radioactive substances.

2.14.2 Package Design and Maintenance and Packaging and Transport

Every three years the RMC RadSO takes a refresher course from an authorized trainer for the transportation of dangerous goods, Class 7 radioactive material. The RadSO receives a certificate by successfully completing a test at the end of the course. This certificate is then signed by the RMC Vice Principal Research who is the employer.

This course includes detailed instruction on the type of containers that are suitable for transporting dangerous goods for Class 7 material. The course also explains the required labelling on the packages and how to measure the transportation index for the package.

2.14.3 Registration for Use

The RadSO is responsible for ensuring that all regulations are met before the package is allowed to be transported from inside the Facility to other departments at RMC and to destinations outside of the RMC Campus. For purposes of inspection and retaining historical knowledge, the Radiation Safety Manual [31] has a section 21 on the Retention of Records and Document List.

3.0 OTHER REGULATORY AREA

3.1 Public Information and Disclosure Program

The SLOWPOKE-2 Facility at RMC maintains the Public Information Program (PIP) and Disclosure Protocol [1] that meets the requirements of the REGDOC 3.2.1: Public Information and Disclosure [111].

The primary objective of the PIP is to communicate effectively the information relating to the health, safety and security of individuals and the environment and to explain Canada's international obligations with respect to the peaceful use of nuclear energy.

An important secondary objective that helps to build and sustain trust and confidence of local communities in nuclear power is to promote education with respect to the RMC SLOWPOKE-2 reactor and other nuclear facilities. In conjunction with communications planning and the public affairs office at RMC, education about radiation safety is promoted in the general Kingston community. One of the key elements here is the commitment to disclose information in a transparent, consistent and timely manner as described in the PIP [1].

Three major groups are targeted by the Public Information Program, namely:

- All military and civilian employees working at RMC,
- Kingston-based DND employees, and
- General public of the Kingston area.

Information about routine operations of the Facility as well as planned and unplanned events is disseminated within these groups via publications on the RMC SLOWPOKE-2 website (https://www.rmc-cmr.ca/en/chemistry-and-chemical-engineering/slowpoke-2-facility), local and social media, and scientific publications.

The SLOWPOKE-2 Facility at RMC regularly participates in the annual scientific family-oriented festival Science Rendezvous that popularize science for the general public.

The SLOWPOKE-2 Facility will continue to explore opportunities to enhance the public information program for target audiences.

The successful completion of the Refuelling Project, under the compliance oversight of CNSC staff, is an example of the transparency shown by the Facility to the public.

3.2 Indigenous Engagement

RMC is situated on the traditional lands of the Haudenosaunee, Anishinaabe and Huron-Wendat peoples. RMC acknowledges the significance of these lands to the Indigenous peoples and RMC expresses its gratitude to be able to live and learn here. The RMC Action Plan on Institutional Equity, Diversity, and Inclusion could be found from the RMC website [2]. Since the commissioning of SLOWPOKE-2 Facility at RMC in 1985, SLOWPOKE has not had any adverse effects on the land surrounding RMC and nor on the surrounding environment. RMC addresses the requirements stated in REGDOC-3.2.2 [112].

The Director General Indigenous Affairs (DGIA) within ADM(IE) is the DND/CAF lead on "Indigenous Engagement and the Duty to Consult". The website to obtain information, templates and tools, reference material and shared documentation on consultations on public engagement activities across the federal government is available for staff from an Intranet [113]. DGIA has posted guidelines for federal officials to fulfill the Duty to Consult, which was published by the Department of Aboriginal Affairs and Northern Development [114]. A Guide to Acknowledge Indigenous People and Traditional Territory was further distributed to all units within the CFB Kingston (including RMC) [115]. An Indigenous Policy Advisor from the Military Personnel Generation Group, National Defence (Government of Canada) is also available within RMC for consultation and communication.

RMC established a program for indigenous youth from across the country called Aboriginal Leadership Opportunity Year (ALOY). ALOY cadets are enrolled in the Canadian Armed Forces for an 11-month period. During that time, they participate in undergraduate programs at RMC, and they participate in many activities with the Officer Cadets. They achieve basic military qualification and other military training. They participate weekly in indigenous education led by an indigenous educator/elder. When students finish the program, they have many options from which to choose, such as the: Regular Officer Training Program at RMC or Non-Commissioned Member (NCM) in the regular force or Primary Reserve (officer or NCM). ALOY cadets may simply go back to their communities having learned more about their leadership abilities, their culture and education capabilities. These students also visit the SLOWPOKE-2 reactor at RMC, as part of their learning on nuclear and radiation safety. RMC has also established an Indigenous Knowledge and Learning Working Group (IKLWG). This group is a core advisory group of committed military and civilian professionals and students who share a common interest in advancing RMC's diversity and inclusion efforts.

Further Information on the ALOY program, IKLWG's mission and acknowledgements from the RMC Commandant and the Principal on indigenous knowledge and learning could be found on the RMC website [116].

3.3 Cost Recovery

In accordance with the Canadian Nuclear Safety Commission Cost Recovery Fees Regulations, RMC is exempt from any fees associated with the planned regulatory efforts.

3.4 Financial Guarantee

The SLOWPOKE-2 reactor located at RMC is the only federal reactor remaining in operation following the shutdown of the National Universal Reactor at Chalk River, Ontario.

The SLOWPOKE-2 Facility, being an integral part of the DND, is owned by DND and is therefore the property of the Crown. The Facility is administered and funded by DND, through the Minister of National Defence under the authority of the Parliament of Canada. The Commandant of RMC is ultimately responsible for its daily operation and maintenance. Costs associated with the future decommissioning of this Facility are addressed in the Preliminary Decommissioning Plan (PDP) [99] and calculated in accordance with REGDOC 3.3.1 [117]. These costs will be paid by DND.

The Deputy Minister of National Defence has reaffirmed the commitment to provide a financial guarantee for the decommissioning of the SLOWPOKE-2 nuclear reactor (See Appendix D). The PDP for the SLOWPOKE-2 Facility [99] was updated in 2022.

4.0 CHANGE REQUESTED BY THE LICENSEE

RMC is requesting a licensing change under Appendix A "Operating Limits", Clause 2 of NPROL-20.00/2023 be changed from "The Licensee shall ensure that the maximum excess reactivity of the reactor does not exceed 4.0 mk."

to "The Licensee shall ensure that the maximum excess reactivity of the reactor does not exceed 4.3 mk.

Appendix C of this submission contains an assessment that supports this licensing change requested by RMC. The impetus for this request is to:

- maintain the useful life of the reactor for 30+ years as per the current design after a successful refuelling with an empty shim tray in September 2021.
- mitigate the burden/dependence on reactor shimming in the future with a slightly higher excess reactivity for the reactor; and
- further enhance worker and radiation safety during shimming (by perhaps decreasing the frequency of maneuvering shim plates to reach the target limit).

Appendix C was originated for the refuelling project. The impact assessment and the safety demonstrated for the 4.3 mk LEU core remain the same for reactor shimming.

The approval of this licensing change will facilitate reactor shimming be achieved slightly above the administrative maximum excess reactivity of 4.0 mk to approximately 4.3 mk. This change is mainly to avoid unnecessary handling of hot shims by SLOWPOKE maintainers as per ALARA. Shimming of the SLOWPOKE-2 Facility using beryllium is required approximately once every 5 years under normal operating conditions.

