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Document Change Control

Document Version	Description of the Changes
1.0	Original document created for the 2003 licence application
2.0	The whole document updated and adapted to the new document format January 2022 for the 10-year licence application in 2023
3.0	Document updated to follow CSA N288.6-12 standard. Site description, ecological risk assessment added and human health risk assessment updated.
3.1	Document was updated in accordance with CNSC recommendations: Executive summary: Statement rewarded to better reflect that Tier 1 risk assessment was an outcome / result of following CSA N288.6-12; Sec. 2.2: Spatial and temporal scopes of the ERA were clarified; Sec. 3.1.1: Distances to the surrounding features and statements regarding Indigenous population added; Sec. 3.2.6: Additional information on the aquatic and terrestrial ecological environment added; Figures 9, 10, and 11 updated with year range; Sec. 4.1.1: Site workers replaced with Naval and Officer Cadets; Table 5: Data from 2017-2020 and definition for DL added; Sec. 4: Kr-87 and 88 added as a stressor; Sec. 4.1.3: Paragraph rephrased and reference added to support statement the only atmospheric immersion dose component is relevant for noble gases; Sec. 4.2.3: Time of reactor run corrected to 92 hours and information about headspace gas activity before purge added; Sec. 4.2.4: Additional uncertainties description added; Sec. 4.3.3: Clarification about incremental dose added; Sec. 4.5 Uncertainties of human health risk assessment added; Sec. 5.1.1: Changed to support choice of receptors; Sec. 5.3: Only benchmark of 100 μGy/h left as the most conservative; Sec.7: Reference to DAOD4003-0 added;

1.0 EXECUTIVE SUMMARY

The SLOWPOKE-2 Facility at the Royal Military College of Canada (RMC), a Class 1 facility, is compliant with the Canadian Nuclear Safety Commission's (CNSC) REGDOC-2.9.1 "Environmental Principles, Assessments and Protection Measures, Version 1.2" [1] partially by producing a document that summarizes the very low environmental risk posed to receptors in the environment surrounding the reactor facility. Thus, this Environmental Risk Assessment (ERA) has been performed using a screening/graded approach as appropriate for this small, low-polluting, critical research reactor. Limiting the already low release of radioactive noble gases by the SLOWPOKE-2 reactor is further reinforced by the following practices:

a) practicing ALARA,
b) retaining fission products from the core for a minimum of 48 hours before purging the gas from the reactor headspace,
c) filtering the exhaust gas through welded ducts,
d) using HEPA filters to trap and contain any particulate matter accompanying the "return air" from irradiations performed on samples so that only argon-41 gas is released through the dedicated SLOWPOKE-2 fans on the roof of Sawyer Building Module 5,
e) containment of the products of the reactor and pool water,
f) minimizing radiation inside the Facility with quality welds and having checked by measurements that there is no uranium contamination on the new, 2021 LEU fuel assembly,
g) having a stainless steel liner covering the pool walls and the bottom of the pool, and
h) monitoring of any alpha and/or beta contamination inside the Facility.

Section 5.2.2 of the Canadian Standards Association (CSA), CSA N288.6-12 [2] allows for a "screening level risk assessment" (SLRA), Tier 1, commensurate with the possible risks a facility poses. Tier 1 allows for a less detailed assessment and is the most conservative manner by which an assessment is permitted to be made. Current ERA demonstrates that radiological releases at the SLOWPOKE-2 Facility at RMC are extremely low, there are no liquid radioactive effluent releases, and there are no other contaminant releases nor any buildup as a result of the radiological releases over 37 years of continual operation based on a 5-day working week. Consequently, there have been no potential risks to human nor to non-human biota receptors in the surrounding environment. As a result, a Tier 1 risk is demonstrated after following the use of CSA N288.6-12.

This ERA confirms that the quantity of release to the environment through the exhaust fan is limited and far from reaching the public dose limit during operating and maintenance activities, as reported in the Annual Compliance Reports.

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2.0 INTRODUCTION

2.1 Background

The SLOWPOKE-2 Facility at RMC is a Class IA nuclear facility according to a classification in the Class I Nuclear Facilities Regulations [3] under the Nuclear Safety and Control Act [4] and is regulated by the Canadian Nuclear Safety Commission (CNSC). Consequently, the Facility is required to produce, have accepted, possess and regularly review and update an environmental risk assessment (ERA) pertaining to the Facility. Previous versions of ERA produced by the Facility are listed on the first page of this document and were limited by the calculation of activity emitted from the reactor. Current submission is the first one that follows the guidance in section 5.2.2 of the Canadian Standards Association (CSA), CSA N288.6-12 [2], which allows for a "screening level risk assessment" (SLRA), Tier 1, commensurate with the very low environmental risks to human health and the ecology such as this facility poses as described in the current ERA. This estimation of risk is based on the years of accumulated data with respect to radioactive releases that are monitored by the monthly sampling and some of which is and has been reported regularly in the facility's Annual Reports to the CNSC [5].

2.2 Goals, Objectives, and Scope

The purpose of this document is to provide the formal, Tier 1 Environmental Risk Assessment of the SLOWPOKE-2 Facility at RMC to meet CNSC's REGDOC-2.9.1: Environmental Protection: Environmental Principles, Assessments, and Protection Measures requirements [1]. The Facility uses Figure 1 and Table A1 from [2] as a guide to perform its ERA. The goal is to evaluate the risk to humans and any ecological receptors for the following spatial and temporal scope limits:

- around the exterior of Sawyer Science and Engineering Building, especially Module 5,
- on the peninsula upon which RMC is located; and
- reactor operation based on the previous 37 years and to span over the next 30 years, due to recent reactor refuelling, will remain unchanged.

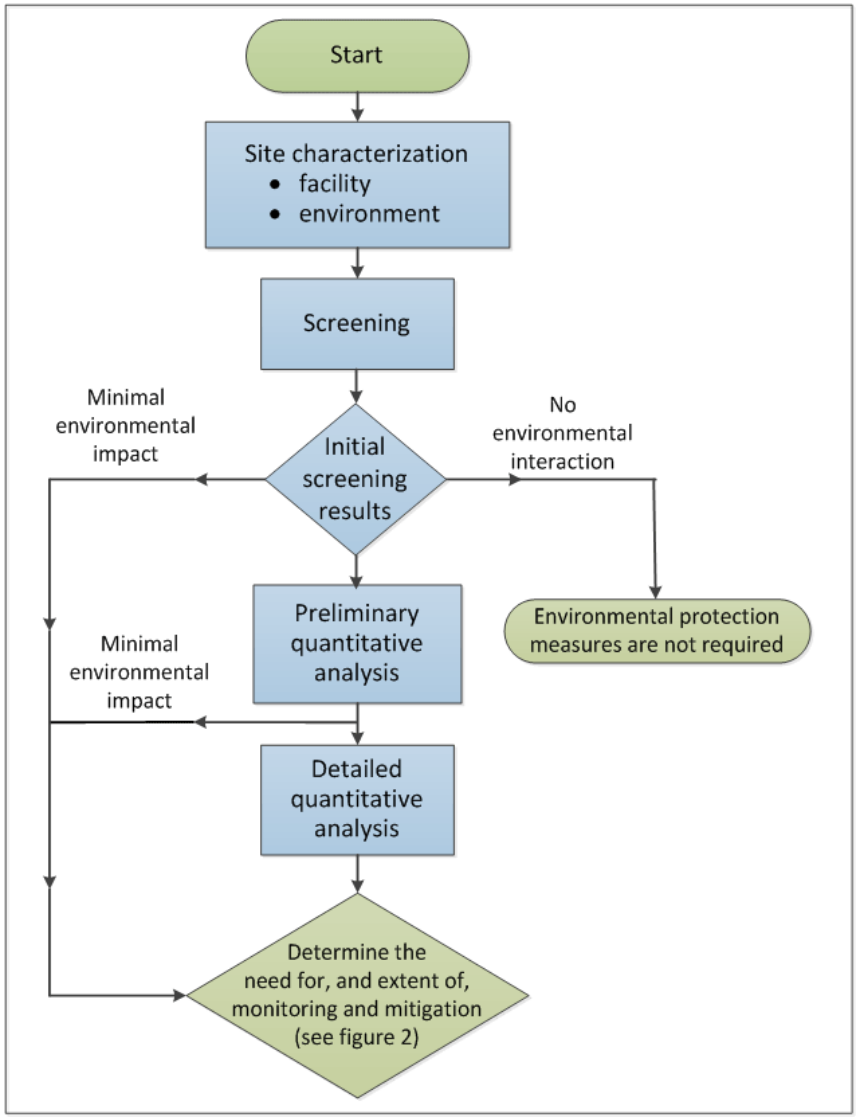

Figure 1. Tiered options for environmental risk assessments from REGDOC-2.9.1 **[1]** (simplified from CSA N288.6). Olive green indicates the possible outcomes from the screening process.

2.3 Organization of Report

This ERA has been structured in accordance with CSA N288.6-12's Annex A, Figure A1 "*Suggested table of contents for an environmental risk assessment report"*, and includes a site description, human risk assessment, ecological risk assessment, conclusions and recommendations, and quality assurance and control (See the Table of Contents). A table containing "shall" clauses from N288.6-12 is also provided as an annex.

3.0 SITE DESCRIPTION

3.1 Engineered Site Facilities

The SLOWPOKE-2 Facility at RMC is an integral part of the Department of National Defence and is therefore the property of the Crown. It occupies space on two floors of the Sawyer Science and Engineering Building Module 5 of the Royal Military College of Canada situated on Point Frederick Peninsula within the City of Kingston (Figure 2).

