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Environmental Risk Assessment
McMaster Nuclear Reactor

Revision 1

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Environmental Risk Assessment
McMaster Nuclear Reactor

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ACRONYMS, UNITS AND GLOSSARY

Note: In the electronic version of this report, acronyms are linked to this list for easy lookup of meaning by the reader.

ABB	Arthur N. Bourns Building
ALARA	as low as reasonably achievable (principle)
ALI	Annual limit on intake [29]
biota	animals and plants living in a particular place
Bq	Becquerel = SI unit of radioactivity strength = the amount of released radiation
kBq	kilo- Becquerel = 1000·Bq
cfm	cubic feet per minute
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
DEL	Derived Emission Limit (synonym of DRL)
DRL	Derived Release Limit (synonym of DEL)
effluent	A liquid release of a hazardous or nuclear substance to the environment [1].
emission	An airborne release of a hazardous or nuclear substance to the environment [1].
ERA	Environmental Risk Assessment
eV	electron Volt = unit of energy used in nuclear physics = 1.602×10^{-19} J.
keV	kilo electron Volt = 1000×eV
IAEA	International Atomic Energy Agency
IAHS	Institute of Applied Health Sciences
ICRP	International Commission on Radiological Protection
GSB	General Sciences Building
Gy	Gray = SI unit of absorbed dose = energy deposited by ionizing radiation in a unit mass of matter being irradiated
nGy	nanoGray = $Gy\times10^{-9}$
ha	hectare, metric unit of area equal to 10,000 m^2
HEPA	High-Efficiency Particulate Absorbing (filter)
HEU	High-Enrichment Uranium
HHRA	Human Health Risk Assessment
HQ	Hazard Quotient [2]
	Estimated dose or concentration divided by benchmark dose or concentration
HVAC	Heating, Ventilation, and Air Conditioning
J	Joule = SI unit of energy
L	Litre (or Liter) is non-SI unit of volume = 1×10^{-3} m^3
LEU	Low-Enrichment Uranium
MDC	Minimum Detectable Concentration
MHRA	Multiple High Radiation Alarm
MNR	McMaster Nuclear Reactor
mR	Milli-Roentgen (unit of measuring ionizing radiation)
mSv	Milli-Sievert = $Sv\cdot10^{-3}$ (SI unit of ionizing radiation dose)
MW	megawatt (unit for measuring power that is equivalent to 10^6 watts)
NFAS	Norfolk Fire and Ambulance Station – Station 10
NRB	Nuclear Research Building

Continues on next page

ACRONYMS, UNITS AND GLOSSARY continued

QMS	Quality Management System
RB	Reactor Building
RCS	Reactor Cooling System
RIFLS	Reactor Irradiation Facilities for Large Samples
SAR	Safety Analysis Report
SI	abbreviation for International System of Units
SLRA	Screening Level Risk Assessment
Sv	Sievert = SI unit represents the stochastic health risk of ionizing radiation.
mSv	milli-Sievert = 10^{-3} Sv
µSv	micro-Sievert = 10^{-6} Sv
$t_{1/2}$	Half life symbol
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
β	Beta (particle) radiation symbol
γ	Gamma (ionizing) radiation symbol

1. INTRODUCTION

The Canadian Nuclear Safety Commission (CNSC) requires an Environmental Risk Assessment (ERA) report to be submitted for the McMaster Nuclear Reactor (MNR). The ERA is an evaluation of hazards that the MNR poses to the environment and of impacts these hazards have on the environment and the public.

REGDOC-2.9.1 [1] outlines "*the CNSC's requirements and guidance to applicants and licensees for developing environmental protection measures, including an ERA*"[1]. It is stipulated that, *for Class I facilities and uranium mines and mills, the licensee shall conduct an ERA in accordance with Canadian Standards Association (CSA) N288.6 [2]*[2]. This standard focuses on the normal operation of a facility (Sections 1.2 and 1.3 in [2]). Hence, the ERA does not cover hypothetical accidents, which are addressed by existing safety analyses (e.g., MNR Safety Analysis Report (SAR) [3] and other reports such as [4]).

The ERA is an iterative activity as illustrated in Figure 1. The MNR is a small, research reactor which houses only small amounts of hazardous substances. With more than 6 decades of safe operating history, ample data is available on the actual (existing) physical and administrative provisions for protecting humans and the environment from harm. It follows that the conservative Tier 1 process of CSA N288.6 [2] (called the Screening Level Risk Assessment (SLRA)) shown in Figure 1 is adequate and appropriate for this report.

This report covers:

- Site characteristics including terrestrial and aquatic environments, climate and meteorology, geology and hydrology (Section 2).
- MNR and its features for limiting hazardous emissions into internal and external environments (Section 3).
- MNR interactions with the environment and the public = airborne emissions, liquid effluents and energy releases to the environment (Section 4).
- Monitoring of hazardous substances within and outside of MNR (Section 5).
- Risk-related criteria = criteria to confirm that there are no concerns with the emissions[3] from the MNR (Section 6).
- Human risk assessment (Section 7).
- Ecological risk assessment (Section 8)
- Summary of findings (Section 9).

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1 Citation (*in italic font*) from Preface of [1].
2 Citation (*in italic font*) from Requirements in Section 4.1 of [1].
3 There are no hazardous liquid effluents from the MNR as explained in Section4.2.

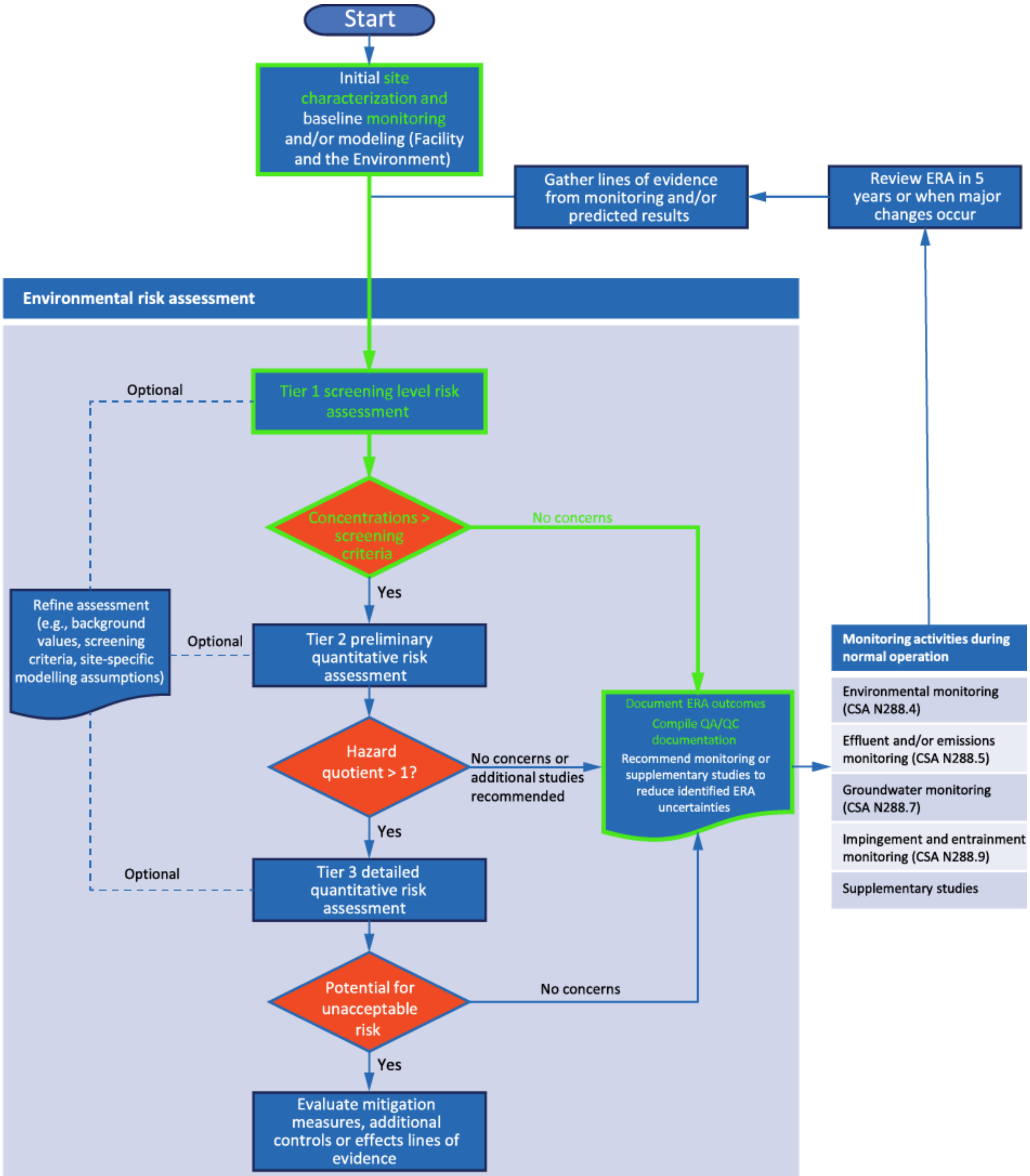

Figure 1: ERA progression through tiers of assessment

Annotated Figure 5.1 from [2].
Green lines and text identify the SLRA tasks.