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GLOSSARY

ADM (IE)	Assistant Deputy Minister (Infrastructure & Environment)
AECL	Atomic Energy of Canada Limited
ALARA	As Low As Reasonably Achievable
ALI	Annual Limit on Intake
ALOY	Aboriginal Leadership Opportunity Year
AWWHSC	Academic Wing Workplace Health and Safety Committee
CALA	Canadian Association for Laboratory Accreditation
CANDU	Canada Deuterium Uranium (reactor)
CCE	Chemistry and Chemical Engineering Department
CF	Canadian Forces
CFB	Canadian Forces Base
CE	Construction Engineering
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
COG	CANDU Owners Group
COVID	Coronavirus Disease
CRTI	Canadian Research and Technology Initiative
CSO	College Standing Orders
CSS	Centre for Security and Science
DAOD	Defence Administrative Orders and Directives
DGIA	Director General Indigenous Affairs
DGNS	Director General of Nuclear Safety
DND	Department of National Defence
EPD	Electrical Personal Dosimeter

ERA	Environmental Risk Assessment
ESAFE	Electrical Safety Authority Field Evaluation
FPP	Fire Protection Program
GUI	Graphical User Interface
HEPA	High-Efficiency Particulate Air
IAEA	International Atomic Energy Agency
IKLWG	Indigenous Knowledge and Learning Working Group
LEU	Low-Enriched Uranium
LSC	Liquid Scintillation Counting
MP	Military Police
MPD	Maximum Permissible Dose
NATO	North Atlantic Treaty Organization
NBT	Neutron Beam Tube
NCM	Non-Commissioned Member
NEW	Nuclear Energy Worker
NFPA	National Fire Protection
NSCA	Nuclear Safety and Control Act
NSRD	Nuclear Substances and Radiation Devices
OSHA	American Occupational Safety and Health Administration
OSL	Optically Stimulated Luminescence
PAD	Personal Alarming Device
PDP	Preliminary Decommissioning Plan
PE	Polyethylene
PIP	Public Information Program
PIT	Physical Inventory Taking

PIV	Physical Inventory Verification
QA	Quality Assurance
RadSO	Radiation Safety Officer
RCAF	Royal Canadian Air Force
RE	Reactor Engineer
REGDOC	Regulatory Document (CNSC)
RMC	Royal Military College of Canada
RO	Reactor Operator
RT	Reactor Technician
SAT	Systematic Approach to Training
SCA	Safety and Controls Area
SIRCIS	SLOWPOKE-2 Integrated Reactor Control & Instrumentation System
SLOWPOKE	Safe Low-Power Critical Experiment
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SPOC	Single Point of Contact
SSC	System, Structure, and Component
TDG	Transportation of Dangerous Goods
TLD	Thermoluminescent Dosimeter
UGSEO	Unit General Safety and Environmental Officer
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPS	Uninterruptible Power Supply
WHMIS	Workplace Hazardous Management Information System

APPENDIX A

CLAUSES IN THE NSCA AND THE REGULATIONS MADE UNDER THE NSCA, MAPPED TO THE RELEVANT SECTIONS OF THIS OPERATION LICENCE APPLICATION

Legislation	Clause(s)	Section(s) in this document
NSCA	24(4)	Every SCA (sections 2.1 through 2.14) 3.0 Other regulatory areas
	26(a), (e)	Every SCA (sections 2.1 through 2.14) 3.0 Other regulatory areas
General Nuclear Safety and Control Regulations (GNSCR)	3(1)(a)	1.2 Identification and Contact Information
	3(1)(b)	1.3 Facility and Activities to be Licensed
	3(1)(c)	2.4 Safety Analysis 2.9 Environmental protection 2.11 Waste management
	3(1)(d)	1.3 Facility and Activities to be Licensed 2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service 2.10 Emergency management and fire protection 2.11 Waste management 2.12 Security
	3(1)(e)	2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection 2.9 Environmental protection 2.11 Waste management 2.12 Security 2.14 Packaging and transport
	3(1)(f)	2.7 Radiation protection
	3(1)(g)	2.5 Physical design 2.12 Security 2.13 Safeguards and non-proliferation
	3(1)(h)	2.5 Physical design 2.12 Security 2.13 Safeguards and non-proliferation

Legislation	Clause(s)	Section(s) in this document
	3(1)(i)	2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection 2.9 Environmental protection 2.10 Emergency management and fire protection (all requirements related to fire) 2.11 Waste management 2.12 Security
	3(1)(j)	2.5 Physical design 2.6 Fitness for service 2.11 Waste management
	3(1)(k)	1.2 Identification and Contact Information 2.1 Management system 2.2 Human performance 2.3 Operating performance
	3(1)(l)	3.0 Other regulatory areas
	3(1)(m)	3.0 Other regulatory areas
	3(2)	2.13 Safeguards and non-proliferation
	10(b)	2.13 Safeguards and non-proliferation
	12(1)(a)	2.1, Management system 2.2 Human performance management 2.7 Radiation protection 2.10 Emergency management and fire protection
	12(1)(b)	2.2 Human performance management 2.7 Radiation protection 2.10 Emergency management and fire protection
	12(1)(c)	2.3 Operating performance 2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection 2.8 Conventional health and safety 2.9 Environmental protection 2.10 Emergency management and fire protection 2.11 Waste management 2.12 Security

Legislation	Clause(s)	Section(s) in this document
	12(1)(d)	2.7 Radiation protection 2.10 Emergency management and fire protection
	12(1)(e)	2.2 Human performance management 2.3 Operating performance 2.7 Radiation protection 2.10 Emergency management and fire protection
	12(1)(f)	2.3 Operating performance 2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection 2.9 Environmental protection 2.10 Emergency management and fire protection
	12(1)(g)	2.10 Emergency management and fire protection 2.12 Security
	12(1)(h)	2.10 Emergency management and fire protection 2.12 Security
	12(1)(i)	2.13 Safeguards and non-proliferation
	12(1)(j)	2.2 Human performance management 2.12 Security
	15	1.2 Identification and Contact Information 2.1 Management system
	15(a)	1.2 Identification and Contact Information 2.1 Management system
	15(b)	1.2 Identification and Contact Information 2.1 Management system
	17(a)	2.2 Human performance management 2.3 Operating performance 2.7 Radiation protection 2.8 Conventional health and safety 2.9 Environmental protection
	17(b)	2.2 Human performance management 2.3 Operating performance 2.7 Radiation protection 2.8 Conventional health and safety 2.9 Environmental protection

Legislation	Clause(s)	Section(s) in this document
	17(c)	2.1 Management system 2.2 Human performance management 2.3 Operating performance 2.7 Radiation protection 2.8 Conventional health and safety 2.9 Environmental protection 2.12 Security
	17(d)	2.2 Human performance management 2.3 Operating performance 2.7 Radiation protection 2.8 Conventional health and safety
	17(e)	2.1 Management system 2.2 Human performance management 2.3 Operating performance 2.7 Radiation protection 2.8 Conventional health and safety 2.9 Environmental protection 2.12 Security
	20(a)	2.14 Packaging and transport
	20(d)	2.13 Safeguards and non-proliferation
	21	2.12 Security
	21(1)(a)	2.13 Safeguards and non-proliferation
	21(1)(b)	2.13 Safeguards and non-proliferation
	22	2.12 Security
	23	2.12 Security
	23(2)	2.13 Safeguards and non-proliferation
	27	2.1 Management system
	28	2.1 Management system
	28(1)	2.12 Security
	29	2.3 Operational performance 2.7 Radiation protection 2.12 Security 2.3.4 Reporting and Trending
	30	2.3 Operating performance 2.12 Security 2.3.4 Reporting and Trending
	31	2.3 Operating performance 2.3.4 Reporting and Trending

Legislation	Clause(s)	Section(s) in this document
	32	2.3 Operating performance 2.3.4 Reporting and Trending
Canadian Nuclear Safety Commission Cost Recovery Fees Regulations	all	3.3 Cost recovery 3.4 Financial guarantee
Class I Nuclear Facilities Regulations	3(a)	2.5 Physical design 2.10 Emergency management and fire protection 2.12 Security
	3(b)	2.4 Safety analysis 2.5 Physical design 2.12 Security
	3(c)	1.1 Background
	3(d)	2.1 Management system 2.4 Safety analysis 2.5 Physical design
	3(e)	2.4 Safety Analysis 2.8 Conventional health and safety 2.9 Environmental protection 2.11 Waste management
	3(f)	2.1 Management system 2.2 Human performance management 2.6 Fitness for service 2.8 Conventional health and safety 2.10 Emergency management and fire protection 2.11 Waste management
	3(g)	2.9 Environmental protection
	3(h)	2.8 Conventional health and safety 2.9 Environmental protection
	3(i)	2.5 Physical design 2.12 Security
	3(j)	3.0 Other regulatory areas
	3(k)	2.11 Waste management

Legislation	Clause(s)	Section(s) in this document
	6(a)	2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service
	6(b)	2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service
	6(c)	2.4 Safety analysis
	6(d)	2.1 Management system 2.3 Operating performance 2.6 Fitness for service
	6(e)	2.1 Management system 2.3 Operating performance 2.7 Radiation protection 2.8 Conventional health and safety 2.11 Waste management 2.14 Packaging and transport
	6(f)	2.13 Safeguards and non-proliferation
	6(g)	2.1 Management system 2.3 Operating performance 2.5 Physical design
	6(h)	2.1 Management system 2.2 Human performance 2.3 Operating performance 2.4 Safety analysis 2.5 Physical design 2.7 Radiation protection 2.8 Conventional health and safety 2.9 Environmental protection 2.10 Emergency management and fire protection 2.11 Waste management 2.12 Security 2.14 Packaging and transport
	6(i)	2.4 Safety analysis 2.5 Physical design 2.7 Radiation protection 2.9 Environmental protection 2.11 Waste management