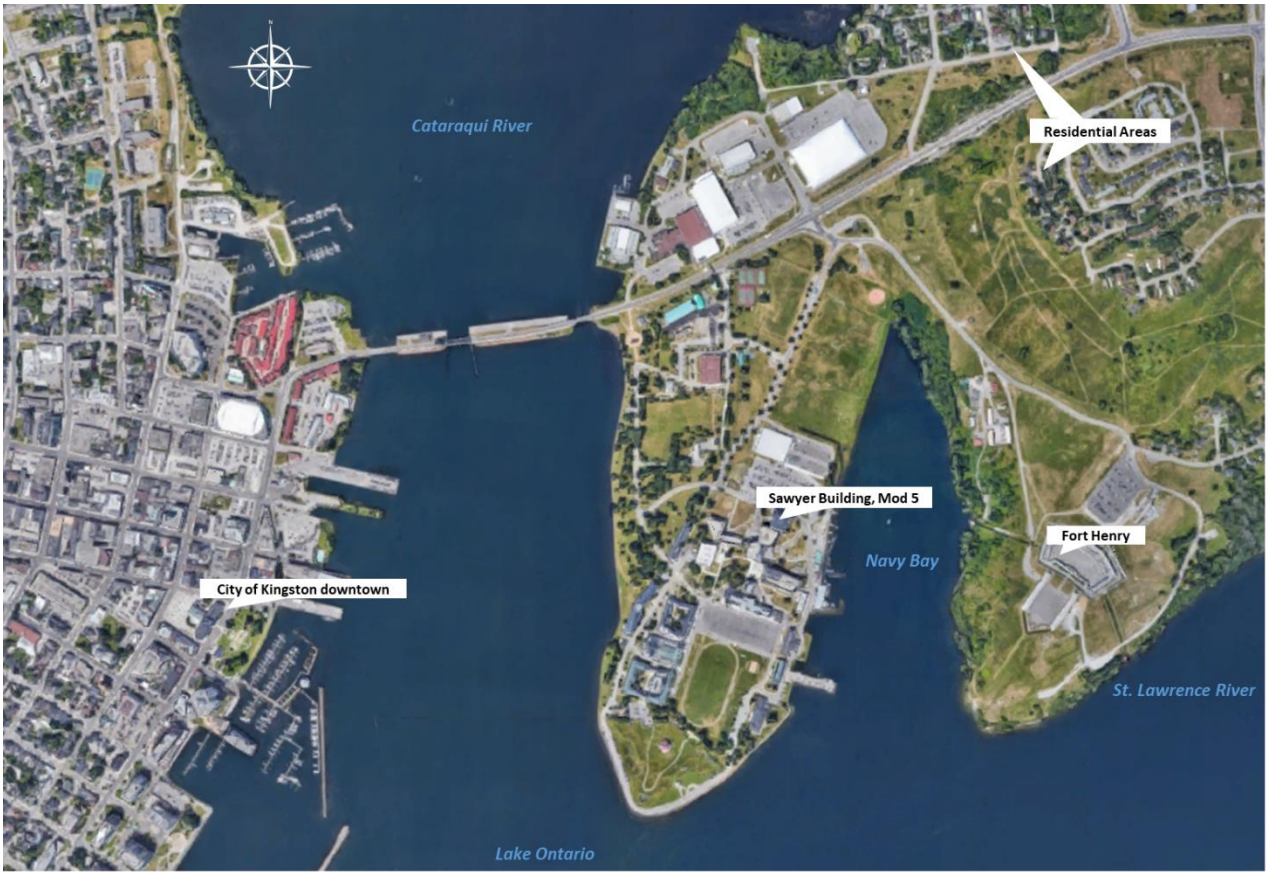

Figure 2. Map showing the SLOWPOKE-2 Facility in Sawyer Building Mod 5 in relation to the rest of the peninsula, city of Kingston, Fort Henry and residential area north of RMC.

3.1.1 Location of the SLOWPOKE-2 Facility relative to surrounding area

The SLOWPOKE-2 reactor at RMC is an inherently safe, very low power (17 kW nominal) research reactor. It is designed be a low-risk facility compared to the Class 1 power reactors in Canada and to much larger research reactors like reactor at McMaster University in Hamilton, Ontario.

The City of Kingston lies to the west and north of RMC. The part of the City to the west of RMC, starting approximately 800 meters away, has a mixture of small businesses and residential units. The northern part 900 meters away and further is mainly residential. The CFB Kingston is situated approximately 1 km northeast from the Facility. Directly to the east of RMC lies Navy Bay and Fort Henry (500 meters) that is a UNESCO Heritage site. Lake Ontario and the beginning of the St. Lawrence River lay to the South of the peninsula on which RMC stands.

Figure 2 depicts Sawyer Building Mod 5 in which the nuclear reactor resides in relation to the rest of the RMC Campus south of Highway 2.

Currently, the longest operating SLOWPOKE reactor facility in Canada is that in Montreal with 46 consecutive years of operation. Other SLOWPOKE reactors in Canada, mostly decommissioned now, operated for at least 25 or more years each. The RMC SLOWPOKE-2 facility has been operating for 37 years and is still ongoing. The data from all seven of these SLOWPOKE Facilities in Canada over an accumulated period of approximately 200 years of operation confirms the low risk of pollution to the environment from SLOWPOKE reactors. The aforementioned data can be obtained from the annual reports to the CNSC by each of these Canadian facilities.

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.

With respect to this ERA the physically nearest indigenous territory to RMC is 63 kilometers by road east of Belleville on the Bay of Quinte in Hastings County. The territory is called the Tyendinaga Mohawk Territory. Because the people living on this land are sufficiently far away from RMC that releases of radioactive material by the Facility will never reach them, the indigenous population there will not be considered in this ERA. Indigenous population within spatial scope of this ERA is treated as member of general public.

The SLOWPOKE-2 Facility at RMC has no authority to contact Indigenous groups directly. Any contact must be done through an explanatory document authorized and signed by the Base Commander of the Canadian Forces Base (CFB) Kingston. RMC and the reactor Facility are lodger units under CFB Kingston and as such are bound by the Base Commander's authority to set out rules, which cover the Base and the lodger units. As communicated with the CNSC's Project Officer, 12 indigenous communities were invited by the Base Commandant (which is more the list identified by the CNSC) to visit the SLOWPOKE-2 Facility to better understand our day-to-day activities and to demonstrate the safe operation of the SLOWPOKE reactor.

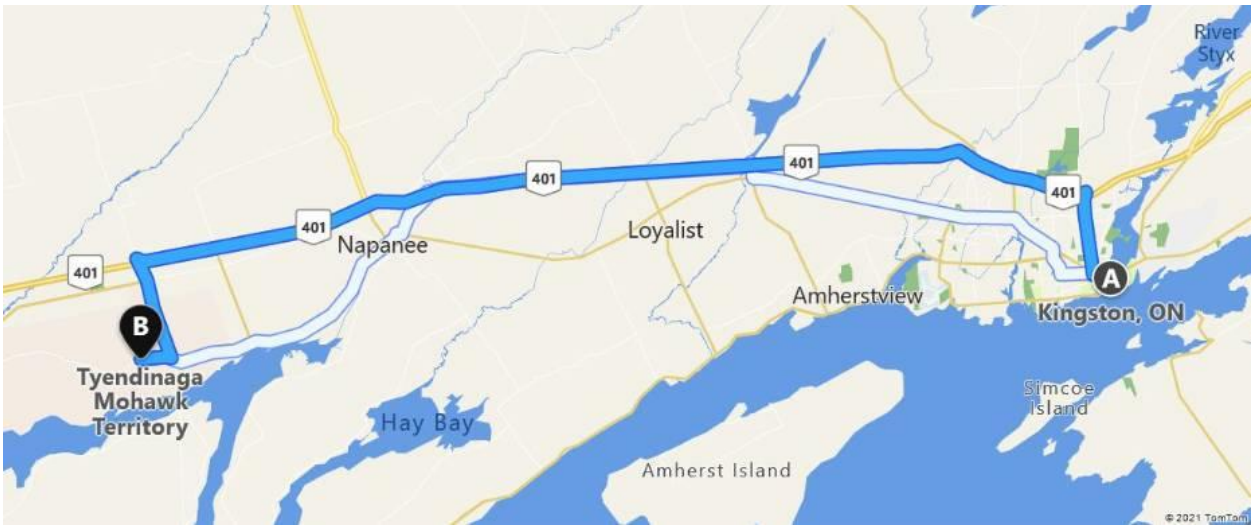

Figure 3. Road map showing location of the Tyendinaga Mohawk Territory in respect to Kingston, ON.

3.1.2 Effluent and Emissions Control and Monitoring

There are no radioactive solid or liquid releases from the facility to the environment. All irradiated samples are kept on site until they decay back to the background levels. After decay, these samples are disposed of as hazardous or usual waste depending on their nature. Hazardous waste disposal is organized by the Chemistry and Chemical Engineering Department at RMC in cooperation with CFB Kingston environmental officer.

A small number of samples that contain very long-lived radioisotopes (years) are stored on site until eventually disposed of into certified radioactive waste storage site (Chalk River) in accordance with CNSC regulations.

Water contained in the reactor container, reactor pool, and pool chillers is in the closed loops and is not released outside of the facility. Reactor water and pool water samples are collected and tested on the monthly basis for presence of alpha, beta, and gamma-radiation to monitor fuel condition. There have been no signs of fuel failure since commissioning of the reactor in 1985 and after its refuelling in September 2021. In rare situations when deionised water from the reactor pool needs to be released into the public sewer system, samples of the water are analyzed for radioactive content prior to disposal. If measurable amount of radiation in the pool water is observed it shall not be released from the facility and shall be treated as other radioactive waste described above.

The only radioactive emission coming out of the facility is through the dedicated exhaust fans from two sources: (1) weekly purging of the reactor headspace, and (2) operation of the pneumatic sample delivery system.

The first source is produced when the gases in the reactor container headspace, which diffuse from the reactor water, are purged for approximately 90 seconds to the outside environment, following a decay for

a minimum of 48 hours. . Hence the total release of radioactive gases amounts to less than 1.3 hours per year. There would be no reason to perform any other evacuation or to increase the duration of the headspace purge for this facility, because it has an aluminum reactor container that is already passivated with an oxide layer, which prevents production of hydrogen through chemical reaction between the aluminum and water. Samples of the headspace air are taken on a monthly basis prior to purge and analysed by the High-Purity Germanium Detector for gamma radiation. Normally the only detectable radioactive substance in the headspace after 48 hours decay time is small amount of radioxenon. The data from these analyses are kept by the Director of the SLOWPOKE-2 Facility who reviews the results with the object of looking for any changes and/or anomalies, which might indicate some action is required.

The second source of atmospheric environmental release is through the operation of the pneumatic sample irradiation system. During this operation, when samples are returned to the irradiation site or extracted from it, Argon-41, produced by the irradiation of the air present in the irradiation sites (1.288 % of the atmosphere by weight and 0.934 % by volume is argon gas), released into the atmosphere through the dedicated exhaust fans.

The ventilation system leading to the dedicated exhaust fans is equipped with HEPA filters to contain potential solid releases through the ventilation system

Detailed calculations of the released doses are provided in section 4.2.

3.1.3 Depiction of the Dedicated SLOWPOKE-2 Exhaust Fans and Dedicated SLOWPOKE-2 Exhaust Stack

The SLOWPOKE-2 Facility at RMC does not release solid or liquid radioactive effluents into environment. The only release potentially containing radioactive materials is in the form of gas through the dedicated stacks of nuclear ventilation located on west side of the roof of the Sawyer Building Module 5 (Figure 4). The two exhaust fans that serve the SLOWPOKE-2 Facility are also located on the same roof that has a limited access with a key available to the maintenance personnel from the CFB Kingston only. One of the exhaust fans (2500 $L \cdot s^{-1}$) is dedicated to the fumehoods of the Facility, headspace purge system and the pneumatic transfer air system for each irradiation controller. The second exhaust fan (945 $L \cdot s^{-1}$) provides general exhaust for the Facility rooms.

Figure 4. Left: West side of the Sawyer Engineering Building Module 5 with visible exhaust stacks on the roof highlighted in red rectangle. Right: Exhaust fan motor (blue) and exhaust stacks for the SLOWPOKE-2 Facility at RMC on the roof of Sawyer Building Module 5.

3.2 Description of the natural and physical environment

3.2.1 Geology

RMC is situated in the West St. Lawrence Lowlands, west of the Frontenac Arch, which is the eastern boundary of the Ontario basin. The arch is breached by the St. Lawrence River east of Kingston. The Ordovician sequences form the north shore of Lake Ontario and dip generally southwest at the rate of a few meters per kilometer, due to the Adirondack uplift. Precambrian shield rock lies unconformably underneath. The Ordovician limestone in the Kingston area is the Black River group and belongs to the Pamelia formation which is described on Map No. 25e of the 25th Annual Report of the Ontario Bureau of Mines [6] as "dove-blue, fine textured, non-fossiliferous limestone yielding an excellent compact building stone".