2. PHYSICAL AND BIOLOGICAL ENVIRONMENT

2.1 General Site Information

This information is updated Section 3.1 of MNR SAR [3] supplemented by information on indigenous interests related to the site.

McMaster University recognizes and acknowledges that it is located on the traditional territories of the Mississauga and Haudenosaunee nations, and within the lands protected by the "Dish with One Spoon" Wampum agreement.

The University's main campus is located at the western end of the City of Hamilton, west of the community of Westdale and east of the town of Dundas (Figure 2). The University is situated on lands previously owned and maintained by the Royal Botanical Gardens.

The campus is bounded on the west by Cootes Drive, on the east by Forsythe Avenue, on the south by Main Street, and on the north by Cootes Paradise valley[4]. The site topology is shown in Figure 3.

MNR is located on the University's main campus. The surrounding area is mostly residential with some commercial activity and light industry as illustrated in Figure 4. Hamilton population in 2022 is estimated at 819,167[5] residents. There are no indigenous communities in the proximity of the MNR (Figure 5).

John C. Munro Hamilton International Airport is located approximately twelve kilometres south of McMaster University (Figure 4). The campus is in the flight path for some take-offs and landings, but the majority of flights are well to the east of the campus. An infrequently used helipad is located about 500 metres to the west of MNR.

The potential for vehicular impact is reduced by separation. The nearest highway or major road is 200 metres from the Reactor Building (Figure 2). Internal roads are speed-limited and there are no lengthy, clear paths leading to the Reactor Building (Figure 6). There are no railway lines within one kilometre of the Reactor Building.

2.2 Natural Environment

This information is from Section 3.2 of MNR SAR [3].

2.2.1 Terrestrial Environment

Cootes Paradise marsh (also known as Dundas marsh) is an 840 ha sanctuary located North of the University in the Dundas Valley (Figure 3). Approximately 250 ha of the sanctuary is wetland[6]. Its two main tributaries are Spencer's Creek to the southwest, and Chedoke Creek to the southeast. Both creeks have been altered to accommodate growth and development in Dundas and Hamilton. Westdale Brook (east of the campus), unnamed creek in the northern part of the campus and Coldwater Creek (to the west) drain into Cootes Paradise marsh. The physical appearance and biotic nature of the Cootes Paradise sanctuary have changed significantly in the last century.

Dundas Valley includes a relatively large forested area which contains plant and animal species that are considered to be rare, threatened or vulnerable, not only locally but also in Ontario and Canada[7]. Several forest types exist in and around the valley. The Broad Leaf Upland Wood is composed of Red Oak, White Oak, Sugar Maple and Red Maple. The Mixed Upland Wood is similar to the Broad Upland

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4 Also known as Dundas valley.
5 https://www.populationu.com/cities/hamilton-population
6 This wetland is not a source of drinking water.
7 See [5] to [9] for lists of animals in the Hamilton Area. See [10] for the list of trees in the Hamilton Area.

Wood except it also contains White Pine and Eastern Hemlock. The Broad Flood Plain Forest is composed of willow and the Tall Shrub Thicket is largely Hawthorn and Large-Toothed Aspen.

The Carolinian forest[8] tends to be lost or fragmented because of development for agriculture and housing and because it lies within areas of the highest population density in Canada. It is currently considered to be disturbed rather than pristine habitat because of heavy recreational use, large populations of invasive plants and proximity to steel mills, heavy industry and other sources of pollutants. Increasing average water levels have reduced the extent of marsh vegetation bordering the forest and increased erosion at the steep banks of Cootes Paradise.

2.2.2 Aquatic Environment

Prior to 1940 Cootes Paradise had a relatively diverse community of aquatic plants which covered the whole western half of the marsh. The water quality, plankton and fish communities were indicative of clear conditions. Water was clear and cool but tended to be depleted of oxygen. Algae were mostly green algae and diatoms[9]. The macrophyte[10] community supported a diverse assemblage of benthic[11] invertebrates while the zooplankton community of Daphnia, copepods and rotifers supported a healthy community of piscivores[12] such as northern pike and largemouth bass. There is relatively low species diversity in all levels of flora and fauna communities, and those present are hardier, pollution-tolerant forms. The macrophyte[10] community is almost entirely emergent plants covering less than ten percent of Cootes Paradise Marsh and only along the fringe. The water is very turbid, warm and high in nutrients, but well-oxygenated because of wind and algal photosynthesis. The water quality is indicative of the Dundas sewage treatment plant being put into operation in 1972. The algal communities are dominated by species which are common inhabitants of sewage ponds such as green algae, diatoms and others. The zooplankton community is dominated by small-bodied cladocerans[13] and rotifers[14], supporting a thriving community of planktivores[15] and benthivores[16]. There are essentially no piscivores[12]. The benthic[11] community consists of pollution-tolerant forms such as blood worms and oligochaetes[17]. Many of the insect families abundant in the past century have disappeared. The fish community is dominated by the fish feeding on the plankton and the benthic[11] prey with a large population of turbidity-tolerant carp and a few sport-fish [11].

Additional information on the Cootes Paradise marsh is available in Appendix D of [12].

2.3 Climate and Meteorology

This information is updated Section 3.6 of MNR SAR [3].

The Hamilton region has a continental climate moderated by proximity to Lake Ontario. The lake modifies both winter and summer extremes and provides additional moisture to intensify precipitating systems. Hamilton has rainy weather (including trace) on more than half of the days in the year. The average annual precipitation in the area is 806 mm with a fairly uniform distribution on both monthly and annual bases. February is the driest month (average precipitation 53.5 mm) while August is the wettest (75.7 mm). Winter (December to February) precipitation arises from frontal depression systems and occurs mainly as snow. Spring precipitation is mainly frontal, with some due to convective

[8] Predominantly deciduous (broad-leaf) forest.
[9] Diatoms are single-celled algae.
[10] Macrophyte is an aquatic plant, large enough to be seen by the naked eye.
[11] Living in the bottom of lakes, rivers and ponds.
[12] Fish-eating animals.
[13] Commonly known as water fleas.
[14] Commonly called wheel animals.
[15] Aquatic organisms that feeds on planktonic food.
[16] Animals that feed of benthic[11] prey.
[17] Earthworms and many small species of freshwater worms.

activities. Most of the summer precipitation is relatively brief and showery, resulting from convective and thunderstorm activities. During autumn, more cold air masses and frontal depressions approach the area, resulting in longer periods of precipitation.

The wind directions at the reactor site are illustrated in Figure 7. Buildings near the Reactor Building (Figure 6) affect the wind distribution slightly by shielding it somewhat from the south and southwest.

Temperature inversions are very common in the area partly because of the Niagara Escarpment; these inversions frequently persist for extended periods.

Additional information is provided in the following sub-sections.