Legislation	Clause(s)	Section(s) in this document
	6(j)	2.4 Safety analysis 2.5 Physical design 2.9 Environmental protection 2.11 Waste management
	6(k)	2.1 Management system 2.2 Human performance management 2.3 Operating performance 2.4 Safety analysis 2.5 Physical design 2.7 Radiation protection 2.9 Environmental protection 2.10 Emergency management and fire protection 2.12 Security
	6(l)	2.1 Management system 2.2 Human performance management 2.12 Security
	6(m)	2.1 Management system 2.2 Human performance management 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection
	6(n)	2.1 Management system 2.2 Human performance management 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection
	14(1)	2.1 Management system 2.9 Environmental protection 2.11 Waste management
	14(2)	2.1 Management system 2.2 Human performance management 2.3 Operating performance 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection 2.9 Environmental protection 2.11 Waste management
	14(4)	2.1 Management system

Legislation	Clause(s)	Section(s) in this document
	14(5)	2.1 Management system 2.2 Human performance management
Nuclear Non-proliferation Import and Export Control Regulations	all	2.13 Safeguards and non-proliferation
Nuclear Security Regulations	all	2.5 Physical design 2.12 Security
	3(b)	2.5.3 Site Characterization
	16	2.5.3 Site Characterization
	37(1), (2) and (3)	2.1 Management system
	38	2.1 Management system 2.2 Human performance management
Nuclear Substances and Radiation Devices Regulations	5	2.7 Radiation protection
	8	2.7 Radiation protection
	20	2.7 Radiation protection
	23	2.7 Radiation protection
	36(1)(a)	2.1 Management system 2.12 Security
	36(1)(b)	2.1 Management system
	36(1)(c)	2.1 Management system
	36(1)(d)	2.1 Management system 2.12 Security
	36(1)(e)	2.1 Management system
Packaging and Transport of Nuclear Substances Regulations, 2015	all	2.14 Packaging and transport

Legislation	Clause(s)	Section(s) in this document
Radiation Protection Regulations	1(3)	2.3 Operating performance 2.4 Safety analysis 2.5 Physical design 2.6 Fitness for service 2.7 Radiation protection 2.9 Environmental protection 2.11 Waste management
	4	2.4 Safety analysis 2.6 Fitness for service 2.7 Radiation protection 2.9 Environmental protection 2.11 Waste management
	5-12	2.7 Radiation protection
	13	2.3 Operating performance 2.4 Safety analysis 2.6 Fitness for service 2.7 Radiation protection 2.11 Waste management
	14	2.3 Operating performance 2.4 Safety analysis 2.6 Fitness for service 2.7 Radiation protection 2.11 Waste management
	15	2.3 Operating performance 2.4 Safety analysis 2.6 Fitness for service 2.7 Radiation protection 2.11 Waste management
	16	2.7 Radiation protection
	20	2.7 Radiation protection 2.11 Waste management
	21-23	2.7 Radiation protection 2.11 Waste management

APPENDIX B

STANDARDS AND RMC REFERENCES RELEVANT TO SAFETY CONTROL AREAS

Safety Control Areas	REGDOC or Other	RMC Supporting Document
Management System	REGDOC 2.1.1: Management System REGDOC 2.1.2: Safety Culture	1. ADM-3: The Management System for the SLOWPOKE-2 Facility at RMC, 2022 2. ADM-2: SLOWPOKE-2 Facility Document Management System, 2017 3. QAP-1: The Quality Assurance Manual, 2022 4. RMC Action Plan on Institutional Equity, Diversity, and Inclusion, at www.rmc-cmr.ca 5. QAP-5: Change Control Procedure, 2017 6. The Reactor Manual for the SLOWPOKE-2 Facility at RMC, 2022 7. Licence Condition Handbook, Rev. 1, 2019 8. QAP-6: SLOWPOKE-2 Issues and Maintenance Database, V.2, 2017.
Human Performance Management	REGDOC 2.2.2: Personnel Training REGDOC 2.2.3: Personnel Certification: Radiation Safety Officer REGDOC 2.2.4: Fitness for Duty: Managing Worker Fatigue REGDOC 2.2.4: Fitness for Duty: Managing Alcohol and Drug Use REGDOC 2.2.5: Minimum Staff Complement	1. The Reactor Manual for the SLOWPOKE-2 Facility at RMC, 2022. 2. OPN-M-2: Procedures' Manual for the SLOWPOKE-2 Facility at RMC, 2019. 3. The Users' Guide to the Neutron Radiology System, RMC 4. Training Program for the Reactor Operators, 2016. 5. QAP-1: The Quality Assurance Manual, SLOWPOKE-2 Facility at RMC, 2022. 6. DOAD 5016-0:Standards of Civilian Conduct and Discipline, 2018. 7. DOAD 5005-3: Employee Assistance Program, 2007.
Operating Performance	NPROL 20.00/2013 Appendix A "Operating Limits"	1. OPN-M-2: Weekly Reactor Maintenance Procedure, 2019 2. QAP-1: The Quality Assurance Manual, SLOWPOKE-2 Facility at RMC, 2022. 3. OPN: List of Procedures, SLOWPOKE-2 Facility at RMC, 2022. 4. The Radiation Safety Manual, 2021 5. SIRCIS Users' Manual, 2012 6. Legacy Document: SLOWPOKE-2 Nuclear Reactor Operation and Routine Maintenance, CPSR-362, Rev. 2, 1985

		7. SEP-4: Fire Protection Program for the RMC SLOWPOKE-2 Facility, 2022 8. The Reactor Manual for the SLOWPOKE-2 Facility at RMC, 2022. 9. QAP-5: Change Control Procedure, SLOWPOKE-2 Facility at RMC, 2017 10. SLOWPOKE-2 Visitor and Dosimeter Log, 2014 11. QAP-6: SLOWPOKE-2 Issues and Maintenance Database, V.2, 2017.
Safety Analysis	REGDOC 2.4.3.: Nuclear Criticality Safety REGDOC 2.4.1: Deterministic Safety Analysis	1. SEP-5: Safety Assessment and Operating Envelope for the SLOWPOKE-2 Reactor at RMC, 2022 2. Atomic Energy of Canada Commercial Products Report, CPR 26, AECL, 1983 3. The Reactor Manual for the SLOWPOKE-2 Facility at RMC, 2022. 4. QAP-1: The Quality Assurance Manual, SLOWPOKE-2 Facility at RMC, 2022. 5. Training Program for the Reactor Operators, 2016. 6. OPN-M-2: Weekly Reactor Maintenance Procedure, 2019. 7. OPN-18: Cadmium Capsule Auxiliary Shutdown, SLOWPOKE-2 Facility at RMC, 2022 8. OPN-20: Manual measurement of excess reactivity, SLOWPOKE-2 Facility at RMC, 2022 9. Impact Assessment of SIRCIS Upgrades on RMC SLOWPOKE-2 Facility, 2011 10. An Environmental Risk Assessment, SLOWPOKE-2 Facility at RMC, 2022 11. SEP-4: Fire Protection Program for the RMC SLOWPOKE-2 Facility, 2022 12. (Legacy Document) CPR77, Description and Safety Analysis for the SLOWPOKE-2 Reactor with LEU Fuel, AECL, 1985 13. (Legacy Document) CPR-26: Description and Safety Analysis for the SLOWPOKE-2 Reactor, AECL, 1983 14. Commissioning Manual for the Royal Military College of Canada SLOWPOKE-2 Reactor, SLWPK4-97000-CM-001, CNL, 2021
Physical Design	REGDOC 2.5.1: General Design Considerations: Human Factors	1. (Legacy Document) CPR-26: Description and Safety Analysis for the SLOWPOKE-2 Reactor, AECL, 1983 2. ADM-3: The Management System for the SLOWPOKE-2 Facility at RMC, ADM-3, 2022 3. The Reactor Manual for the SLOWPOKE-2 Facility at RMC, 2022 4. The Radiation Safety Manual, RMC, 2021 5. OPN-3: Initiating new projects, SLOWPOKE-2 Facility at RMC, 2022 6. OPN-8: Samples storage, SLOWPOKE-2 Facility at RMC, 2022