On the Geological Survey of Canada Map 13 (1965), Surficial Geology, "glacial deposits, ground moraine: sandy till" is indicated.

Soil information was obtained by various civilian and military groups prior to construction of the Sawyer Building.

Borehole No. B was drilled just to the east of the SLOWPOKE-2 pool where the main laboratory is now located. Referring to the elevations above sea level in feet, where the surface elevation is 249.8 feet, the results are listed in Table 1. Soil information from test pit No. 2 that was excavated at the (now) SE corner of Module 5 is also listed in Table 1.

Table 1. Soil information at Borehole No. B and test pit No. 2 for Sawyer Mod. 5 construction site

Borehole No. B:

Elevation above sea level	Soil information
249.8 ft. (76.14 m)	6 inches topsoil clay fill-soft, gray and brown, some gravel sizes, wet
240 ft. (73.15 m)	peat-brown, soft, wet
236 ft. (71.93 m)	limestone-gray, broken seams of silty clay (bedrock)
234.5 ft. (71.48 m)	end of bore hole (sound bedrock)

Notes:
1. Borehole advanced and cased to 15-ft. depth on 1 Oct 1971.
2. Water level at surface.

Sulfur determinations	SO_4^{2-} (%)	pH
Ground water	traces	8.0
Soil 2 ft. to 4 ft (0.6-1.2 m).	traces	8.0
10 ft. (3 m) (peat)	0.55%	7.0

Test Pit No. 2:

Elevation above sea level	Soil information
0-9 ft. (0-2.7 m)	Fill, pieces of limestone mixed with clay, considerable water flow into excavation
9 ft. (2.74 m)	Limestone, unable to penetrate. Water level 2.5 ft. (0.75 m) at the end of work

Due to the historical nature of the site, most of it contains fill material. The limestone bedrock at the pool location is at 236.2 feet (72 m) above sea level.

3.2.2 Seismology

RMC is located in seismic zone 1 according to the National Building Code of Canada seismic hazard maps [7]. The assigned peak ground acceleration ratio as a fraction of gravitational acceleration is 0.1 g. This means that there is 2% chance that an earthquake with an active peak acceleration level of 0.1 g (1/10 acceleration of gravity) will occur within next fifty years

The remaining factors in the equation for computing seismic forces, V=ASKIFW, for the base shear were chosen according to the National Building Code [8] for a structure built in this area.

Renovation Update on Seismology (2012):
RMC located in Kingston, Ontario is in a low seismic area in southeastern Ontario. The spectral acceleration values, as a fraction of gravitational acceleration are: Sa(0.2)=0.30, Sa(0.5)=0.16, Sa(1.0)=0.084, Sa(2.0)=0.024 [7]. These hazard values are based on a probability of being exceeded of 0.0004 in any given year, or once in 2,475 years. Thus these accelerations are called "2,500 year" accelerations generated by the earthquakes in the region.

The National Building Code of Canada equation for base shear is:

$$V = \frac{S(T_a)M_V I_e W}{R_d R_o}$$

where $S(T_a)$ is the spectral acceleration at the fundamental period of the structure multiplied by the site factor, M_v is a factor to account for higher mode shapes, I_e is the importance factor, W is the building weight and R_dR_o are the ductility and overstrength factors respectively.

For Module 5 $S(T_a)$=0.064, M_v=1.163, I_e=1, W=53,920 KN R_dR_o=3x1.3 and the resulting base shear is V=1,116 KN.

A seismic retrofit was performed in 2012. A new seismic force resisting system of buckling restrained braces was installed to resist the lateral earthquake forces. In addition a mechanical penthouse was added at the roof level increasing the height and weight of the structure somewhat. However the caisson details around the SLOWPOKE reactor remain unchanged. Table 2 gives the caisson details around the SLOWPOKE reactor and factored (1.25D+1.5L+0.5S) loads on the caissons considering the retrofit and addition.

Extensive seismic upgrade was done to the exterior of Sawyer Building Module 5.

In order to address the current building standards the engineering design team recommended that seismic bracing be added to the exterior walls of Sawyer Mod 5 (Figure 5) during renovations that began May 2012 and lasted 12 months. The purpose of the proposed additional bracing is to address lateral load issues connected with the original 1970 design of the Sawyer complex. However, to limit impact to the reactor the design team decided to proceed with "wing walls" on Sawyer Mod 5 in addition to the standard cross bracing (all on the east side). Originally the intent was to introduce the steel cross bracing on the north wall, but due to the close proximity to the reactor, the alternate plan was introduced.

Table 2. Caisson Details around the SLOWPOKE-2

Column Grid	1A (6A)	1B (6B)	2A (8A)	2B (8B)
Factored load (kips)	1,380	1,540	1,640	1,820
Size	28 x 28			
Reinf.Vert.	12-#8			
Ties	Typical detail dwg. 201			
Caisson Diam.	52 in.			
Caisson Depth into rock	8’	10’	7’	8’

Figure 5. Seismic bracing added to the exterior walls of Sawyer Mod 5 during 2012-2013 renovation.

The Sawyer Building has churn-drilled caissons reinforced with concrete and steel at 30 ft. centers on which the columns for the five floors were constructed (Figure 6). For the four caissons and columns nearest the pool (Figure 7), details are listed in Table 3.