2.3.1 Climatic Aspects

2.3.1.1 Physiography (Physical Geography)

Hamilton lies at the foot of the Niagara Escarpment, which here turns from a westerly to a northerly trend. This 61-metre step in the landscape tends to deflect winds, to cause temperature contrasts between its crest and its foot, to induce condensation when humid air is forced to rise over it, and thus causing development of clouds, fog, and precipitation. Conversely, air dropping down over the Escarpment tends to be adiabatically warmed, leading to evaporation rather than condensation. In the Hamilton District the Escarpment's influence is modified by the Dundas Valley over a distance of 25 kilometres. This re-entrant, formed by river and ice erosion, trends from WSW to ENE as seen in Figure 3. It acts like a funnel on moving air. This topological feature influences wind patterns around MNR (Figure 7), which tend to appreciably differ from the city patterns (Figure 8). Often, especially in spring and autumn, the Dundas Valley provides steady orographic[18] lift for cool, stable, saturated air moving westward from Lake Ontario, in which case the University becomes shrouded in fog. Above the cool, foggy air is usually found a temperature inversion, at the level of the Escarpment crest, above which warm air flows in a direction quite different from that in the valley. Such a weather condition may persist for a week or more and cause smog over the eastern industrial zone of Hamilton.

2.3.1.2 Water Bodies

Air passing over Lake Ontario tends to be cooled or warmed by convection and thus made more stable or more unstable, depending on the season. Similarly, air masses passing over the lake evaporate water and thus have higher humidity and increased probability of condensation on reaching shore. Generally, winds from the E, ENE, and NE bring instability showers of rain or snow or else stability drizzle or fog. Burlington Bay and Cootes Paradise tend to accentuate such conditions over the McMaster campus as long as waters remain unfrozen.

2.3.1.3 Latitude

At approximately 43°10' north of the equator, Hamilton receives the sun's rays at an angle of 70°15' at the June solstice and at 23°15' at the December solstice. The energy balance of the atmosphere, and thus the dependent climatic elements, undergo a typically wide middle-latitude fluctuation between the seasonal extremes.

2.3.1.4 Altitude

Since McMaster University lies at about 99 metres above sea level, the normal lapse rate air temperatures are about 0.5°C lower than at sea level. By the same argument, temperatures at the base of the Niagara Escarpment are about 0.5° warmer than at the crest.

[18] Associated with or induced by the presence of mountains.

2.3.1.5 Prevailing Winds

The location of Hamilton places it on the south-west side of the North Atlantic belt of high cyclonic frequency and to the south-east of the Canadian source region of cold high-pressure air masses. The City's climate is thus dominated by SW-NE or W-E air flow. Winds from McMaster University flow towards Hamilton and Burlington one-third to one-half of the days in an average year (Figure 7).

2.3.1.6 Air Masses, Fronts, and Storms

Winds from west and south-west occur most frequently over Hamilton but they are often interrupted by other air streams, controlled by the procession of cyclones and anticyclones which dominates the migration zones of the Polar and Arctic Fronts. In winter Hamilton lies slightly to the south of the mean position of the Arctic Front, which separates Continental Arctic air from the milder Continental Polar. Cyclonic disturbances involving such cold air masses seldom lead to heavy precipitation unless a mass which is forced to rise has been previously modified by passage over a water body. Quite frequently in every Hamilton winter, Modified Maritime Polar air from the north-east and Modified Maritime Tropical air from the south override the Continental air, bringing cloud, heavy precipitation and strong cyclonic wind flow.

In summer, Hamilton lies within the belt over which the Polar Front migrates, separating Maritime Tropical from Modified Continental Polar air. Although cyclonic wind circulations and associated frontal precipitation occur frequently in summer, much of Hamilton's rainfall in this season comes from thunderstorms which develop in unstable Maritime Tropical air as a result of differential surface heating and/or mechanical turbulence set off by the Niagara Escarpment.

2.3.2 Climatic Elements

2.3.2.1 Temperature

Occurrences and values of temperatures above 21°C and below -6°C are shown in Tables 1 and 2, respectively. The age of the data should not be taken as an indication of a lack of applicability. February is the coldest month and July the warmest, their average daily temperatures being separated by 27°C.

2.3.2.2 Precipitation, Including Snowfall

The distribution of precipitation (including rain and snow) is uniform throughout the year. There is no summer maximum because of the proximity of unfrozen Lake Ontario in winter and the influence of frontal lift at all seasons. Snowfall taken alone reaches a maximum in January and occurs in seven months of the year. Total snowfall is small, representing only 125 - 150 mm out of a total precipitation of nearly 788 mm. Rain falls in nearly every winter month.

2.3.2.3 Wind

In the Hamilton area, calm conditions are rare. Strong winds occur frequently, especially in winter. Lake breeze, which develops under weak geostrophic wind[19] conditions on clear days in response to differential heating over land and water surfaces, has rather a unique development in Hamilton. Steel making processes in the heavy industrial zone by Hamilton harbour add substantial heat to the natural heat mechanism. As a result, lake breeze is established from March to October and gains its maximum intensity in July and August. Land breeze forms at night in most of the months of the year, with a maximum intensity in July. Lake and land breeze patterns are quite localized, and only occasionally extend beyond the Niagara escarpment to some distance to the south. Average wind frequency and speed

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[19] the theoretical wind that would result from an exact balance between the Coriolis force and the pressure gradient force

for the period 1990 to 1999 are shown in Figure 8. The monthly variations for the same period are in Figures 3-6 through 3-17 of the MNR SAR [3].

2.4 Geology

This information is from Section 3.4 of MNR SAR [3] and from [4].

The campus lies immediately south of Cootes Paradise and approximately 1 km north of the Niagara Escarpment on a plain within a broad topographic depression known as the Dundas Valley (Figures 2 and 3). This valley was cut prior to the Great Ice Age by a major river; during the Ice Age the valley was partially filled with glacial debris. A post-glacial lake, Lake Iroquois, extended well up the Dundas Valley west of the present Town of Dundas, forming a pronounced embayment. The pre- and postglacial geomorphic processes have resulted in a relatively deep layer (12-50 m) of sediment, with shallow coarser-grained sediments deposited on top of underlying silts. The Reactor Building is constructed within these coarser-grained deposits.

Given that there are no contaminated liquid effluents from the MNR (see Section 4.2), details of geological and hydrogeological properties outlined in Annex C of CSA N288.6-22 [2] are not required for this ERA.

2.5 Hydrology

This information is from Section 3.5 of MNR SAR [3].

The subsurface sediments below the McMaster campus area form the following hydro-geological zones; a bedrock surface aquifer[20] (Zone 1), a silty-clay aquitard[21] (Zone 2), and a near surface aquifer (Zones 3 and 4). The coarse-grained Zone 1 sediments form a relatively deep aquifer[20] which lies directly on the bedrock surface. Water in the aquifer arrives either from poorly sorted coarse sediments or from fractured portions of the bedrock. The thick fine-grained Zone 2 deposits form an aquitard[21] which appears to be continuous from the base of the Niagara Escarpment to Cootes Paradise and for at least 10 kilometres from west to east. The predominantly fine-grained nature of Zone 2 sediments severely retards groundwater movement, although fractures may provide local conduits for vertical groundwater flow. It is unlikely that any direct hydraulic connection exists between the bedrock surface aquifer and the overlying aquifer. Zone 3 and 4 sediments form a near-surface aquifer[20] across the campus area, with low-permeability Zone 2 sediments forming the base. This upper aquifer[20] extends continuously from near the Niagara Escarpment in the south to Cootes Paradise in the north. Regional groundwater flow is northward and north-eastward towards Cootes Paradise and Hamilton Harbour. The above noted aquifers are not sources of potable groundwater (i.e., drinking water).

Zone 3 sediments form the major aquifer[20] body below the campus area since the upper sediments of Zone 4 are largely de-watered. Groundwater flow in Zone 4 deposits is probably mainly downward into Zone 3. Groundwater flow beneath MNR is likely to be towards the north, in the direction of Cootes Paradise; there may also be a slight north-eastward component.