		7. OPN-9: Preliminary gamma-survey, SLOWPOKE-2 Facility at RMC, 2022 8. OPN-10: Working with open sources, SLOWPOKE-2 Facility at RMC, 2022 9. OPN-11: Reporting unusual daily doses or active samples to RadSO, SLOWPOKE-2 Facility at RMC, 2022 10. OPN-24: Using the Neutron Beam Tube, SLOWPOKE-2 Facility at RMC, 2022
Fitness for Services	REGDOC-2.6.3, Aging Management	1. OPN-1: Signing in and out of the Facility, SLOWPOKE-2 Facility at RMC, 2022. 2. OPN-M-2 Weekly Reactor Maintenance, 2019. 3. D. Younger-Lewis and G. Burbidge, SLOWPOKE-2 Nuclear Reactor Operation and Routine Maintenance, CPSR-362, Rev. 2, AECL, 1985. 4. QAP-6: SLOWPOKE-2 Issues and Maintenance Database, V.2, 2017. 5. The SLOWPOKE-2 Committee Meeting Summary for 2021, 2021.
Radiation Protection	REGDOC 2.7.1: Radiation Protection	1. The Radiation Safety Manual, RMC, 2021 2. SEP-1: Radiation Safety for the SLOWPOKE-2 Facility, 2019 3. Consolidated Licence, Nuclear Substance and Radiation Device Licence No. 13266-3-26.2 4. OPN-11: Reporting unusual daily doses or active samples to RadSO, SLOWPOKE-2 Facility at RMC, 2022 5. OPN: List of Procedures, SLOWPOKE-2 Facility at RMC, 2022.
Conventional Health and Safety	REGDOC 2.8.1: Conventional Health and Safety	1. DAOD 2007-1, General Safety Program, Defence Administrative Orders and Directives, 2017 2. Occupational Health and Safety, Canada Labour Code (R.S.C., 1985, c. L-2), 2017 3. Canada Occupational Health and Safety Regulations, SOR/86-304, 2021 4. DAOD 2007-0, Safety, Defence Administrative Orders and Directives, 2004 5. DAOD 4003-1 Hazardous Materials Management, Defence Administrative Orders and Directives, 2017 6. OPN-8: Samples storage, SLOWPOKE-2 Facility at RMC, 2022
Environmental Protection	REGDOC 2.9.1.: Environmental Protection	1. An Environmental Risk Assessment, SLOWPOKE-2 Facility at RMC, 2022 2. DAOD 4003-0, Environmental Protection and Stewardship, 2004 3. OPN-M-9: Acquiring Pool Water Sample, SLOWPOKE-2 Facility at RMC, 2022

		4. OPN-17: Gamma-Ray Spectroscopy using HPGe detector, SLOWPOKE-2 Facility at RMC, 2022 5. ASG069: Gross Alpha / Beta Radioactivity of Aqueous Samples by Liquid Scintillation Analysis, ASG at RMC, 2021 6. OPN-M-10: Acquiring Headspace Air Sample, SLOWPOKE-2 Facility at RMC, 2022 7. Environmental Effects Review, SLWPK4-509200- ENA, CNL, 2021 8. Design Plan: Tooling and Shielding Plan for Irradiated Fuel Removal, SLWPK4-123500-DP-001, CNL, 2021 9. Commandant's Environmental Policy Statement, 2021 10. OPN-11: Reporting unusual daily doses or active samples to RadSO, SLOWPOKE-2 Facility at RMC, 2022
Emergency Management and Fire Protection	REGDOC 2.10.1: Nuclear Emergency Preparedness and Response	1. The Reactor Manual for the SLOWPOKE-2 Facility at RMC, 2022 2. CSO2100-2: Your guide to Responding to Emergencies, RMC, 2018 3. (Confidential and internal) After Action Report of the Incident Response Exercise for the SLOWPOKE-2 Facility at RMC and Assessment Plan for The Incident Response Exercise, 2021 4. SEP-4: Fire Protection Program for the RMC SLOWPOKE-2 Facility, 2022
Waste Management	REGDOC 2.11: Framework for Radioactive Waste Management and Decommissioning in Canada, V.2 REGDOC-2.11.1, Waste Management, Volume I: Management of Radioactive Waste REGDOC-2.11.2, Decommissioning	1. The Radiation Safety Manual, RMC, 2021 2. ADM-5: Preliminary Decommissioning Plan, SLOWPOKE-2 Facility at RMC, 2022
Security	REGDOC 2.12.2: Site Access Security Clearance REGDOC 2.12.3: Security of Nuclear Substances: Sealed Sources and Category I, II, and III Nuclear Material, V. 2.1	1. (Confidential) SEP-3: SLOWPOKE-2 Facility RMC Site Security Plan, October 2019. 2. (Confidential) SEP-2: Security Directives for the SLOWPOKE-2 Facility, 2019 3. The Radiation Safety Manual, 2021
Safeguards and Non-Proliferation	REGDOC 2.13.1: Safeguards and Nuclear Materials Accountancy	1. (Confidential) Design Information Questionnaire, SLOWPOKE-2 Facility at RMC, 2022 2. Letter IAEA to CNSC: Statement of conclusions of inspection in accordance with Article 90(b) of the Safeguards Agreement (INFCIRC/164), 2020

		3. 2021 Annual Physical Inventory Taking documents
Packaging and Transport	REGDOC 2.14.1: Volume I, Information Incorporated by Reference in Canada's Packaging and Transport of Nuclear Substances Regulations REGDOC 2.14.1: Packaging and Transport, Volume II: Radiation Protection Program Design for the Transport of Nuclear Substances	1. The Radiation Safety Manual, RMC, 2021 2. OPN-7: Transportation of radioactive materials, SLOWPOKE-2 Facility at RMC, 2022 3. SEP-1: Radiation Safety for the SLOWPOKE-2 Facility, 2019
Reporting	REGDOC-3.1.2, Reporting Requirements, Volume I: Non-Power Reactor Class I Facilities and Uranium Mines and Mills	1. RMC Annual Compliance Report.
Public Information and Disclosure	REGDOC 3.2.1: Public Information and Disclosure	1. ADM-4: Public Information Program and Disclosure Protocol, SLOWPOKE-2 Facility at RMC, 2022
Indigenous Engagement	REGDOC 3.2.2: Indigenous Engagement	1. RMC Action Plan on Institutional Equity, Diversity, and Inclusion, www.rmc-cmr.ca/en/division-graduate-studies-and-research/royal-military-college-canada-action-plan-institutional, RMC, 2021. 2. Indigenous Affair, http://intranet.mil.ca/en/infrastructure-environment/aboriginal/issues.page, Defence Team Intranet, DND, 2021. 3. Aboriginal Consultation and Accommodation, https://www.rcaanc-cirnac.gc.ca/DAM/DAM-CIRNAC-RCAANC/DAM-CNSLTENGE/STAGING/texte-text/intgui_1100100014665_eng.pdf, Department of Aboriginal Affairs and Northern Development, 2011. 4. Guide to Acknowledging Indigenous People and Traditional Territory, DND, 2021. 5. Indigenous Knowledge and Learning, https://www.rmc-cmr.ca/en/indigenous-knowledge-and-learning/indigenous-knowledge-and-learning, RMC, 2021.
Financial Guarantee	REGDOC 3.3.1: Financial Guarantees for Decommissioning of Nuclear Facilities and Termination of Licensing activities	1. ADM-5: Preliminary Decommissioning Plan, SLOWPOKE-2 Facility at RMC, 2022 2. Letter of Financial Guarantee signed by the DM of DND, 2022

APPENDIX C

REPORT SUPPORTING A CHANGE OF LICENSING LIMIT IN MAXIMUM EXCESS REACTIVITY FROM 4.0 MK TO 4.3 MK

REVIEW OF DOCUMENT ENTITLED

"*SLOWPOKE-2 TRANSIENT ANALYSIS:*

EXPERIMENTS VS CALCULATIONS

FOR HEU AND LEU CORES

***B.J. LEWIS, 6 JULY 2019*"**

by

HUGUES W. BONIN, PhD, P.Eng., FCIC, FCNS

Professor Emeritus

Document #RMC-CCE-HWB-19-1, 22 November 2019

REVIEW OF DOCUMEN T ENTITLED "*SLOWPOKE-2 TRANSIENT ANALYSIS: EXPERIMENTS VS CALCULATIONS FOR HEU AND LEU CORES - B.J. LEWIS, 6 JULY 2019*"

by HUGUES W. BONIN, PhD, P.Eng., FCIC, FCNS Professor Emeritus

Introduction

The procedure toward the refuelling of the SLOWPOKE-2 nuclear research reactor at the Royal Military College of Canada (RMC) are presently under way, with the actual replacement of the spent reactor core with a fresh fuel assembly planned for 2021 or 2022. Taking advantage of the licensing of the reactor core replacement and the commissioning of the new reactor core, the management of the SLOWPOKE-2 Facility at RMC plans to submit to the regulator, the Canadian Nuclear Safety Commission (CNSC), a request for authorizing an increase of the reactor's excess reactivity from +4.0 mk to +4.3 mk.