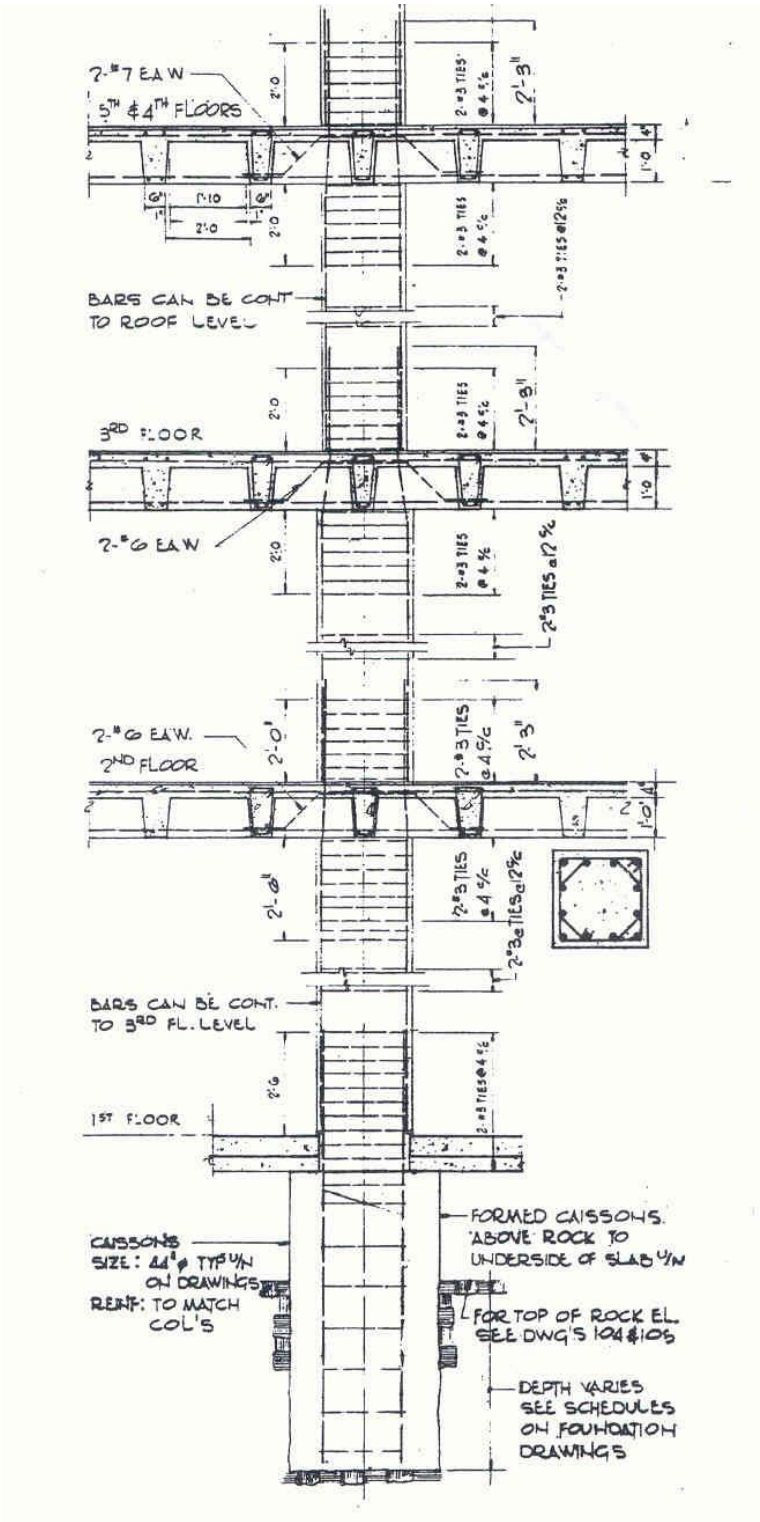

Figure 6. Typical Details of Column and Caisson, Sawyer Building Complex

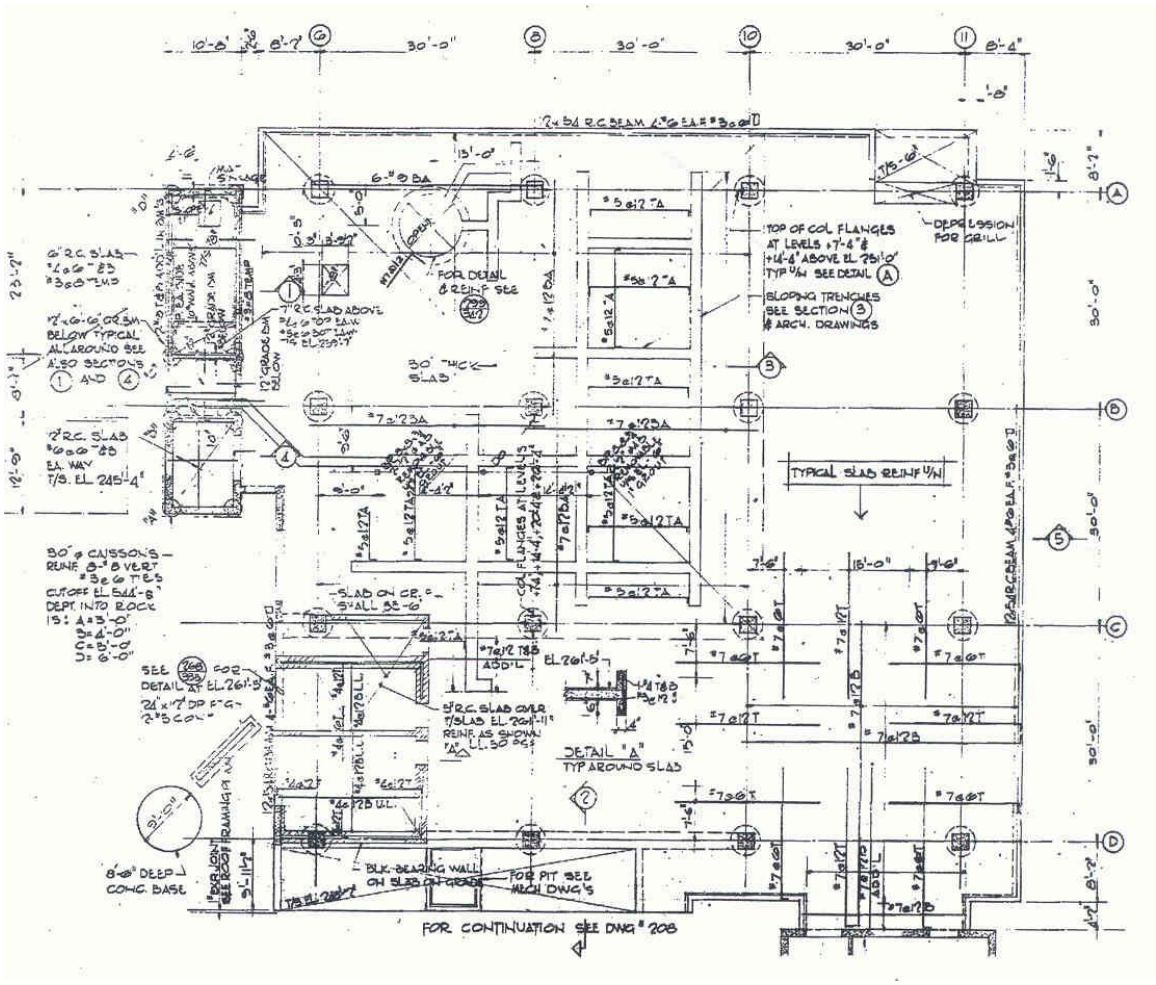

Figure 7. Foundation Plan, Sawyer Building, Module 5.

Table 3. Caisson and Column Schedule

Data Mark	B6(0W)	B8(FE)	A6(NW)	A*(NE)
Dead Load (K)	575	700	514	659
Live Load (K)	280	330	213	259
Size	28x28			
Rein. Vert.	12-#8in.			
Ties	see typical detail in Figure 7			
Caisson Diam.	52 in.			
Caisson Depth into rock	8’	10’	7’	8’

3.2.3 Groundwater

According to the Lake Ontario-St. Lawrence River Plan [9], under the present regulation plan, Lake Ontario is controlled by the St. Lawrence Seaway Authority from the dam at Upper Iroquois at a level between a minimum of 243.29 ft. and a maximum of 247.29 ft. with a mean of 245.12 ft. These elevations are referenced to the Geodetic Survey of Canada Datum. The highest lake level ever recorded is 249.08 ft.

The Module 5 finished first floor elevation is 251.0 ft. (76.5 m) above sea level and the water table at the pool site is approximately 246.1 ft. (75 m), as shown in Figure 1**Error! Reference source not found.**. The pool water level is indicated as 18 in (45.7 cm). below the first floor level (249.5 ft. (76 m) asl). The groundwater level was indicated by the bore hole and test pit investigations described in Table 1 to be at elevations 249.8 ft. (76.1 m asl) and 243.3 ft. (74.2 m asl), respectively.

A report to the Governments of Canada and the United States by the International Joint Commission was issued in June 2014 [9]. In this report maximum and minimum levels of Lake Ontario for Plan 1958DD and Plan 2014 are stated (Table 4).

Table 4. Figures from "Spaghetti Graphs" which used historical water supply data for 1900 - 2000

	Maximum Water Level above sea level m, ft	**Minimum Water Level above sea level m, ft**
Plan 1958DD	75.7 m, 248.36 ft	73.75 m, 241.96 ft
Proposed Plan 2014	75.73 m, 248.46 ft	73.56 m, 241.34 ft

Soil tests were undertaken for sulphate (traces) and pH (8.0) only before building construction. Limestone and clay are the main components of soil, so it is possible that their elemental constituents (eg., Ca, Mg, Na, K, Fe, Al, S, SO_4^{2-}, Cl^-, CO_3^{2-}) could be activated during reactor operation. However, groundwater is separated from the reactor water by concrete pool walls lined with stainless steel and does not come into close contact with reactor container. Moreover, the neutron flux outside the pool will be less than 10^5 $n \cdot cm^{-2}s^{-1}$ and consequently the combination of ground water movement that would limit exposure of elements to neutrons and the fairly short half-lives of resulting radioisotopes means that the activities in ground water will be well below corresponding exemption quantities [10].

3.2.4 Surface Water

There are no rivers on the Frontenac Peninsula. Any runoff from buildings would enter the waters surrounding the peninsula (Figure 2) via storm water sewer lines and drainage ditches.

3.2.5 Potable Water

Most of Kingston's drinking water including the one on the Frontenac Peninsula comes from the Lake Ontario. The closet water purification plant is situated on the King street approximately 2 km upstream from RMC and is unlikely to be affected by ground water from RMC. The closest wastewater treatment station is at Ravensview approximately 3 km downstream from RMC (Figure 8).

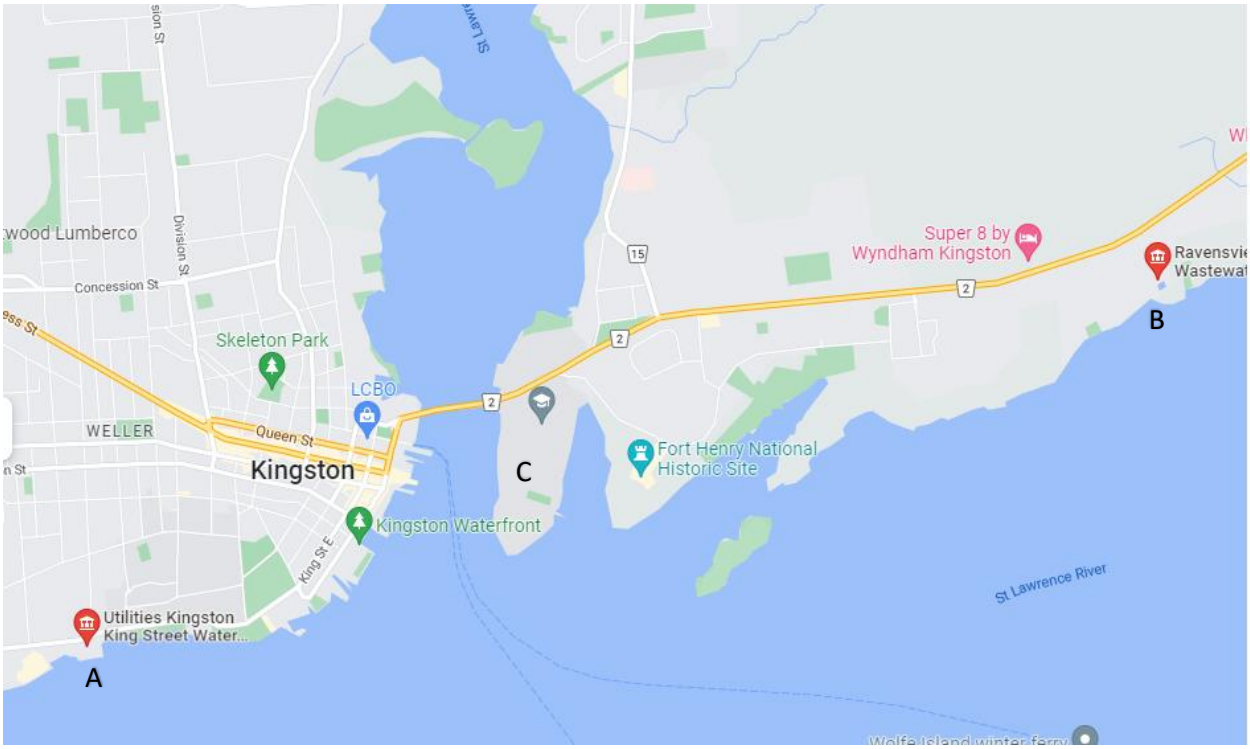

Figure 8. Location of the King Street Water purification plant (A) and Ravensview wastewater treatment facility (B) in Kingston relative to RMC (C) (© Google).

3.2.6 Vicinity: Terrestrial and Aquatic Environments

The Point Frederick Peninsula is surrounded by the fresh waters of Kingston Harbour, Lake Ontario and Navy Bay. There are fish in the waters typical for lake Ontario, but no especially prominent area of bullrushes or other aquatic plants that reach above the surface of the water. Approximately 1 km north from the center of peninsula there is an edge of the Great Cataraqui Marsh which is considered a provincially significant wetland [11] with abundant vegetation consisting mainly of bulrushes with some sages and grasses. Great Cataraqui Marsh is a nesting area for various birds and turtles, as well as spawning ground for northern pike [12]. No endangered floral species have been noted around Point Frederick Peninsula or in the Great Cataraqui Marsh.

Sixteen species of reptiles and amphibians have been noted in the area. Of five turtle species, three are designated rare provincially: the Northern Map, the Stinkpot, and the Blandings.

More than 200 species of migratory and resident birds were seen in the Kingston area [13]. Endangered species include the king rail, the loggerhead shrike, and the red knot. Threatened species include the least bittern, the common nighthawk, the chimney swift and the red-headed woodpecker (summer residents) and the golden-winged warbler and hooded warbler (winter migratory). Birds of special concern include the black tern and short-eared owl (summer residents) and the peregrine falcon (winter migratory) [12].

Small mammals such as groundhogs, rabbits, squirrels, minks, chipmunks, and mice are abundant on the peninsula.

Upon the Point Frederick peninsula sit the buildings of RMC used for administration, teaching/lectures, residences for students, parking lots, a parade square, grass-covered fields mainly used for sports, and groups of trees.

Extending north from the reactor area at grade level are a paved sidewalk, light standards, roadway, concrete curb and car park (Figure 2). Pedestrian traffic is mainly between the building and car park, at either ends of Module 5. At the northwest end, there is an exit/swipe card entrance door; an entrance/exit door is located at the south end of the corridor. Most of the pedestrian traffic is through the main entrance (3 doors) at the northeast corner of Module 5. East and south of the reactor area is the Chemical Engineering Main Laboratory used for undergraduate experiments; to the south are storage rooms. The doors leading outwards from the reactor room are electronically lockable (to stop ingress) but allow free egress at all times from the reactor room.

There is also a SLOWPOKE laboratory on the second floor where most of the work with radioactive materials occur. The laboratory is adjacent to the mezzanine that used mainly as a passageway, another chemistry research laboratory, and the corridor. The corridor is used infrequently due to the stairwells to the northeast main door and west door being located at the south and west sides of Module 5, respectively. A gamma radiation probe is mounted in this north corridor hallway, with visual indication and visual and audible alarms, monitored by a readout unit inside the SLOWPOKE laboratory. The readout unit in the laboratory also monitors a gamma and a neutron radiation directly above the reactor pool at the second floor level. Bilingual warning signs are located at the two adjacent concrete pillars in the corridor and have inscribed, "When the radiation alarm sounds, DO NOT advance beyond the floor markings", as well as the radiation trefoil symbol.