The base of MNR lies seven metres below the surface in silty sands. Given that the sediments are mostly unsaturated, any released water would migrate until it reached the top of Zone 3 deposits. Static groundwater elevations across the campus suggest that water movement in Zone 3 is towards the north and northeast. Groundwater migrating into Zone 3 would be discharged to the unnamed creek north of the campus and would ultimately enter Cootes Paradise.

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[20] Aquifer is a body of permeable rock which can contain or transmit groundwater.

[21] Aquitard is a geologic formation or stratum that lies adjacent to an aquifer and that allows only a small amount of liquid to pass.

A transport time of approximately 22 years has been calculated [13] for contaminated water to migrate from the reactor vicinity to the creek. Additional information on the hydrology is available in Appendix B of [12].

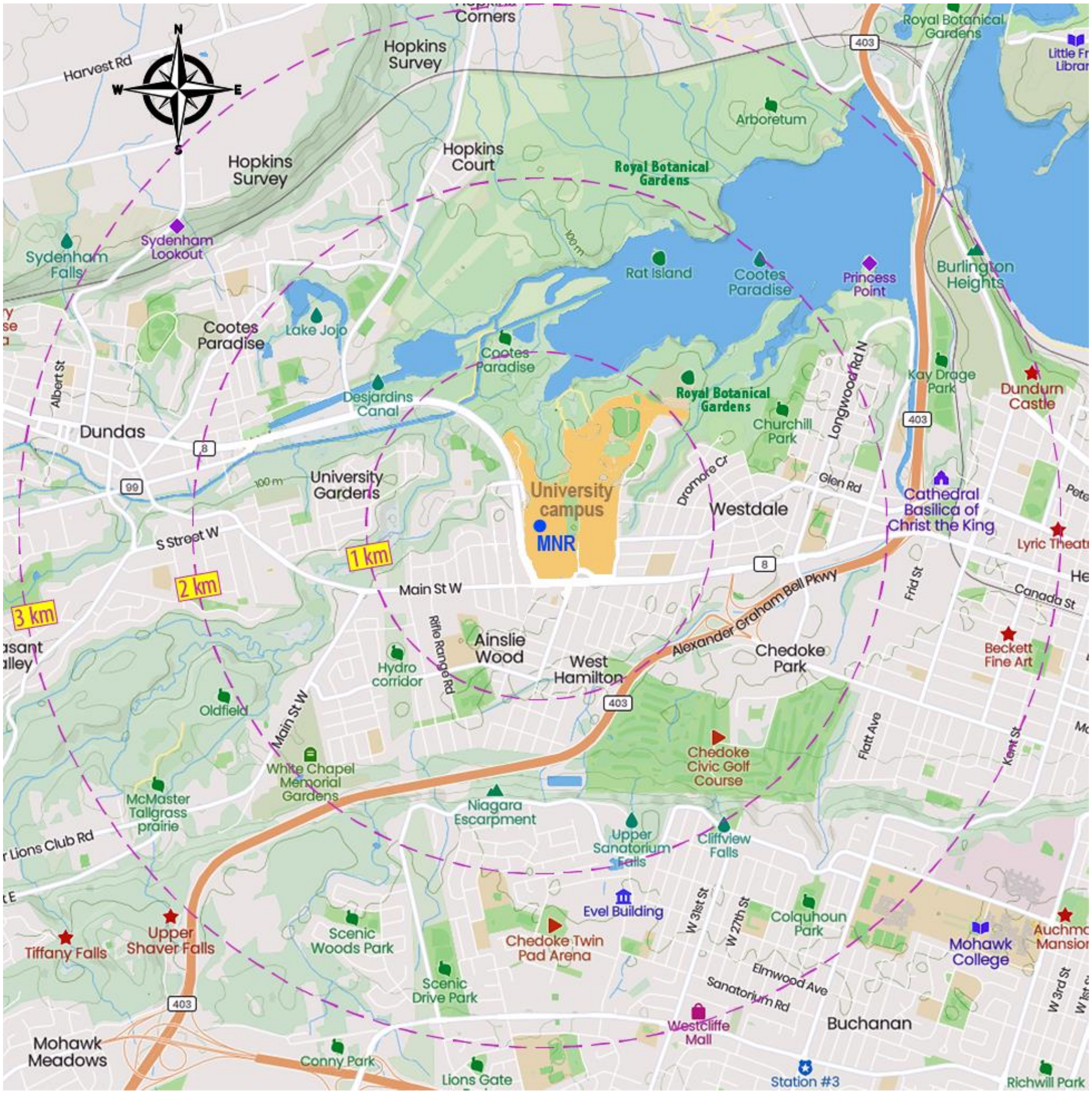

Figure 2: Site map

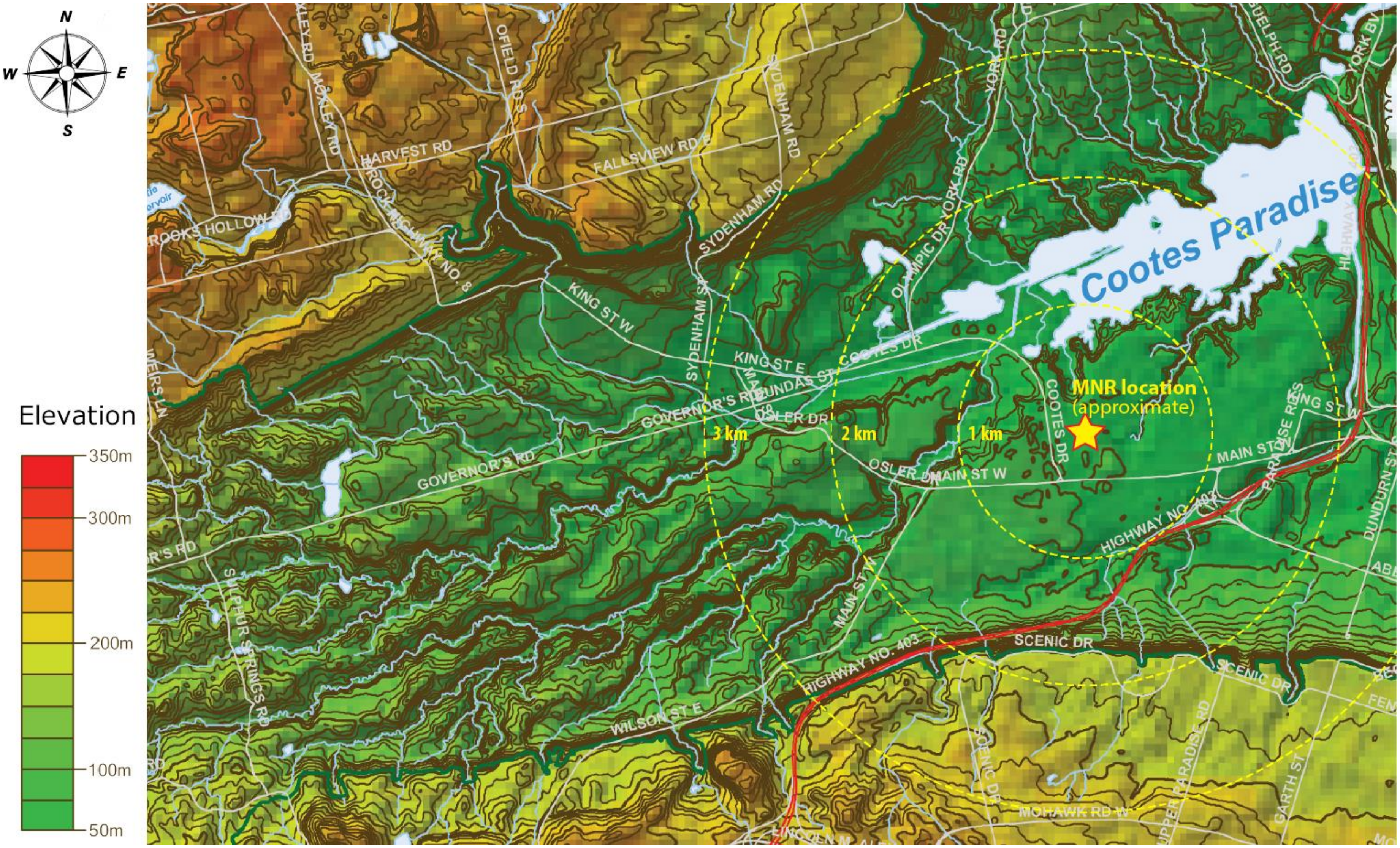

Figure 3: Site topography

Annotated Figure 3-10 in [4]