The purpose of the present document is not to assess explicitly the merits of the +0.3 mk increase of excess reactivity that is proposed, but to examine through an independent review the safety analysis related to such an increase prepared by Dr. B. J. Lewis [1]. It is important to note that the remarkably long core life of the Low Enriched Uranium (LEU) fuelled SLOWPOKE-2 nuclear reactor at RMC is mostly due to the largely predominant use of the reactor at half-nominal power (10 kW *vs* 20 kW), resulting in a slower rate of depletion of the fuel.

Prompt Criticality

Nuclear reactor engineering textbooks [2,3] explain the important role of delayed neutrons in nuclear reactor kinetics theory. For a nuclear reactor using predominantly uranium-235 as its fissile fuel, the fraction of delayed neutrons is called β and is equal to 0.0065. For example, when a reactivity of $\rho = 0.001$ is inserted rapidly in a ^{235}U fuelled reactor, the neutron flux takes more than 100 s to increase tenfold. However, if the step positive reactivity increase is equal to β or +0.0065, then the same increase of the neutron flux occurs some 1 s after the reactivity insertion. For a step increase of reactivity of $\rho = +0.014$, the neutron flux would grow tenfold in about 0.2 s. Recall that these examples are for a nuclear reactor for which all the neutrons are prompt, thus emitted at the time of the uranium fissions. For this reason, a reactor for which $\rho = \beta$ is called "prompt critical". The time taken by the reactor to increase its flux level by a factor of e = 2.7183 is called the reactor period. With the period in the examples above being so short, the control of the reactor would be very hard to achieve, if not impossible. Such large steps of positive reactivity insertions must be avoided. In the case of the LEU-fuelled SLOWPOKE-2 reactor at RMC, the proposed excess reactivity that would make possible a step positive reactivity insertion of +0.0043 (+4.3 mk) is significantly less than the +6.5 mk reactivity insertion that would make the reactor prompt critical.

However, for the SLOWPOKE-2 reactor, the effective value of the delayed neutron fraction is clearly larger than the 0.0065 value discussed above. This is due to the presence of important quantities of beryllium-9 nuclei that make the neutron reflector surrounding the reactor core. In addition to fast neutrons, the fissile nuclei emit gamma photons when they undergo fission, in addition to producing fission fragments and subsequent fission products which also emit gamma photons. The fission fragments and fission products have measurable half-lives which may be relatively long for many of them. Part of the gamma photons escape the reactor core and interact with the reflector's material, the ^{9}Be nuclei in particular, triggering (γ, n) nuclear reactions. The neutrons produced from these nuclear reactions are called photoneutrons and many of them re-enter the reactor core and contribute to the fissions in the reactor core. The overall effect of the photoneutrons is to increase significantly the delayed neutron fraction.

In the AECL-4770 document [4] , the effective delayed neutron fraction (indicated as $\bar{\gamma}\beta$) is determined as 0.00788, giving a value of 7.88 mk (or 0.788%, \$1 or 100 ¢) for the step positive reactivity increase that leads to the prompt critical state for the SLOWPOKE-1 reactor. For the High Enriched Uranium (HEU) SLOWPOKE-2 reactor at Ottawa (Tunney's Pasture), the exact value for $\bar{\gamma}\beta$ is not explicitly given in Ref. 4, but it is possible to determine it from Table 3 at page 47 of Ref. 4 (or Appendix A of Ref. 1) by using the reactivity for each one of the "Index" lines of the table, then finding the average value for all the "Index" lines. For example, for "Index" = 2.9, the reactivity is 6.0 mk or 76 ¢. Knowing that the effective delayed neutron fraction $\bar{\gamma}\beta$ is equal to the prompt critical reactivity of \$1 or 100 ¢, then for the HEU SLOWPOKE-2 reactor, $\bar{\gamma}\beta = (6.0 \text{ mk} \times 0.001 \text{ \$ mk}^{-1}) / (0.76 \text{ \$}) = 0.00789$. Therefore, the step positive reactivity insertion is, for this example, equal to +0.00789 or +7.89 mk. For all the "Index" lines in the table, the average is $(\bar{\gamma}\beta)_{avg} = 0.00793 \pm 0.00012$ (or +7.93 mk ± 0.12 mk).

The value of the effective delayed neutron fraction for the LEU- fuelled SLOWPOKE-2 reactor has been published as 0.81923% (8.1923 mk) [5]. This reference also presents a value of the effective delayed neutron fraction for the HEU-fuelled SLOWPOKE-2 reactor, the value given being of 0.83110%. Reference 5 was published in 1996 at the time when the HEU-fuelled SLOWPOKE-2 reactor at École Polytechnique had its spent core replaced with a new LEU-fuelled core very similar to the LEU core of the SLOWPOKE-2 reactor at RMC. The text in Ref. 5 indicates that the values of the $\bar{\gamma}\beta$ were taken from the Safety Report [6]. The positive step reactivity insertion of +4.3 mk is significantly smaller than the +8 mk step reactivity increase that produces the prompt critical conditions for the LEU-fuelled SLOWPOKE-2 reactor. Therefore, from the neutron kinetics view point, the findings presented above indeed support Dr, Lewis' conclusions [1] on the safety of the LEU-fuelled SLOWPOKE-2 reactor at RMC subjected to a maximum step positive reactivity insertion of +4.3 mk.

Thermal-hydraulics Considerations

The thermal-hydraulics aspects of transients resulting from step positive insertions of reactivity must be examined. Even if a +4.3 mk step reactivity insertion is significantly too small for bringing the reactor to a prompt critical condition as discussed above, the consequences of such an insertion must be determined in order to ensure that the reactor components and their materials retain their integrity.

The reactor fuel for the LEU SLOWPOKE-2 reactor is made of sintered UO_2 pellets with a 19.8% enrichment. The pellets are inserted in Zircaloy-4 tubes called cladding and sealed by welded-on end caps such that each fuel pin is leak-tight, to prevent any escape of fission products in the moderator/coolant. The control rod is made of a cadmium wire clad by an aluminium alloy sheath. The unique control rod slides inside an aluminium alloy guide tube located in the central axis of the core. The aluminium alloy is also used for the end plates of the core, for the tray that holds the top reflector plates and for the inner reactor vessel. Finally, the reflector is made of beryllium, with a bottom segment, a radial reflector about 11 cm thick and 22 cm height, and, of course, the reflector shims that are added at some 2-year intervals as the reactor fuel depletes. Table 1 below presents the melting temperatures for the materials used in the fabrication of the reactor core and reflector. The values come from various text books.

Table 1: Melting Temperatures for Various Materials

Used in the Fabrication of the LEU SLOWPOKE-2 Reactor Core and Reflector

MATERIAL	MELTING TEMPERATURE (^oC)
URANIUM DIOXIDE (UO_2)	2885
ZIRCALOY-4	1850
ALUMINIUM	660.32
CADMIUM	321.07
BERYLLIUM	1280

The behaviour of the SLOWPOKE reactor core was investigated experimentally and also via computer simulations for a variety of step positive reactivity insertions. Historically, experimental work was first carried out on the SLOWPOKE-1 and SLOWPOKE-2 reactors, both HEU-fuelled, at AECL research centres at Chalk River and at Kanata (Tunney's Pasture), near Ottawa. The results of this experimental work are reported in Ref. 4, and they demonstrate that the integrity of both reactors has not been compromised even if step positive reactivity insertions as high as +6.48 mk have been actually implemented. Figure 1 below is one of the figures reported in Ref. 4 (p.60) that illustrate the behaviour of the reactors from large step positive reactivity insertions, for a time up to 125 seconds following the beginning of the insertion. For the largest reactivity insertions, three power peaks are observed: the fast peak first, the prompt peak some seconds after, and the delayed peak several seconds after the second peak. Past the delayed peak, the reactor power decreases steadily because the positive reactivity of the core is counter acted by the negative reactivity coefficients due to the fuel and moderator/coolant temperature and density, and, in some cases, by a modest void fraction that appears for the largest positive reactivity insertions. Table 2 presents numerical results reported by AECL's