3.2.7 Land Use

Since 1874 the land of the Point Frederick Peninsula is used to house a university for the training and education of future officers for the Canadian Armed Forces. The land use will not change for the foreseen future.

3.2.8 Climate

City of Kingston, Ontario, where RMC is situated, has a moderate humid continental climate with cooler summers and colder winters than most of Southern Ontario. Proximity to Lake Ontario moderates the climate but increases humidity in the area, which occasionally leads to increased precipitation.

This effect of Lake Ontario also generates a consistent predominantly southwesterly mild to strong breeze throughout the year.

There are typically several freezing rains in the winter months and regular storms in the summer months that can lead to the loss of power on peninsula. The reactor facility is equipped with an auxiliary natural gas generator and uninterrupted power supplies to keep reactor and monitoring equipment operational during periods of power loss.

Figures 9 to 11 show average annual temperatures, precipitations, as well as wind strength and direction in Kingston.

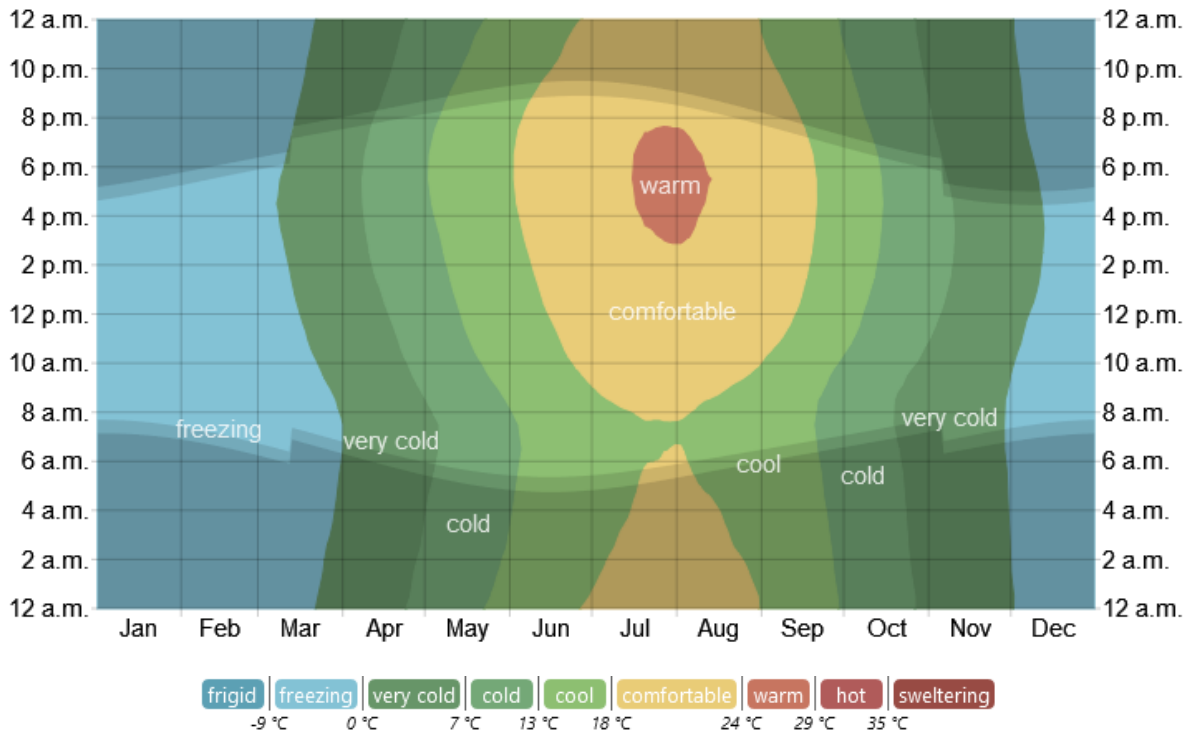

Figure 9. Average hourly temperatures in Kingston in 2014-2021 period, ON (© WeatherSpark.com)

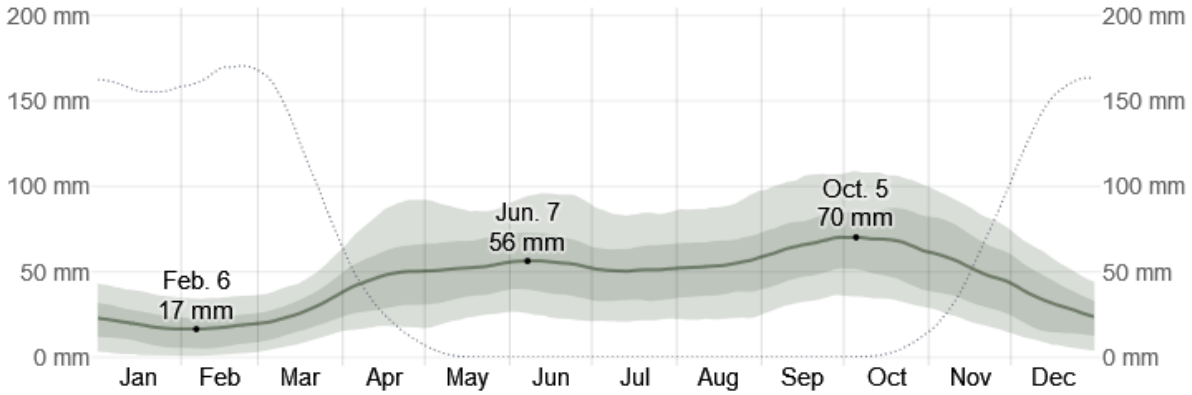

Figure 10. Kingston's 2014-2021 average rainfall (solid line) accumulated over the course of a sliding 31-day period centered on the day in question, with 25th to 75th and 10th to 90th percentile bands. The thin dotted line is the corresponding average snowfall (© WeatherSpark.com)

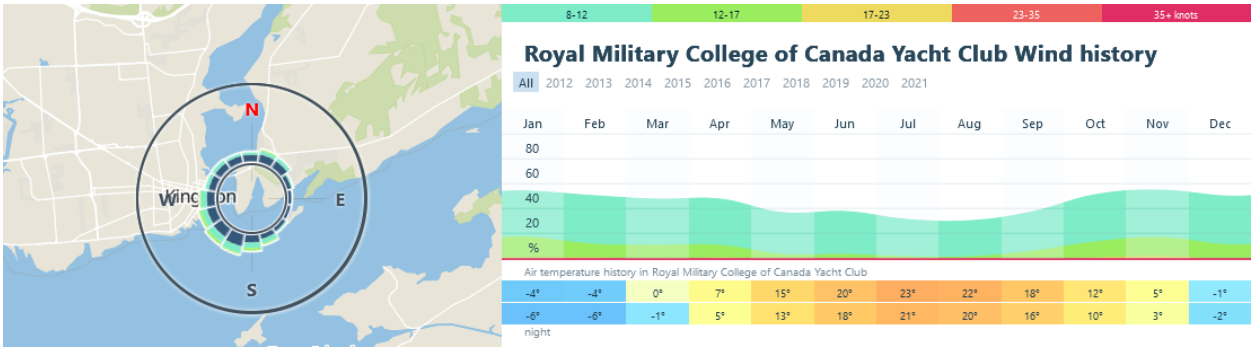

Figure 11. Wind statistics for RMC for the period 2012-2021 (© Windy.app)

3.2.9 Population

RMC on the Point Frederick Peninsula has about 2500 occupants when classes are in session. This includes military and civilian personnel, as well as cadets and students. CFB Kingston, which is to the east of RMC, has a population of 1500. The population of the City of Kingston is approximately 130,000 permanent residents, which swells by another roughly 30,000 when Queen's University has classes in session.

3.2.10 Environmental Monitoring

There are no hazardous liquid effluents or solid waste released from the facility to the environment. The only direct environmental release is through the atmosphere of small quantities of radioactive noble (not

reactive) gases that decay quickly into their non-radioactive forms. Past assessments have indicated no need for monitoring. Any future need for monitoring is being evaluated as part of the present document.

3.2.11 Environmental Management System

RMC is a lodger unit of Canadian Forces Base (CFB) Kingston located up the hill from and east of RMC has an environmental officer who manages the environmental policies for the Base and for RMC in accordance with DAOD 4003-0 Environmental Protection and Stewardship [14].

3.2.12 Environmental Emergency Preparedness

If there were a nuclear environmental event at the SLOWPOKE-2 Facility at RMC, the Facility administration would likely ask for support from Atomic Energy of Canada Limited (AECL)/Canadian Nuclear Laboratories (CNL) located at Chalk River, Ontario, both for their nuclear expertise and as the designer of SLOWPOKE. The same practice was followed for the 2021 August/September refuelling project to cover the possible scenario of a nuclear accident during the transport of the original, 1985 spent fuel; that is, the CNL emergency response team would have been contacted. No accidents occurred during the 2021 August/September fuel replacement project [11]. For 37 years the SLOWPOKE reactor has never caused any nuclear incident at RMC.

4.0 HUMAN HEALTH RISK ASSESSMENT

4.1 Problem Formulation

It is required of any workplace in Canada to protect the health and safety of both on-site workers and the general public who may be in the vicinity of the workplace.

There are no radioactive or hazardous liquid or solid waste releases from the SLOWPOKE-2 Facility at RMC. Therefore, only gas emissions from the facility will be considered for the general public exposure including air inhalation and air immersion (cloud shine).

In addition to the gas exposure, on-site workers, who are classified as nuclear energy workers (NEWs), may be exposed to radiation and other hazardous compounds through the contact with samples they are working with. Safety procedures for facility workers are discussed in the "Safety Assessment and Operating Envelop for the SLOWPOKE-2 Reactor at RMC" [12], as well as various site-specific operating procedures, and are not part of this ERA.

4.1.1 Receptor Selection and Characterisation

For this ERA the Officer and Naval Cadets (O/N Cdts) as well as the general public of all ages are the candidates for the Facility's receptor selector selection. Although O/N Cdts attending RMC are not members of the general public in the sense that they are regulated by the Canadian Department of National Defence (DND) and not by the public nuclear regulatory body, namely the CNSC, it still

behooves the SLOWPOKE-2 Facility to promote their good health, safety, and minimize any radiation in the area of their classrooms, laboratories, recreational areas such as the soccer fields, etc.

For the purpose of this ERA the most conservative approach is taken and the critical receptor is chosen as a member of general public which includes members of Indigenous population.

4.1.2 Stressor Selection

The SLOWPOKE-2 Facility releases no radioactive or hazardous liquids to its surrounding environment. The releases to the atmosphere are only gaseous and limited to radioxenon (Xe-133), radiokrypton (Kr-87, Kr-88) and radioargon (Ar-41). These are noble gases and as such are not chemically active, which means they do not chemically react with virtually anything. Gases have a fairly short half-lives of 1.82 hours for Ar-41, 1.27 hours for Kr-87, 2.84 hours for Kr-88, and 5.25 days for Xe-133, which means they decay to the background level within days.