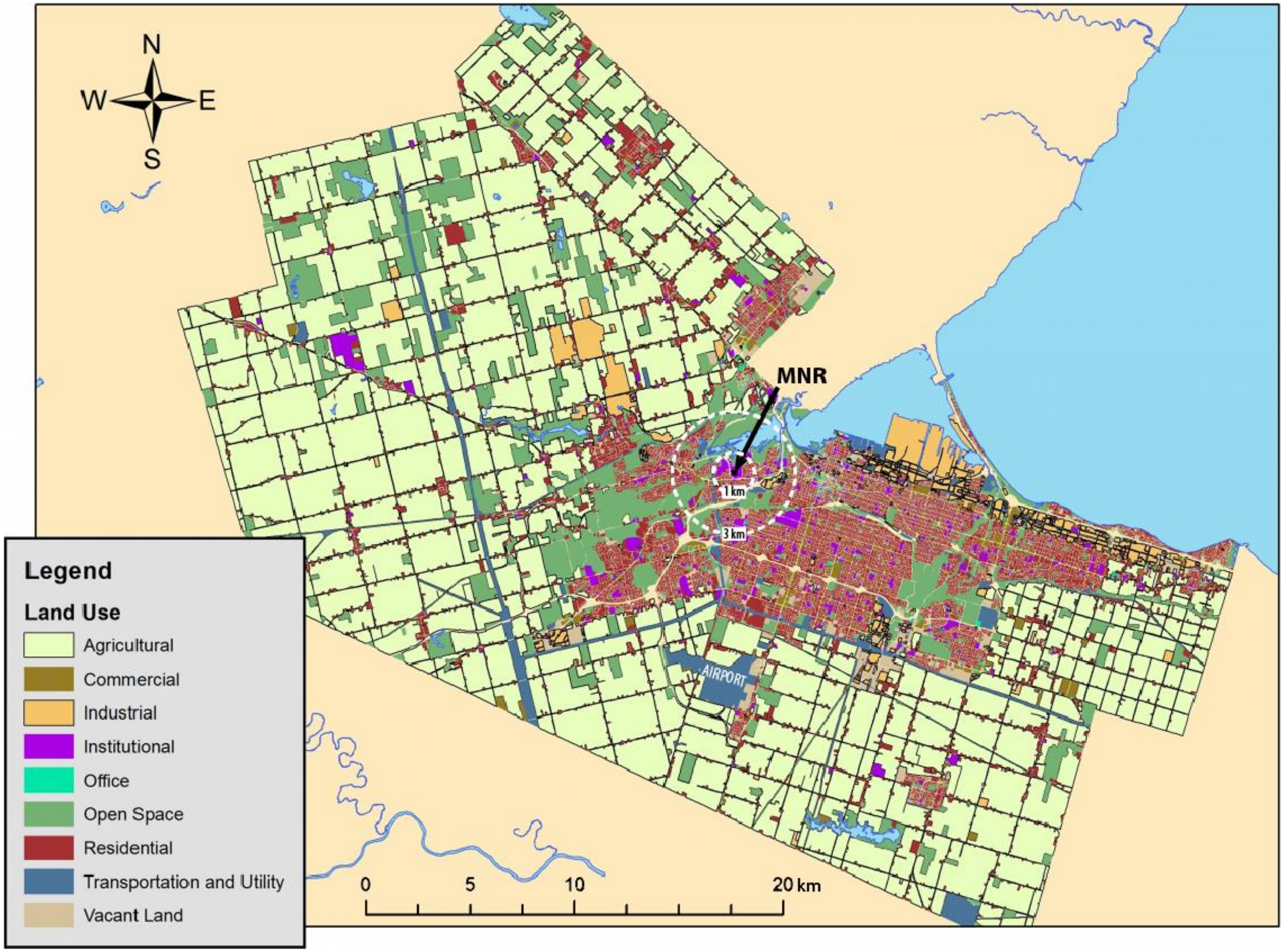

Figure 4: Hamilton land use (2016)

Annotated map from https://uwaterloo.ca/library/geospatial/blog/post/city-hamilton-land-use-2016