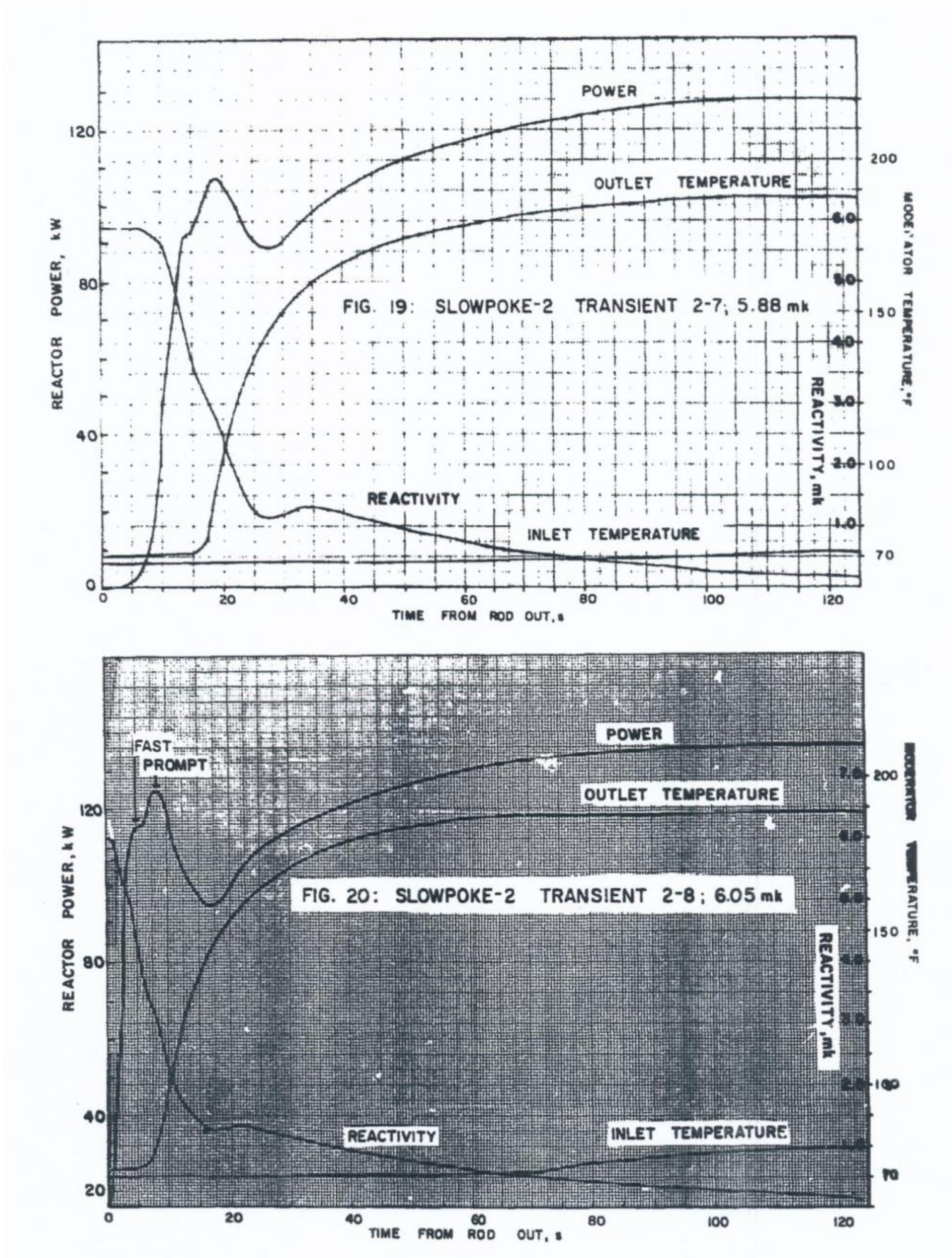

Figure 1: SLOWPOKE-2 Transients for +5.88 mk and +6.05 mk

Step Reactivity Insertions (Ref. 4, p. 60).

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Table 2: SLOWPOKE-2 Transient Experiments: Summary of Data (Ref. 4, p.47).

INDEX	T_p	$1/T_p$	Reactivity		Outlet Temp., °F		Peak Powers, kW			Energy to Peak Power, kW.s			Time to Delayed Peak
	s	s^{-1}	mk	¢	Initial	Peak	Delayed	Prompt	Fast	Delayed	Prompt	Fast	s
2-1	7.80	0.128	3.44	43.6	73.6	160	64	-31	-	14000	-890	-	350
2-2	5.38	0.186	3.97	50.4	74.0	170	77	-40	-	17000	-930	-	300
2-3	3.65	0.274	4.53	57.6	72.6	177	95	53	-	16000	890	-	230
2-4	3.26	0.307	4.70	56.9	73.6	181	103	61	-	14000	790	-	180
2-5	2.22	0.450	5.24	66.5	73.8	187	110	76	-65	16000	720	-380	200
2-6	1.88	0.532	5.46	69.3	74.8	191	117	89	-73	15000	690	-360	120
2-7	1.36	0.735	5.88	74.6	70.7	188	129	109	95	15000	810	-400	140
2-8	1.18	0.847	6.05	76.8	72.2	197	139	124	115	18000	770	410	150
2-9	1.2	0.83	6.0	76.0	78.3	-	-	116	106	-	740	430	-
2-D	9.66	0.104	3.14	39.8	67	-	56	-	-	-	-	-	270
2-C	14.0	0.071	2.64	33.5	80	145	42	-	-	13000	-	-	500
2-B	26.7	0.038	1.87	23.8	77	128	27	-	-	10000		-	700
2-A	60.0	0.017	1.11	14.1	76.5	119	12	-	-	7000	-	-	1400
AVERAGES										- -	800	400	

research teams. The highest coolant outlet temperature is reported as 197 °F (91.6 °C). This is well below the melting point of cadmium.

For the LEU-fuelled SLOWPOKE-2 reactor, experimental work was performed at the Royal Military College of Canada and at École Polytechnique de Montréal. In addition, a numerical simulation software, SLOWKIN, was developed at the Institut de Génie Nucléaire of École Polytechnique. The experimental and numerical results have been published in two reports [5,7]. The work done at École Polytechnique examines the behaviour of the LEU fuelled SLOWPOKE-2 reactor following a step positive reactivity insertion of +4.3 mk, as part of a selection of several values. Tables 3 and 4 below present the results as predicted by SLOWKIN. Table 5 provides a detailed view of the axial temperature profile in a LEU fuelled core submitted to a +4.3 mk step reactivity increase.

Figures 2, 3 and 4 provide graphical views of the behaviour of the LEU SLOWPOKE-2 reactor and Figure 5 compares sets of measured results with values predicted by SLOWKIN. The numerical results include the calculated amounts of coolant void for the largest step reactivity increases. Table 6 shows that this small void fraction translates into negative reactivity coefficients and contributes to the inherent safety of the LEU fuelled SLOWPOKE-2.

As it is the case for the HEU reactor, the results for the LEU fuelled SLOWPOKE-2 reactor confirm the inherent safety of the reactor and indicate that the maximum local temperature reached for the +4.3 mk step reactivity insertion (and even for higher values) results in values clearly inferior to the melting temperatures of the materials, and cadmium in particular.

Table 3: LEU-Core Behaviour at Delayed Peak (Core Average) (Ref. 5, p. 38).

Reactivity	*1 mk*	*2 mk*	*3 mk*	*4 mk*	*4.3 mk*	*5 mk*	*5.5 mk*	*6 mk*
peak power (kW)	13.95	41.62	69.06	85.96	89.42	96.31	100.59	103.98
time (min)	26.6	10.7	5.68	3.50	3.16	2.64	2.43	2.28
T_{inlet} (°C)	21.15	23.07	24.28	24.22	24.24	24.31	24.40	24.53
T_{outlet} (°C)	38.24	51.37	61.43	66.32	67.28	69.26	70.50	71.49
$T_{moderator}$ (°C)	30.66	38.77	44.87	47.53	48.06	49.17	49.89	50.49
T_{fuel} (°C)	57.37	92.52	118.55	132.05	134.57	139.31	142.07	144.18
T_{sheath} (°C)	52.14	81.67	100.30	114.21	116.20	119.89	122.01	123.61
void (%)	0.0	0.0	0.012	0.113	0.156	0.269	0.358	0.441
flow (kg/s)	0.188	0.338	0.426	0.468	0.476	0.491	0.500	0.507
MCHFR	47.28	14.86	8.51	6.65	6.36	5.84	5.55	5.32

Table 4: Reactivity Compensation (mk) at the Delayed Peak in LEU (Ref. 5, p. 38).