The data sources come both from the regular, monthly analysis of a sample of reactor container water and of a sample of headspace gas. The results are recorded and appear in the Facility's Annual Compliance Reports to the CNSC [5]. The environmental releases from the sample transfer operation system were measured by the SLOWPOKE-2 Facility at the Saskatchewan Research Council [13]. These measurements can be directly applied to RMC's SLOWPOKE-2 Facility because of the identical reactor design.

The irradiated samples are kept in the facility for the delay and decay until the majority of the samples decay to the background level and can be disposed of as hazardous waste via Chemistry and Chemical Engineering Department at RMC. Samples that do not decay to the background level are kept on site until disposed of at a certified radioactive waste disposal site in accordance with CNSC regulations. The irradiated samples are excluded as a potential stressor because they are not released to the environment, and are dealt with by qualified SLOWPOKE-2 facility or waste disposal personnel as described elsewhere [12].

Table 5. Activity in Bq/L of the headspace purge gas in 2017-2021* [5]. *Highest detected levels for each isotope are highlighted in bold.

Month sample taken	2021			2020			2019			2018			2017		
	Xe-133	**Ar-41**	**Kr-87, Kr-88**	**Xe-133**	**Ar-41**	**Kr-87, Kr-88**	**Xe-133**	**Ar-41**	**Kr-87, Kr-88**	**Xe-133**	**Ar-41**	**Kr-87, Kr-88**	**Xe-133**	**Ar-41**	**Kr-87, Kr-88**
January	<DL	<DL	<DL	0.26	<DL	<DL	<DL	<DL	<DL	<DL	<DL	**0.05**	0.7	<DL	<DL
February	<DL*	<DL*	<DL*	<DL	<DL	<DL	<DL	<DL	<DL	7.8	<DL	<DL	0.72	<DL	0.04
March	0.10	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	**8.0**	<DL	<DL	0.98	<DL	<DL
April	<DL	<DL	<DL	0.61	<DL	<DL	<DL	**0.02**	<DL	2.6	<DL	<DL	0.46	<DL	0.03
May	<DL	<DL	<DL	0.78	<DL	<DL	<DL	<DL	<DL	3.2	<DL	<DL	0.34	<DL	<DL
June	<DL	<DL	<DL	0.68	<DL	0.04	0.03	<DL	0.03	0.97	<DL	<DL	0.13	<DL	<DL
July	0.08	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.56	<DL	<DL	0.14	<DL	<DL
August	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.07	<DL	<DL
September	<DL	<DL	<DL	0.75	<DL	<DL	0.015	<DL	<DL	<DL	<DL	<DL	0.20	<DL	<DL
October	<DL**	<DL**	<DL**	<DL	<DL	<DL	0.04	<DL	<DL	2.1	<DL	<DL	0.91	<DL	<DL
November	0.37	<DL	<DL	0.37	<DL	<DL	0.06	<DL	<DL	2.7	<DL	<DL	0.22	<DL	<DL
December	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.1	<DL	<DL

* Samples taken on March 1st, 2021.

** Samples taken on November 1st, 2021.

DL – Detection limit estimated by the GammaVision (ORTEC) software and dependent on the gamma-spectroscopy instrument, count time, decay time, and background.

The release of fission product gases from the headspace purge is measured monthly (Table 5). The elements in the gas are identified and quantified by gamma ray spectroscopy. A headspace purge is usually performed after a minimum of 48 hours decay of radioactive products in the reactor container water and the container headspace while the reactor is off during weekends. As a result, Ar-41 or Kr-87 or Kr-88 are rarely detected as their half-lives are less than 3 hours. Another possible radioactive component of the headspace purge is Xenon-133, which has a half-life of 5.3 days. There has been no abnormal observation reported, with the measured Xe-133 activities within expectations, for the last 37 years.

4.1.3 Selection of Exposure Pathways

Since the release from the facility consists only of the gaseous emission to the atmosphere, the possible radiation exposure pathways are cloudshine or external exposure to the gas containing radioargon and radioxenon. According to the CSA-N288.1-20 [18] only the atmospheric immersion dose components are relevant for noble gases. Since these gases are chemically inert, they do not enter environmental compartments other than air and do not contribute to inhalation, ingestion, or groundshine doses.

4.1.4 Human Health Conceptual Model

For the most conservative scenario of human exposure the member of the general public (critical receptor) was chosen to visit the roof top of the Sawyer Module 5 building next to the exhaust stack and be surrounded by the emission coming from the stack and containing both radioargon and radioxenon (Figure 12).

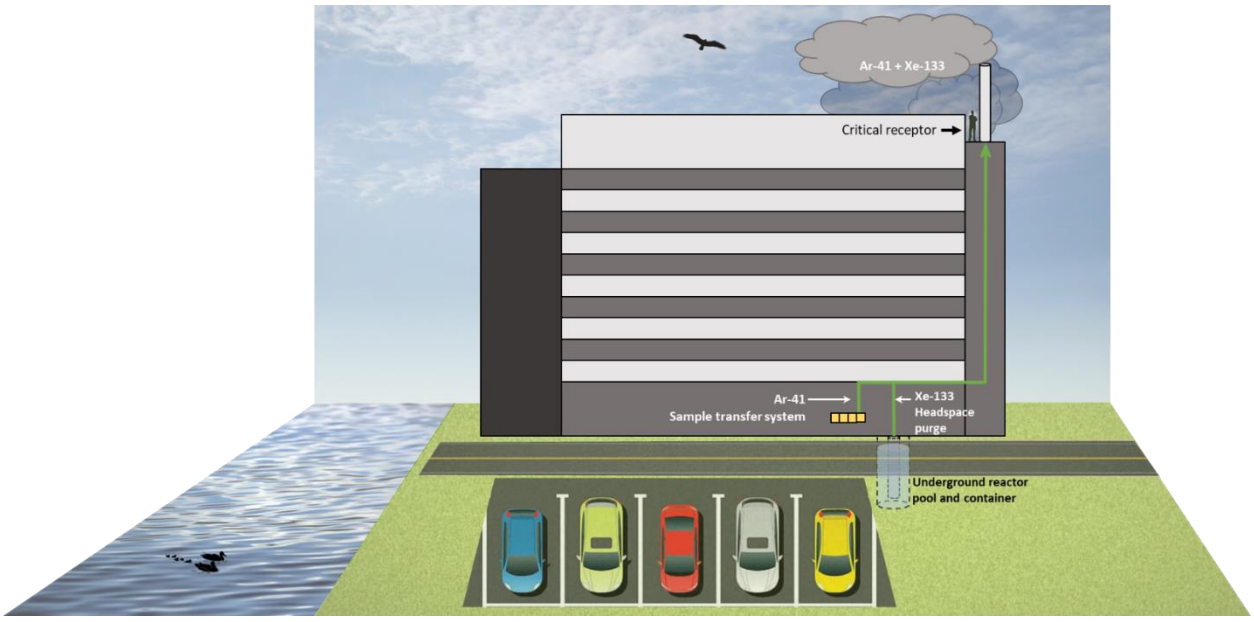

Figure 12. Conceptual site model indicating exposure source, pathways and receptors.

4.2 Exposure Assessment

The only exposure pathway for the released radioactive gases from the Facility is through the welded ducts that carry the gases, Ar-41, Kr-87, Kr-88, and Xe-133, from both the return air from the irradiation of samples and from the weekly reactor container headspace purge up three and four floors respectively to the Sawyer Module 5 rooftop exhaust fans and exhaust stacks. Inside the first and second floors of the Facility, there are HEPA filters in the release pathways that capture any particulate material that may accompany the release of gases to the atmosphere.

Eventually this release of radioactive gases to the roof of Sawyer Mod 5 will be both diluted and dispersed to the ground where there is a large parking lot across the street from the reactor facility for around 400 cars and soccer fields even further away from Sawyer Building Module 5.

4.2.1 Exposure location

The general public on the Frontenac Penninsula as well as in the city of Kingston is potentially exposed to the gaseous radiation from the exhaust stack on the roof of Sawyer Module 5. However, the further away from the exhaust the more diluted and dispersed the radiation is, both because of the distance travelled and mixing with the atmosphere. Therefore, the highest possible dose the member of general public can receive from the reactor effluent will be on the rooftop of Sawyer Module 5 next to the exhaust stack (Figure 12). This scenario was chosen as a most conservative approach for further calculations.

4.2.2 Exposure duration and frequency

As previously mentioned in this discussion, there is a 90 second release of reactor container headspace gases every week of the year (75% of the time on Mondays and otherwise on Tuesdays), giving an annual exposure duration of predominantly Xe-133 as well as potential radioargon and radiokrypton of approximately 78 minutes, at the exhaust fans and exhaust stack five floors above ground level.

During the five-day work week, air containing Ar-41 is released to the atmosphere as samples travel through the sample transfer system to the reactor and back to lead receivers in the SLOWPOKE-2 analysis laboratories, usually on the second floor of the SLOWPOKE-2 Facility. Instrumental neutron activation analysis (INAA) is not done every day of the working week nor is it generally ongoing for the entire 7.5 hour working day. Consequently, the Ar-41 in the sample delivery system is not produced and thus not released on a daily basis. The reactor at RMC is operated for around 720 hours per year based on the maximum value for the last three years [5], which corresponds to 3 h per work day.

Table 6. Emission content, duration and frequency

Isotope	Duration	Frequency
Xe-133 (headspace)	90 s/event	52 times/year (weekly)
Ar-41 (sample transfer)	3h/day	250 days/year

4.2.3 Exposure and dose calculations

Headspace:

From monthly gamma measurements of a 10-liter sample of headspace gas as reported in the Facility's annual compliance reports to the CNSC, predominantly Xe-133 and periodically Ar-41 and Kr-87, 88 produce numbers larger than the detection limit for their activity. Because the human receptor is assumed to be next to the fan where radiation is emitted, no dilution factor is considered.

Calculation 1

1) Normally all of the activated argon and krypton will have decayed away by Monday morning, which is when a head space purge is done after a minimum of 48 hours of decay. Usually only xenon will remain to be purged. However, for the conservative estimation, highest measured activities of 0.02 Bq/L for radioargon and 0.05 Bq/L for radiocrypton in the headspace gas from the past five years of monitoring will be considered.
   It worth mentioning that in 2021 headspace gas was analyzed directly after reactor operation at high power for 7 hours. It has been found that main radioactive component of the headspace gas was Ar-41 with activity of 3.7 kBq/L. Although this activity is significantly higher then the one measured during routine headspace purge, it is not going to be used for current calculations since headspace gas is not purged during or directly after reactor operation.

2) As per the RMC SLOWPOKE-2's licence applications in 2002/2003 and 2012/2013, a highest ever measured value of 14 $Bq.L^{-1}$ was used for conservative estimation. This purged xenon was measured after a 92-hour run at 5 kW (quarter-power) [14]. The SLOWPOKE-2 reactor is run at half power (10 kW) 99.9 % of the year, and thus the 1994 study was scaled to 28 $Bq.L^{-1}$. The highest value of 8 $Bq.L^{-1}$ measured in 2018 (Table 5) is more than 3 times lower than this conservative estimate.