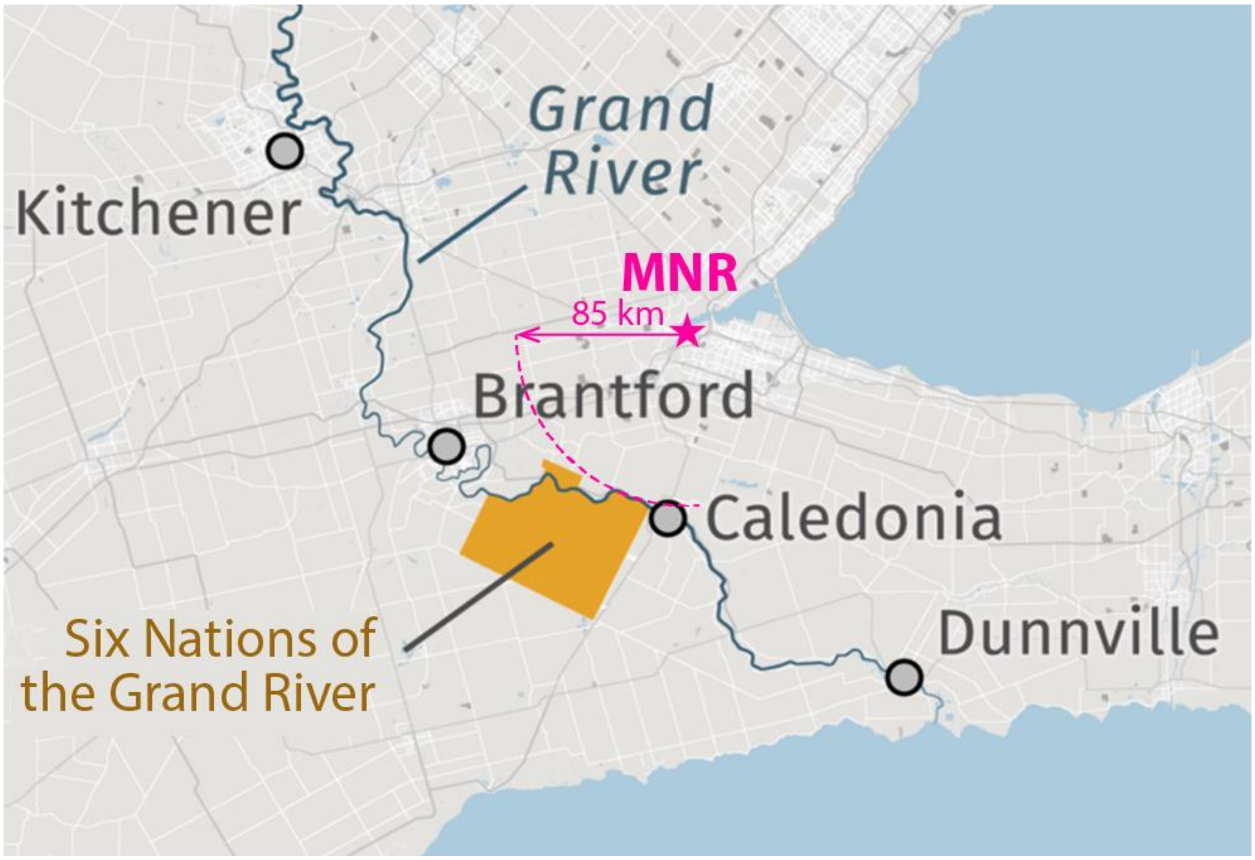

Figure 5: Location of an indigenous community nearest to MNR

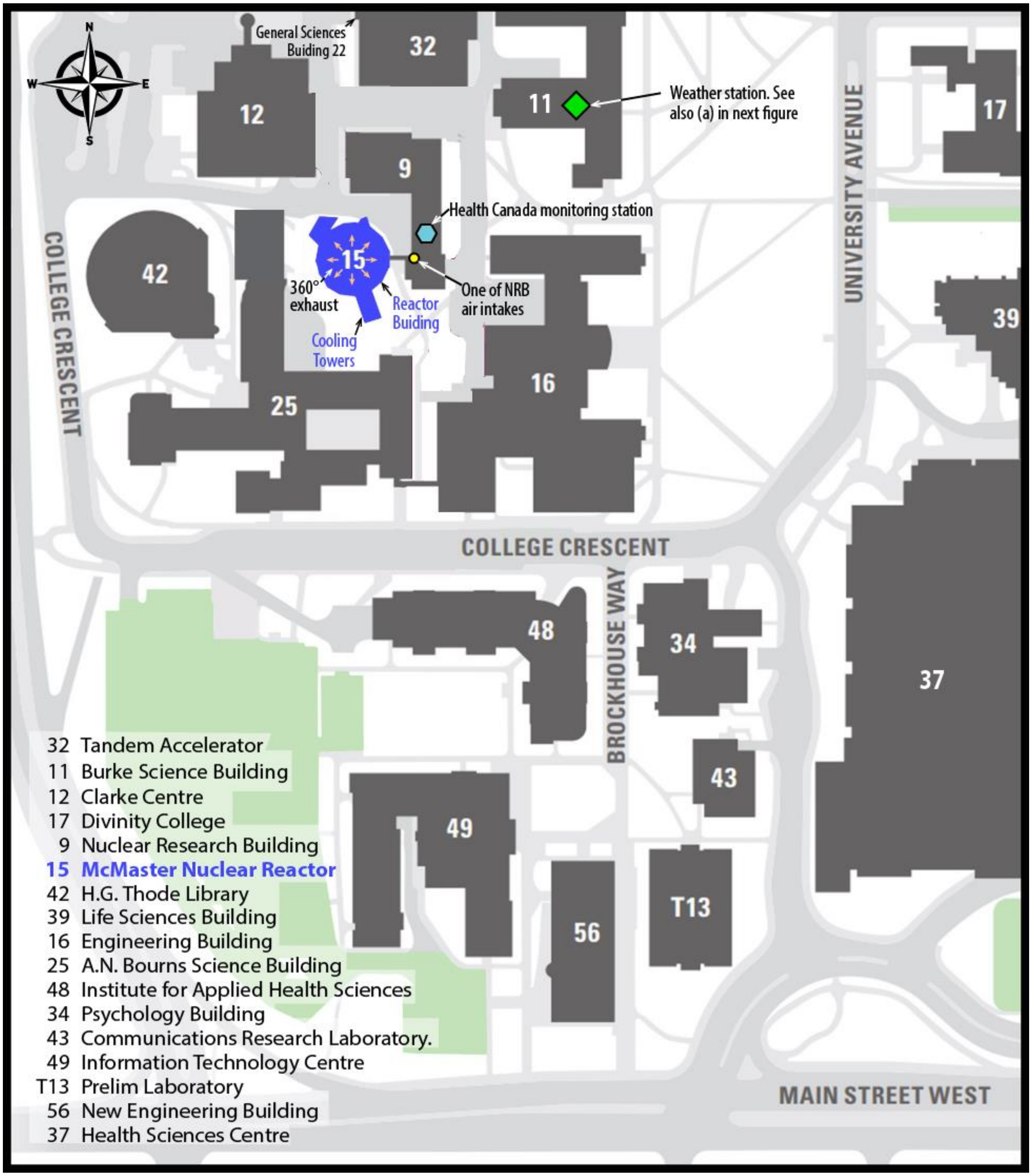

Figure 6: Surroundings of the McMaster Nuclear Reactor

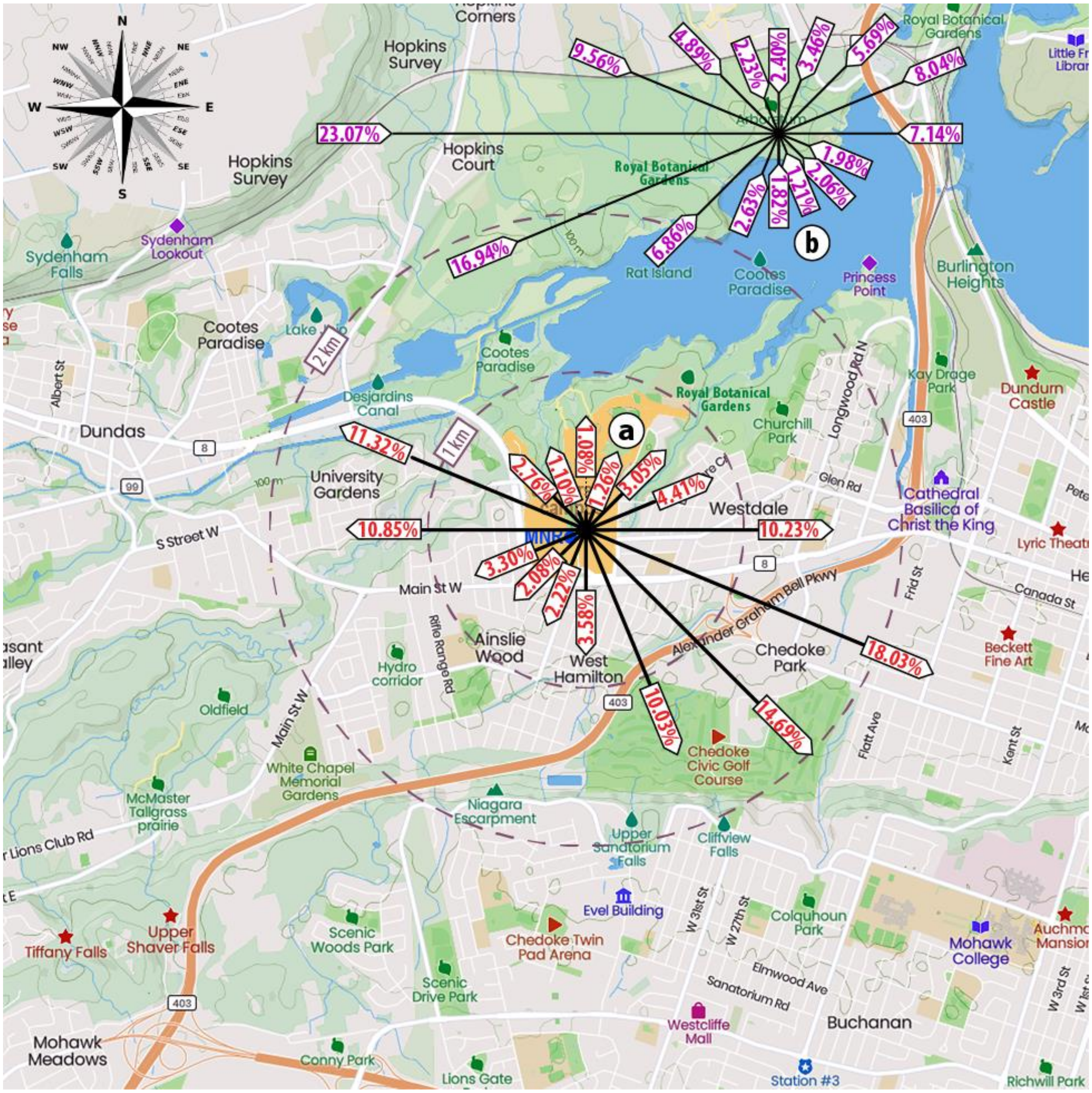

Figure 7: Wind directions around MNR

This is annotated Figure 2. Frequency as percent of all wind directions at (a) Burke Science Building ***(directions from MNR)****, and at (b) Royal Botanical Gardens* ***(directions to Arboretum)****. Lengths of direction lines are proportional to frequency percentage.*

(a) Prevalence summarized from hourly observations for years 2016 to 2021 from McMaster School of Earth, Environment & Society.