Insertion (mk)	ρ_{fuel} (mk)	ρ_{mod} (mk)	ρ_{refl} (mk)	ρ_{void} (mk)	*Peak Power* (kW)
1.0 mk	-0.380	-0.628	0.055	0.0	13.95
2.0 mk	-0.787	-1.343	0.132	0.0	41.62
3.0 mk	-1.002	-2.017	0.179	-0.053	69.06
4.0 mk	-1.139	-2.347	0.174	-0.498	85.96
4.3 mk	-1.165	-2.416	0.175	-0.686	89.42
5.0 mk	-1.213	-2.562	0.178	-1.180	96.31
5.5 mk	-1.241	-2.659	0.182	-1.571	100.59
6.0 mk	-1.262	-2.741	0.187	-1.930	103.98

Table 5: Axial Temperature Distribution in LEU for the +4.3 mk Insertion at the Time of Maximum Void (6.4 min).

plane	Tmod (°C)	Tsheath (°C)	Tfuel (°C)	void (%)	heat flux (kW/m2)	CHFR
15	67.921	123.267	139.677	0.197	96.107	7.130
14	65.599	119.909	135.658	0.066	90.877	7.721
13	63.406	120.274	136.632	0.071	96.253	7.451
12	61.079	121.425	138.753	0.097	104.392	7.028
11	58.550	122.376	140.572	0.120	112.362	6.689
10	55.823	122.749	141.683	0.124	119.072	6.474
9	52.928	122.474	141.939	0.107	124.036	6.380
8	49.909	121.486	141.265	0.076	126.983	6.400
7	46.815	119.806	139.610	0.040	127.846	6.528
6	43.699	117.258	136.881	0.012	126.702	6.762
5	40.611	114.010	133.239	0.001	123.775	7.098
4	37.593	110.209	128.876	0.000	119.456	7.533
3	34.682	106.337	124.420	0.000	114.714	8.025
2	31.886	103.421	121.175	0.000	112.222	8.379
1	29.151	104.221	122.681	0.000	118.779	8.080

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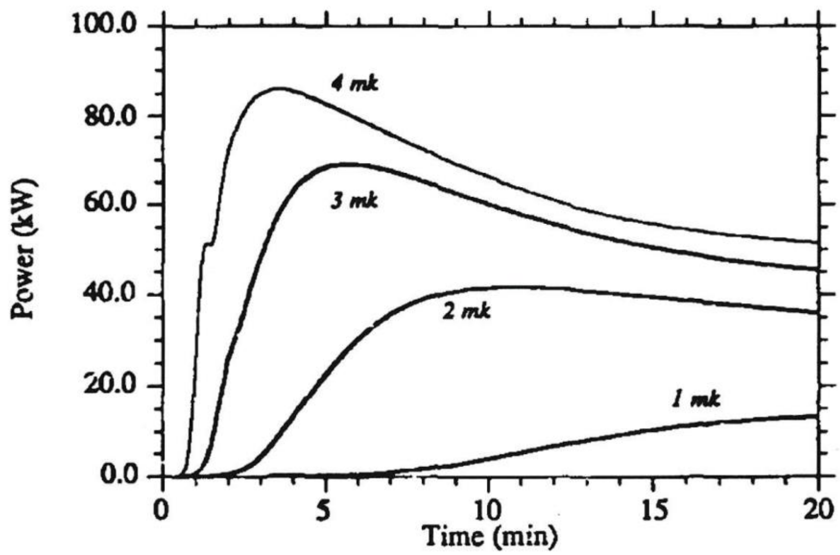

Figure 2: Self-Limited Reactivity Transients in LEU (1-4 mk) (Ref. 5, p.42).

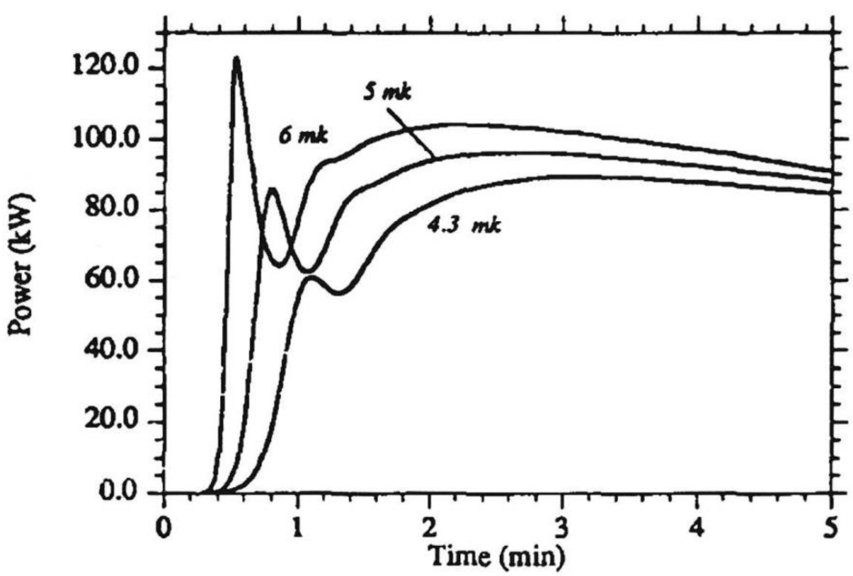

Figure 3: Self-Limited Reactivity Transients in LEU (4.3-6 mk) (Ref. 5, p.42).

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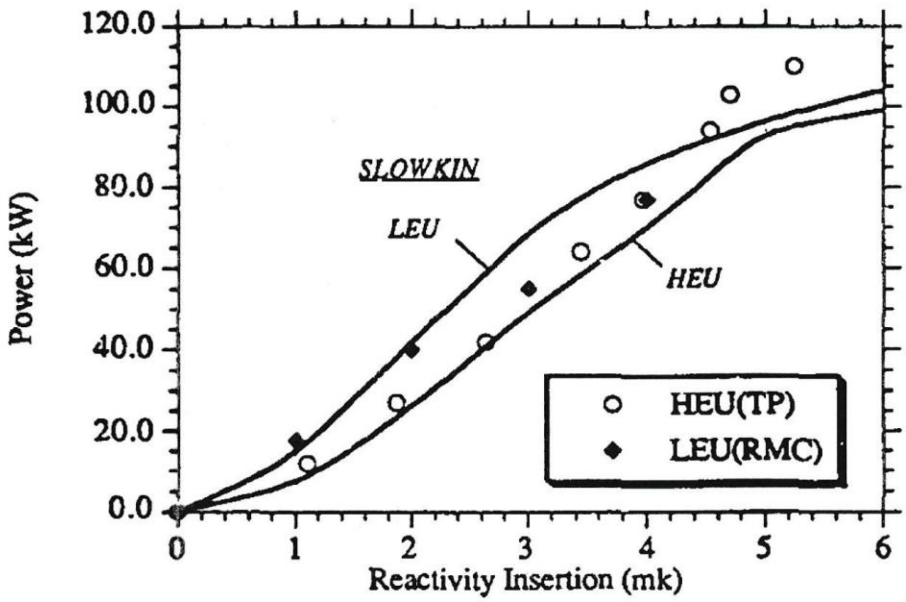

Figure 4: Delayed Peak Power in SLOWPOKE (SLOWKIN *vs* Measurements (Ref. 5, p.43).

The JM-1 reactor

Since the refuelling of the SLOWPOKE-2 reactor at École Polytechnique, another SLOWPOKE-2 reactor has been refuelled, with its spent HEU core replaced with a fresh LEU core in September 2015. This reactor is the JM-1 reactor at the University of West Indies, in Kingston, Jamaica. The United States Department of Energy was involved in the refuelling project and the Argonne National Laboratory was tasked to prepare the Safety Analysis Report [8].