3) According to CPR-26 [15], Section 3.3.3 *Reactor Monitor Level*, pages 3.29 and 3.20, the gas space height inside the reactor container is usually 394 mm. The outer diameter of the reactor container is 0.61 m. Thus, the volume of the headspace inside the reactor container is:

$$V(headspace) = 0.394\,m \times 3.14 \times \left(\frac{0.61\,m}{2}\right)^2 = 0.115\,m^3 = 115\,L$$

4) Only the external dose coefficients for cloud shine from Xe-133 of 1.39 x 10^{-15} Sv s^{-1} Bq^{-1} m^3, from Ar-41 of 6.13×10^{-14} Sv s^{-1} Bq^{-1} m^3, from Kr-87 of 3.94×10^{-14} Sv s^{-1} Bq^{-1} m^3, and from Kr-88 of 9.72×10^{-14} Sv s^{-1} Bq^{-1} m^3 are provided by Health Canada [16]. No inhalation dose coefficients are available. Dose coefficient from Kr-88 will be conservatively used for radiokrypton calculations as a larger value of two.

5) The area of the staircase rooftop is 3m × 7.5m, and the plume is assumed to remain 5.0 m into the air above the roof.

6) Therefore, the calculated dose for a worker on the staircase roof during a 90 second headspace purge period is the following.

$$Dose(Xe) = \frac{28\,\frac{Bq}{L} \times 115\,L \times 90\,s \times 1.39 \times 10^{-15}\,\frac{Sv \cdot m^3}{Bq \cdot s}}{3\,m \times 7.5\,m \times 5.0\,m} = 3.58\ \times 10^{-12} Sv$$

$$Dose(Ar) = \frac{0.02\,\frac{Bq}{L} \times 115\,L \times 90\,s \times 6.13 \times 10^{-14}\,\frac{Sv \cdot m^3}{Bq \cdot s}}{3\,m \times 7.5\,m \times 5.0\,m} = 1.13\ \times 10^{-13} Sv$$

$$Dose(Kr) = \frac{0.05\,\frac{Bq}{L} \times 115\,L \times 90\,s \times 9.72 \times 10^{-14}\,\frac{Sv \cdot m^3}{Bq \cdot s}}{3\,m \times 7.5\,m \times 5.0\,m} = 4.47\ \times 10^{-13} Sv$$

$$Total\ Dose = 4.14\ \times 10^{-12} Sv$$

7) A headspace purge is performed 52 weeks a year during reactor maintenance, giving a total dose over the year of 52 × 4.14 × 10^{-12} Sv = 2.15 × 10^{-10} Sv= 2.15 × 10^{-4} μSv.

Irradiation sites:

The release of air from irradiation sites occurs primarily when sample travels to the irradiation site or returns to the lead receiver in the SLOWPOKE-2 laboratory. The argon in the air, which is inside the irradiation air tubes, is irradiated along with the sample, producing the radioactive isotope Ar-41.

The direct measurement of the activity of emissions from the sample transfer system is a non-trivial task and is not performed at the SLOWPOKE-2 Facility at RMC. However, it was measured previously at the Saskatchewan Research Council (SRC) SLOWPOKE-2 Facility [13]. Due to the same reactor design these measured values can be directly applied to the SLOWPOKE-2 Facility at RMC and will be used for the calculation of the following exposure for an adult receptor standing next to the stack on the staircase roof.

Calculation 2:

1) The SLOWPOKE-2 reactor is run at half power 99.9 % of the year, which equates to a thermal neutron flux of 5×10^{11} neutrons/(cm^2·s) as measured by the control neutron detector. This flux value is sustained at about 1.5 times the height of an irradiation vial. The flux falls off drastically above a height of 8.57 cm in an inner irradiation tube.

2) At RMC the reactor is normally on for approximately 720 hrs per year, based on the maximum reported operating hours from 2019, 2020 and 2021 [5] or 2.9 hours per day considering 250 working days in a year. Three hours per day will be used in the following calculations.

3) For the same Low Enriched Uranium (LEU) fuel from 1985 to the autumn of 2021, the irradiation of argon in air at half power is not expected to have changed and is expected to remain unchanged for the next licensing period of 2023 to 2033. As per the SRC SLOWPOKE-2's measurements [13], the maximum activity of 10.6 Bq/L in the out-air emission was observed during the sample transfer system operation after 10 hours of continuous irradiation.

4) The air flow for the sample transfer system at RMC's SLOWPOKE-2 Facility is approximately 500 L/min. The duration of each sample transfer is between 2 and 10 seconds. For a conservative approach, a duration of 0.5 minute per transfer is chosen giving 250 L of air expelled from the facility for each transfer.

5) Each sample irradiation requires 2 transfers: one into the reactor and one back into the lead receiver.

6) Annually, around 1000 samples are irradiated in the facility [5]. For a conservative approach, 2000 samples were chosen for current calculation or 8 samples per day considering 250 working days in a year.

7) The volume of the air receiving the stack emission and containing Ar-41 at the rooftop of the Sawyer Building Module 5 (where the adult receptor is standing) is the same as in calculation 1: 3.0 m × 7.5 m × 5.0 m = 112.5 m^3.

8) A value of 6.13×10^{-14} Sv·m^3/(Bq·s) is the external dose coefficient for cloud shine for Ar-41 [16]. No inhalation dose coefficients are available. The resulting dose is:

$$Daily\ Dose = \frac{10.6\frac{Bq}{L} \times 250\ \frac{L}{transfer} \times 2\frac{transfers}{sample} \times 8\ \frac{samples}{day} \times 3\,h \times 3600\frac{s}{h} \times 6.13 \times 10^{-14}\ \frac{Sv \cdot m^3}{Bq \cdot s}}{112.5\,m^3}$$

$$= 0.25\ \mu Sv/workday$$

$$Annual\ Dose = 0.25\frac{\mu Sv}{workday} \times 250\frac{workday}{year} = 62.5\ \mu Sv/year$$

The sum of the activity released to a worker on the rooftop of the Module 5 staircase is conservatively estimated to be 2.15×10^{-4} µSv/year from headspace gas purge and 62.5 µSv/year from Ar-41, giving a total dose of 62.5 µSv/year.

4.2.4 Uncertainties in exposure calculations

The exposure scenario discussed above used the most conservative approach. The calculated dose value of 62.5 µSv/year is based on conservative assumptions such as the highest measured activity values for emitted radioisotopes, conservative durations and frequencies, and represents an overestimation.

In reality, it is unrealistic that any member of the general public or NEW will be present on the rooftop of the Sawyer Module 5 every workday of the year during reactor operation. In addition, rooftop has a limited access with a key available to the maintenance personnel from the CFB Kingston only thus limiting access to unauthorised personnel.

Moreover, the dose coefficients used assume a semi-infinite source geometry where a person is at the centre of a sphere that is cut in half through the centre horizontally, and the semi-infinite sphere is assumed to have a uniform concentration of radionuclides [18]. This simplification overestimates the dose to a person located near the source by the factor more than 10 for Ar-41 and Xe-133.

If a member of the public stood on the sidewalk exterior to the N-W staircase to Mod 5, the dose received from the gas falling straight down from the top of an exhaust fan would be even smaller than 62.5 µSv/year because of the dilution of the air from the stack on its way down to the ground (19.5 m building height). Even this would be a worst-case scenario in which one assumes that the wind pushes the air straight down from the rooftop stack while in reality atmospheric air movement will dilute and disperse the emission.

Exposure duration in the atmosphere and external surroundings of Sawyer Module 5 is further decreased by the relatively short half-lives of the released radioactive gases Ar-41 (less than two hours) and Xe-133 (less than one week). The intensity of the exposure to the general public will be reduced by the dilution and dispersion of the gases from the Sawyer Building rooftop to the ground.

4.3 Toxicity Assessment

4.3.1 Toxicological reference values

Both argon and xenon are inert, non-toxic gases without listed toxicological reference values [18].

4.3.2 Radiation dose limits and targets

In Canada, Radiation Protection Regulations [19] set limits for the amount of radiation the public and NEWs may receive in addition to the background and medical doses. The effective dose limit for the general public is set at 1 mSv per calendar year.

The recommended annual dose does not include radiation received from the background radiation and medical procedures. Canadian regulations follow the recommendations of the International Commission on Radiological Protection as well as guides of the International Atomic Energy Agency.

Because both releases are noble gases, which are chemically inert at normal conditions and are not alpha emitters, minimal harm is expected to the human body.

4.3.3 Uncertainties in toxicity assessment

The average annual incremental doses received by the general public in Canada from facilities and /or activities licenced by CNSC are typically significantly below 1 mSv per year and ranges from 0.001 to 0.1 mSv according to CNSC [20].

4.4 Risk Characterization

The exposure values obtained from calculations 1 and 2 indicate that the maximum estimated annual dose to the worker or the public outside of Sawyer Building Mod 5 will be 62.5 μSv or less. This value is significantly lower than the 1 mSv/year limit for the general public and non-radiological worker. The conclusion is, therefore, that the risk to humans by the gaseous releases by the SLOWPOKE-2 Facility is negligible.

In addition, the SLOWPOKE-2 Facility exercises ALARA principles and practices mitigation in order to lessen any effects of radioactivity on the general public, its own workers, contractors and maintenance workers, the rest of the people who occupy Sawyer Building Mod 5, the OCdts, graduate students, researchers, visitors to the Facility and visitors to RMC. Occasions when visitors to RMC are numerous are the Canadian Thanksgiving weekend, when the first year RMC students undertake to complete a rigorous obstacle course, and graduation in the spring and fall.

The following points exemplify mitigation practiced by the SLOWPOKE-2 Facility.

1) All persons working in the Chemistry and Chemical Engineering Department of RMC must take a course, fill out a signed sheet after searching for safety features such as the location of eyewash stations in their area of work in the Department, and write a test in both the Workplace Hazardous Materials Information System (WHMIS) and basic facts about radioactivity.
2) Upon request, construction workers will be given a briefing on radiation by the Radiation Safety Officer (RadSO) for RMC. Maintenance workers who, for example, change the fan belt in the SLOWPOKE-2 exhaust fans, check with the Director with respect to reactor activity before

going to the rooftop to perform maintenance and/or repairs. Contractors and maintenance workers are members of the general public.

3) For occasions when the radioactivity associated with the reactor facility is higher than it is during the rest of the year, the Facility attempts to do its work at time when there are fewer people on Campus. These altered times may be on weekends, overnight, after exam periods, and in the summer or around Christmas. Two such instances of trying to work during a scarcity of people on Campus happened for the refuelling event, which occurred in August/September 2021, and times when neutron radiography is in progress. For potential serious risks, the population of Sawyer Mod 5 would be restricted from coming to work for that day.
4) The Facility has a policy that the reactor must be off if anyone under the age of 18 years is having a tour of the Facility.
5) Every person working in the Facility, as well as visitors, receive personal electronic dosimeters for the period of the visit. The dose received, if any, is recorded in the SLOWPOKE-2 Visitor's Log, which is kept for posterity.

4.5 Uncertainties of human health risk assessment

The human health exposure scenario discussed above used the most conservative approach. The calculated activity doses are based on the highest measured activities of emission. Duration and frequency of exposure is also significantly overestimated. Dose coefficient constants used for calculations are taken from literature where they were estimated based on the simplified scenario of exposure that also overestimates the exposure in more than 10 times. The dilution and dispersion of the emission by air would also dramatically decrease the dose potentially received by public.