(b) Prevalence summarized from hourly observations for years 2000 to 2009 from Environment Canada[22]*.*

Human population in grey areas. Wild fauna and flora in green areas..

22 This data is used in legacy calculations of atmospheric dispersion of the emissions from MNR.

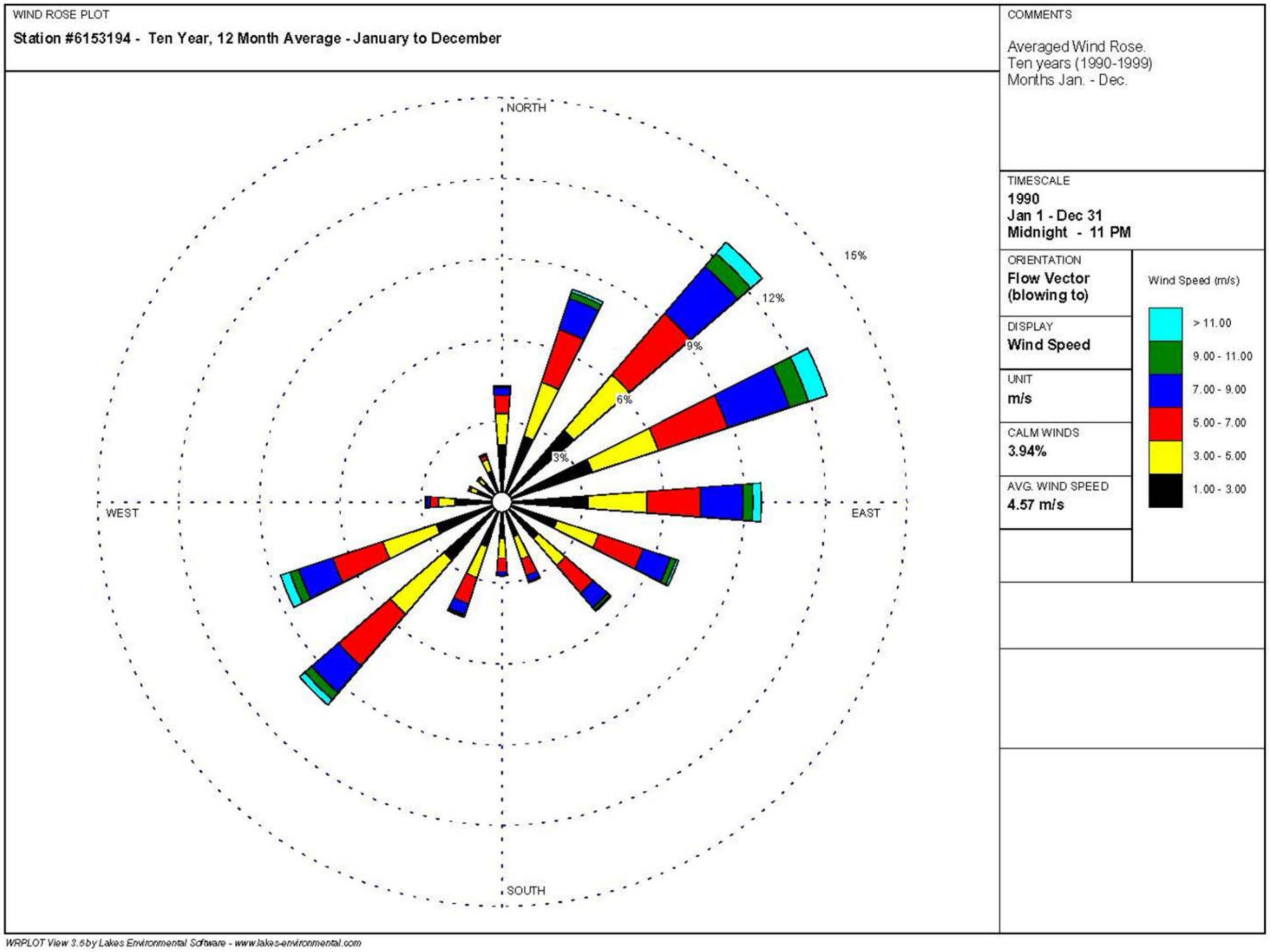

Figure 8: 1990 Hamilton average annual wind direction and speed

Figure 3.5 in [3].

Table 1: Frequency of temperatures above 21°C, 1898-1956

Temperature Range	Number of days
21.7 - 26.7°C	2716
27.2 - 32.2°C	1922
32.8 - 37.8°C	448
Over 37.8°C	14

Number of days with temperatures above 21.1°C to show annual variations				
	1953	1954	1955	1956
21.7 - 26.7°C	67	67	66	77
27.2 - 32.2°C	45	40	49	28
32.8 - 37.8°C	13	8	22	3
Over 37.8°C	...	...	1	...

Table 3-2 in [3][23]

Table 2: Frequency of temperatures below -6.7°C, 1898-1956

Temperature Range	Number of days
-12.2 to -7.2°C	1596
-25 to -12.7°C	847
Below -17.8°C	270

Number of days with temperatures below -6.7°C for the last four years to show annual variations				
	1953	1954	1955	1956
-12.2 to -7.2°C	67	67	66	77
-25 to -12.7°C	45	40	49	28
Below -17.8°C	13	8	22	3

Table 3-3 in [3][23]

[23] The age of the data should not be taken as an indication of a lack of applicability.

3. FACILITIES AND OPERATIONS

The MNR is located in the south-west quadrant of the campus (Figure 2).

3.1 Reactor Building

The MNR building is illustrated in Figures 9 and 10. It is the reinforced concrete structure[24] described in Section 4.1 of the MNR SAR [3] commonly called the containment. It forms the outermost barrier to the release of radioactivity into the environment. The free air volume of the containment is approximately 8500 m^3.

The building is occupied by the operating staff during reactor operation, and it may be unattended when the reactor is shut down. The ventilation system of the building (Figure 11) provides heating, ventilation, and air conditioning as well as performs the safety function of 'vented confinement' for areas of the building that may house radioactive materials other than irradiated fuel. Fresh air is drawn into the building through the inlet damper by the Pre-Heat fan at a rate of 4,800 cfm (136 m^3/min)[25]. Some of this air is diverted to the Office fan which supplies the offices, stairwells, washrooms and the Iodine Production Enclosure. The remaining air is distributed throughout the building and re-circulated by the Reactor Hall fan at the nominal flow of 5,000 cfm (140.2 m^3/min). All building volumes are at sub-atmospheric pressure relative to the outside environment[26]. The exhaust air is filtered through particulate and High-Efficiency Particulate Absorbing (HEPA) filters before discharge through the exhaust damper. The nominal outflow is also 4,800 cfm (136 m^3/min). A Geiger counter in the exhaust duct monitors airborne activity. If an elevated radiation level is detected, the inlet and exhaust ducts are automatically sealed by the dampers, and the inlet and exhaust fans are shut off.

The building has four floors as illustrated in Figures 12 through 15. Radioactive materials are located either within one of the pool segments (irradiated fuel submerged in pool water) or on the sub-terrain floor of the building (waste) as indicated in Figure 12. In addition, small amounts of radioactive substances used to produce the medical isotope Iodine-125 are handled and temporarily stored on the Experimental Floor as indicated in Figure 14. Miscellaneous non-radioactive chemicals are present at various building locations as listed in Appendix A of [17].

3.2 Reactor

The reactor is a low-power[27], pool-type research reactor illustrated in Figure 16. It is operated since 1959. Initially, it used High-Enrichment Uranium (HEU), eighteen-plate (sixteen fuelled, two dummy) fuel assemblies. At times, ten-plate (all fuelled) HEU fuel assemblies have also been used. The reactor was converted to Low-Enrichment Uranium (LEU) fuel between 1999 and 2006. General specifications of the current (LEU) reactor are given in Table 3[28].