The analysis was based on the computer codes MCNP and PLTEMP/ANL. MCNP Version 5 was used for the neutronics calculations, MCNP being a Monte Carlo-based neutron transport probabilistic code. The Argonne National Laboratory developed code PLTEMP/ANL V 4.9 which was used for the thermal hydraulics analyses. For the LEU fuelled JM-1 core, the effective delayed neutron fraction was determined with MCNP as $\beta_{eff} = 0.787 \pm 0.006\%$. (Ref. 8, p. 44). Figure 5 shows the relation between the reactivity insertion and the peak power. For a +4.3 mk step reactivity insertion, the delayed peak LEU experimental value is close to 80 kW. Table 6 below presents results for LEU for a +5.88 mk step reactivity insertion. For the delayed peak, the reactor power is 128 kW giving a coolant temperature of 53.8 ^{o}C and a fuel temperature of 228.5 ^{o}C. Again, the predicted behaviour for the JM-1 LEU fuelled SLOWPOKE-2 reactor confirms the findings of the studies on the École Polytechnique LEU

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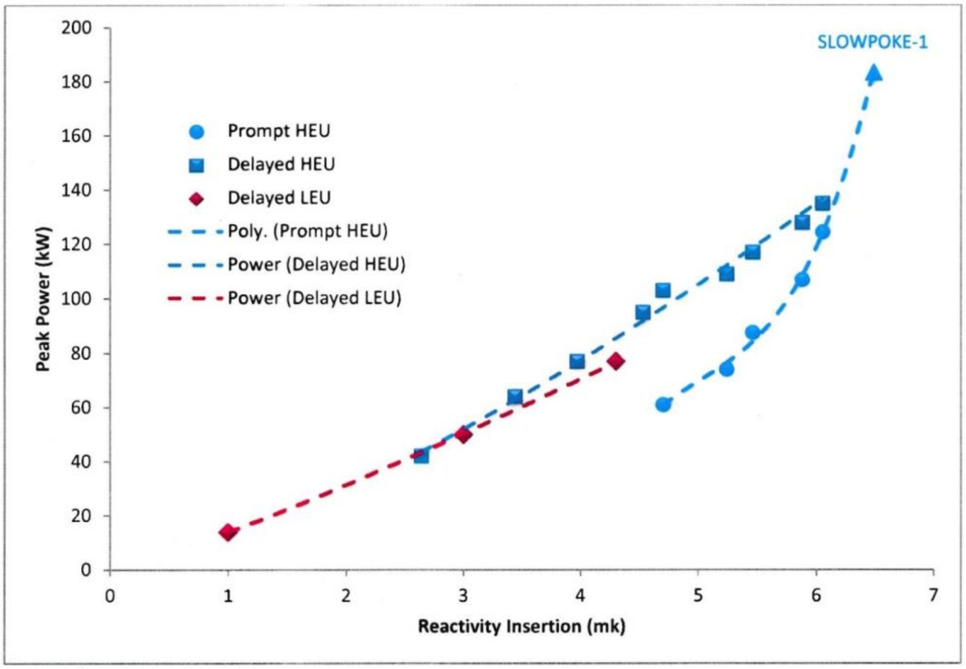

Figure 5: SLOWPOKE-2 Transient Power Peaks Measurements
after Sudden Reactivity Insertions. (Ref. 8, p.50).

Table 6: LEU Power Transient Peaks Key Parameters (5.88 mk Insertion) (Ref. 8, p.52).

	Fast peak	Delayed peak
Remaining excess reactivity	2.7 mk	0.2 mk
Reactor power	107 kW	128 kW
Coolant temperature	27.2°C	53.8°C
Fuel temperature	205°C (185°C increase)	228.5°C (208.5°C increase)
Coolant reactivity	−0.28 mk	−2.51 mk
Fuel temperature coefficient	−0.008 mk/°C	−0.008 mk/°C
Fuel reactivity	−1.48 mk	−1.67 mk
Voids reactivity	−1.42 mk	−1.50 mk
Void coefficient	−2.62 mk/%	−2.62 mk/%
Void upper threshold	0.54%	0.57%

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reactor and on the LEU fuelled SLOWPOKE-2 reactor at RMC. The computer simulation credibility is strengthened by the fact that the computer codes used by the ANL researchers are very different than the codes used by the École Polytechnique team. In particular, the neutronics calculations at École Polytechnique were carried out using deterministic codes (DONJON/DRAGON) whereas MNCP5, a probabilistic code, was used at ANL for the neutronics simulations.

Conclusions

This review of the report prepared by Dr. B. J. Lewis indeed confirms his findings and conclusions. The step insertion of the requested +4.3 mk reactivity would not lead to an unsafe operation of the SLOWPOKE-2 reactor at RMC provided with the fresh replacement LEU fuel core. The several simulations carried out on very similar SLOWPOKE-2 reactors show that the magnitude of the proposed step reactivity increase of +4.3 mk is way too small to cause any concerns about ensuring the control of the reactor. The simulations and experimental data also demonstrate that the highest local temperatures reached are all too low to cause the loss of integrity of the reactor's components including the fuel and the cadmium control rod. Such conditions ensure that no radioactive contaminants would be released to the environment from the reactor vessel.

References

1. B.J. Lewis, "*Slowpoke-2 Transient Analysis: Experiments vs Code Calculations for HEU and LEU Cores*", Report submitted on 6 July 2019 to Dr. Paul K. Chan, Manager, SLOWPOKE-2 Facility at Royal Military College of Canada.

2. S. Glasstone & A. Sesonske, "*Nuclear Reactor Engineering*", 3rd Ed., Van Nostrand Reinhold Co., New York, 1981, p. 248-250.

3. B. Lewis, E. Nihan Onder & A.A. Prudil, "*Fundamentals of Nuclear Engineering*", John Wiley & Sons, Chichester, U.K., 2017, p. 124-132.

4. R.E. Kay, J.W. Hilborn & N.B. Poulsen, "*The Self-Limiting Power Excursion Behaviour of the SLOWPOKE Reactor Results of Experiments and Qualitative Explanation*", Atomic Energy of Canada Limited Report AECL-4770, Chalk River Nuclear Laboratories, Chalk River, Ontario, January 1976, p. 15.

5. D. Rozon & S. Kaveh, "*SLOWKIN: A Simplified Model for the Simulation of Transients in a SLOWPOKE-2 Reactor*", Institut de Génie Nucléaire, École Polytechnique de Montréal, Report IGE-219 (rev. 1), August 1997, Table 1, p. 6.

6. D.J. Winfield, "*Safety Analysis Report for the École Polytechnique SLOWPOKE-2 Reactor*", Atomic Energy of Canada Limited AECL Report RC-1598, October 1996.

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8. F. Puig, D. Harle, C. Grant & J. Preston, "*JM-1 SLOWPOKE-II Research Reactor Supporting Analysis Report for the Conversion from HEU to LEU*", Argonne National Laboratory Report ANL/RTR/TM-17/4, Dec. 2017.

Signed: *Hugues Bonin*

Hugues W. Bonin, PhD, P.Eng., FCIC, FCNS, Professor Emeritus
Howe Island, ON, 22 November 2019

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APPENDIX D

LETTER OF FINANCIAL GUARANTEE

UNCLASSIFIED

ional Defence | Défense nationale
Deputy Minister | Sous-ministre

National Defence Headquarters
Ottawa, Ontario
K1A 0K2

Quartier général de la Défense nationale
Ottawa, (Ontario)
K1A 0K2

Ms. Rumina Velshi
President and Chief Executive Officer
Canadian Nuclear Safety Commission
280 Slater Street
P.O. Box 1046, Station B
Ottawa, ON
K1P 5S9

SLOWPOKE-2 NUCLEAR REACTOR: LICENCE RENEWAL

Dear Ms. Velshi:

The purpose of this letter is to provide a response to the licencing requirement of the Canadian Nuclear Safety Commission (CNSC) for a financial guarantee regarding the decommissioning of the SLOWPOKE-2 nuclear reactor located at the Royal Military College of Canada (RMC) in Kingston, Ontario.

This small research reactor supplies the primary means by which education in nuclear matters is provided to the Canadian Armed Forces (CAF) personnel, including undergraduate and graduate students. It also provides research and other services to the CAF as exemplified by radiography for the flight surfaces of its aircraft as well as the support to the Federal Government programme for Nuclear Emergency Response.

The SLOWPOKE-2 facility, being an integral part of the Department of National Defence (DND), is owned by DND and is therefore the property of the Crown. The facility is administered and funded by DND, through the Minister of National Defence under the authority of the Parliament of Canada. The Commandant of RMC is responsible for its daily operation and maintenance. To this end, costs associated with the future decommissioning of this facility to CNSC standards as addressed in the preliminary decommissioning plan will be paid by DND.

Sincerely,

Bill Matthews
Deputy Minister of National Defence

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