5.0 ECOLOGICAL RISK ASSESSMENT

5.1 Problem Formulation

The ecological risk assessment is being undertaken to evaluate and recommend mitigation measures for any stresses that operation of the SLOWPOKE-2 Facility may exert on its surrounding ecological environment.

As previously mentioned in this document, the Facility does not release any radioactive or hazardous liquid or solid materials to the environment. Hence, only gas emissions will be assessed for ecological risk. Also, to ensure a conservative approach, the exposure scenario will be limited to the rooftop of the Sawyer Building Module 5 where the highest possible exposure can be received.

5.1.1 Receptor Selection

As described previously in section 4, there are no radioactive or dangerous solid waste and/or liquid effluents coming from the SLOWPOKE-2 Facility at RMC into the surrounding environment. The only

radioactive releases from the reactor are gaseous emissions consisting of small amounts of noble gases. As per the clause 5.1.8 of CSA N288.1-20: "Only the atmospheric immersion dose components are relevant for noble gases. Since these gases are chemically inert, they do not enter environmental compartments other than air and do not contribute to inhalation, ingestion, or groundshine doses." Therefore, benthic invertebrates, terrestrial plants, and aquatic plants, zooplankton, and fish from the surrounding waters of Navy Bay, the beginning of St. Lawrence River and Kingston Harbour were not chosen as potential receptors.

As a result, small mammals, birds with terrestrial and aquatic habitats, amphibians or reptiles, and some of the soil invertebrates are potential receptors.

For a conservative approach, only maximum possible exposure may be considered. Since maximum possible exposure from the gaseous emissions would be received on the rooftop of the building next to the exhaust stack, only birds and some soil invertebrates like spiders are the identified receptors. Exposure of small animals like mice is possible, but unlikely. However, it has been shown [21] that effects of radiation exposure on birds are similar to those on mammals, and therefore small mammals and birds will be discussed interchangeably.

The closest potential habitat for the endangered spices, such as king rail [12], is approximately 2 km north of the Facility. The atmospheric immersion doses at this location will be decreased dramatically in comparison to doses at the rooftop stack due to dilution, as described in Chapter 4.2.4. As a result, endangered spices are not going to be considered as a receptor if the calculated hazard quotient for ecological species at the stack will be negligible.

5.1.2 Stressor Selection and Characterization

Section 4.1.2 above applies to EcoRA.

Radioactive and hazardous waste produced in the facility is disposed of at the certified waste facilities.

5.1.3 Selection of Exposure Pathways

As stated in the CSA N288.6-12 [2], the non-reactive noble gases are not taken up by plants or animals and, therefore, inhalation intakes of noble gases by animals does not need to be considered. Therefore, only the external exposure (cloudshine) will be discussed.

5.1.4 Exposure Duration and Frequency

Section 4.2.2 above applies to EcoRA.

For the most conservative scenarios, birds or small mammals will be assumed to nest near the exhaust stack on top of the roof, and insects will be assumed to spend their entire lives at this location.

5.2 Exposure Assessment

Section 4.2 above applies to EcoRA.

The annual radioactive release value estimated in section 4.2 of 62.5 μSv/year can be converted to 62.5 μGy/year or, considering constant exposure through the year, 7.1×10^{-3} μGy/h.

5.3 Toxicity Assessment

The CNSC does not place a maximum annual dose that animals and birds are not to exceed, but there are number of studies of radiation effects on different life forms [21] and CSA N288.6-12 outlines maximum annual doses in accordance with UNSCEAR recommendations. The effects of radiation exposure on birds has been shown to be similar to those on small mammals while invertebrates were less radiosensitive.

The gaseous releases of radioargon and radioxenon by the Facility do not accumulate on the grounds of RMC due to atmospheric mixing/dilution, their inert nature, and short half-lives. While these noble gases are going through their decay processes of hours and days, they are not alpha emitters and therefore are not harmful when inhaled by animals and birds.

UNSCEAR 2008 [21] lists dose rates below which no significant effects in living organisms are expected. For invertebrates this value is 220 μGy/h, for small mammals it is 100 μGy/h, and for the generic ecosystem it is 0.6 μGy/h. For a conservative assessment 100 μGy/h will be used for all terrestrial biota.

5.4 Risk Characterisation

The dose rate of 7.1×10^{-3} μGy/h estimated for emission release from the facility is significantly smaller than dose rates listed for small mammals (100 μGy/h) (applicable to birds), invertebrates (220 μGy/h), and the generic ecosystem (0.6 μGy/h). For a conservative assessment 100 μGy/h will be used for all terrestrial biota. This is demonstrated by hazard quotients (estimated dose divided by benchmark dose) that are orders of magnitude lower than the acceptable level of 1 (Table 7). The low hazard quotient indicate that risk to ecological receptors is negligible.

Table 7. Dose benchmark and hazard quotients for small mammals and invertebrates

	Estimated dose, μGy/h	**Benchmark dose, μGy/h**	**Hazard quotient**
Small mammals, birds, and invertebrates	7.1×10^{-3}	100	7.1×10^{-5}

5.5 Uncertainties of ecological risk assessment

The exposure scenario discussed above used the most conservative approach. In reality, ecological receptors are unlikely to spend much time in the zone because there is better habitat elsewhere.

The doses in other habitat areas distanced from the rooftop stacks would be significantly lower due to dispersion and dilution in atmosphere and relatively short half-lives of radioargon and radioxenon, as mentioned previously in section 4.2.4.

Since noble gases do not enter soil, plant, and water environmental compartments, there are no exposure to the habitats of these areas.

6.0 CONCLUSIONS AND RECOMENDATIONS

The calculations shown in this ERA confirm that the SLOWPOKE-2 Facility is indeed a very low risk-polluting facility to humans and to the ecological environment. As documented in the RMC Annual Compliance Reports to the CNSC for the past many years, the Facility:

a) Releases no radioactive liquids in the environment. In rare situations when deionised water from the reactor pool needs to be released into the public sewer system, samples of the water are analyzed for radioactive content prior to disposal.
b) Practices delay-and decay to allow the vast majority of irradiated samples to decay to the background level prior to disposal as hazardous waste via Chemistry and Chemical Engineering Department at RMC. Wastes with radioactivity levels above background are disposed of to a certified radioactive waste disposal site in accordance with CNSC regulations.
c) Practices delay-and-decay to allow the buildup of fission gases in the headspace of the reactor container to decay for a minimum of 48 hours before the gas is released to the exhaust fan on the roof of the western staircase to Sawyer Building Mod 5 to minimize radioactive emission.
d) Regularly measures and records the radioactive content of the pool water and, separately, the reactor water for the presence of radioactive isotopes and their quantity. No radioisotopes are normally found in the pool water. Reactor container water analysis did not show signs of the fuel failure since reactor commissioning in 1985 and after refuelling in September 2021.

The only direct release from the Facility into the environment is an emission to the atmosphere of the noble gases Xenon-133, half-life = 5.245 days, and Argon-41, half-life = 1.82 hours, from the reactor headspace and Ar-41 in the return-air from irradiation sites. Calculations in Section 4.2.2 of the present document demonstrate that radiation exposure from reactor headspace and irradiation sites gaseous releases in a form of Xenon-133 and Argon-41 are minimal and well below CNSC recommended annual exposure dose of 1mSv/year for the general public. Values are also substantially lower than benchmark doses for ecological receptors.

This ERA concludes that the RMC SLOWPOKE-2 reactor has:

1. No hazardous liquid effluents or solid waste released to the environment.
2. Low emissions.

3. Annual doses to the general public of less than the public limit of 1 mSv/year for each of its 37 years of operation. The facility exercises ALARA principles to minimize exposure to workers and general public.
4. Very low doses to birds, small mammals, and insects, which are below ecological benchmarks.
5. No measurable environmental impacts.

There are no new recommendations for increased monitoring. The Director of the SLOWPOKE-2 Facility at RMC keeps analysis and monitoring records of the radioactivity of the reactor water and also of the reactor container headspace and, monthly, observes the trend of the data, which should show any unusual occurrences developing. At that point, action would be taken by the Director to correct any abnormal situations.

7.0 QUALITY ASSURANCE / QUALITY CONTROL

The SLOWPOKE-2 Facility along with the Analytical Science Group at RMC is accredited to the ISO 17025 standard by the Canadian Association for Laboratory Accreditation Inc. (CALA) and exercises QA/QC system [26] in accordance with the standard. The facility is audited by CALA inspectors on a regular basis.

All data obtained through the regular maintenance/monitoring program is submitted to CNSC as part of the annual report.

7.1 Planning

The Facility has learned from experience over the past 37 years, and will continue to learn in the future, how to plan sampling and analyses in order to stay vigilant to unfolding situations in the operation of the Facility.

7.2 Data Gathering

With respect to the environment and keeping aware of the condition of the fuel pins, data is gathered from the monthly gamma, beta, and alpha analysis of reactor water and the headspace gas in the reactor container.

7.3 Data Management

The data so gathered is kept in a database by the Director of the SLOWPOKE-2 Facility. The database is saved on an external hard drive as well as on the Director's computer.

7.4 Data Analysis

The analysis of the "what and how much" of the radionuclides found during gamma ray spectroscopy is done by a software program. The results are saved in a database by the Director of the Facility and duly reported in SLOWPOKE's annual compliance reports to the CNSC.

7.5 Report Preparation

The Director prepares all reports concerning the Facility and distributes the information as required by the CNSC and also as necessary.

7.6 Record Keeping

The Director of the SLOWPOKE-2 Facility at RMC is responsible for all record keeping for the Facility. All records are kept in the Director's computer as well as on an external hard drive. Records are not deleted, but the information kept while the Facility is in operation; that is, not decommissioned.

8.0 REFERENCES

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[26] *The Quality Assurance Manual SLOWPOKE-2 Facility,* 2022.

ANNEX A: TABLE OF "SHALL" CLAUSES FROM N288.6-12

SLOWPOKE-2 Facility at RMC Compliance with Requirement Clauses of CSA N288.6-12

CSA N288.6-12 Section	"SHALL" Statement	Compliance (Y/N) or Not Applicable (NA)
4	**Environmental risk assessment objectives and report format**	
4.2.1	The licensee shall prepare an ERA report summarizing the results of the assessment.	**Y**
5	**Environmental risk assessment framework, tiers, and timelines**	
5.3.1	A nuclear facility shall review its ERA to verify its applicability and shall update it, as necessary, consistent with the overall iterative process for the ERA.	Review = **Y**, Update as necessary = **Y**
5.3.2	The review process and findings shall be thoroughly documented.	Intention = **Y**
8	**Evaluation of uncertainty**	
8.2.2	The ERA shall identify and discuss the uncertainties associate with the models and and data used in preparing the assessment, focussing on uncertainties that are important to the risk result.	**NA**
10	**Quality assurance and quality control**	
10.2	All aspects of the ERA process shall have appropriate QA and QC.	**Y**
11	**Periodic review of the ERA**	
1.1	A nuclear facility shall review its ERA to verify its applicability and shall update it, as necessary, consistent with the overall iterative process for the ERA.	Review = **Y**, Update as necessary = **Y**
Annexes A through H, inclusive	These annexes are all "informative".	**Not Mandatory**