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[24] The structure was built in accordance with procedures and standards in effect in 1959.
[25] The recent fan upgrade has increased the air inflow and outflow from 3500 cfm to 4800 cfm.
[26] This means no emission other than that through the engineered exhaust duct.
[27] The MNR is designed for 10 MW thermal power. It is currently licensed to operate at ≤ 5 MW and it operates at 3 MW over the past 2 decades.
[28] Additional information on the reactor is provided in Section 5 of MNR SAR [3].

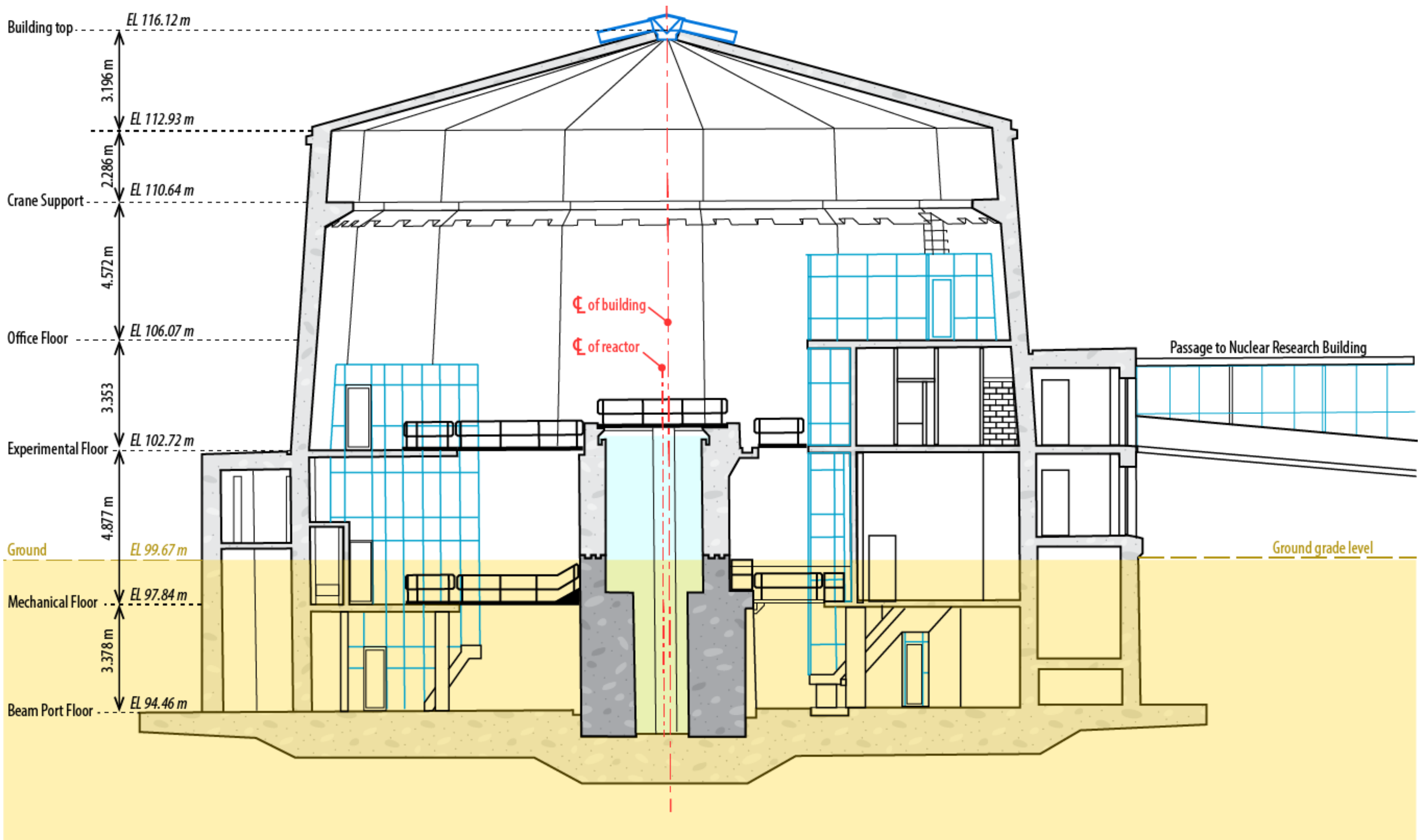

Figure 9: MNR building E-W section

Redrawn Figure 4-1 in [3] with ground grade shown.

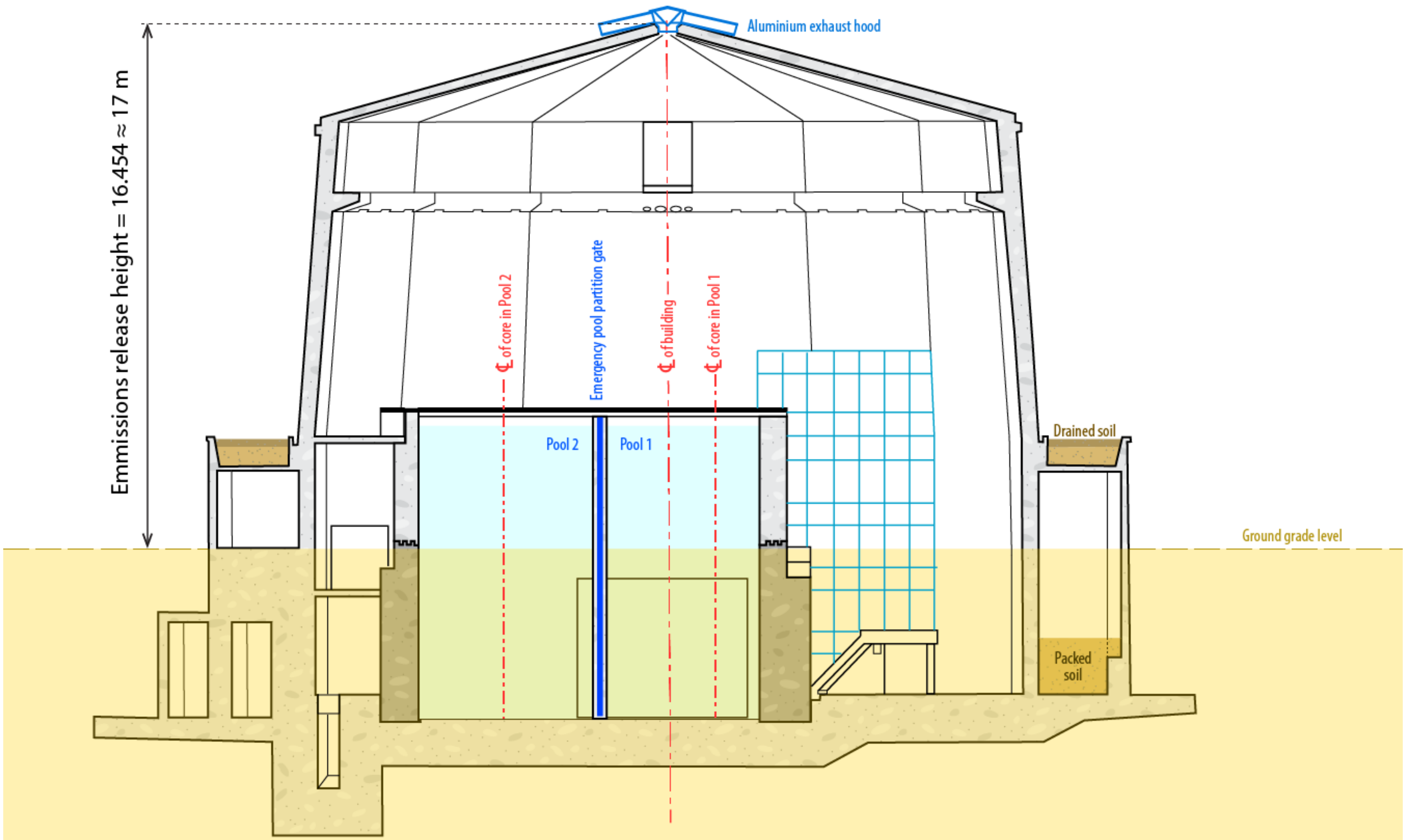

Figure 10: MNR building N-S section

Redrawn Figure 4-2 in [3] with grade with height of emissions release enumerated.

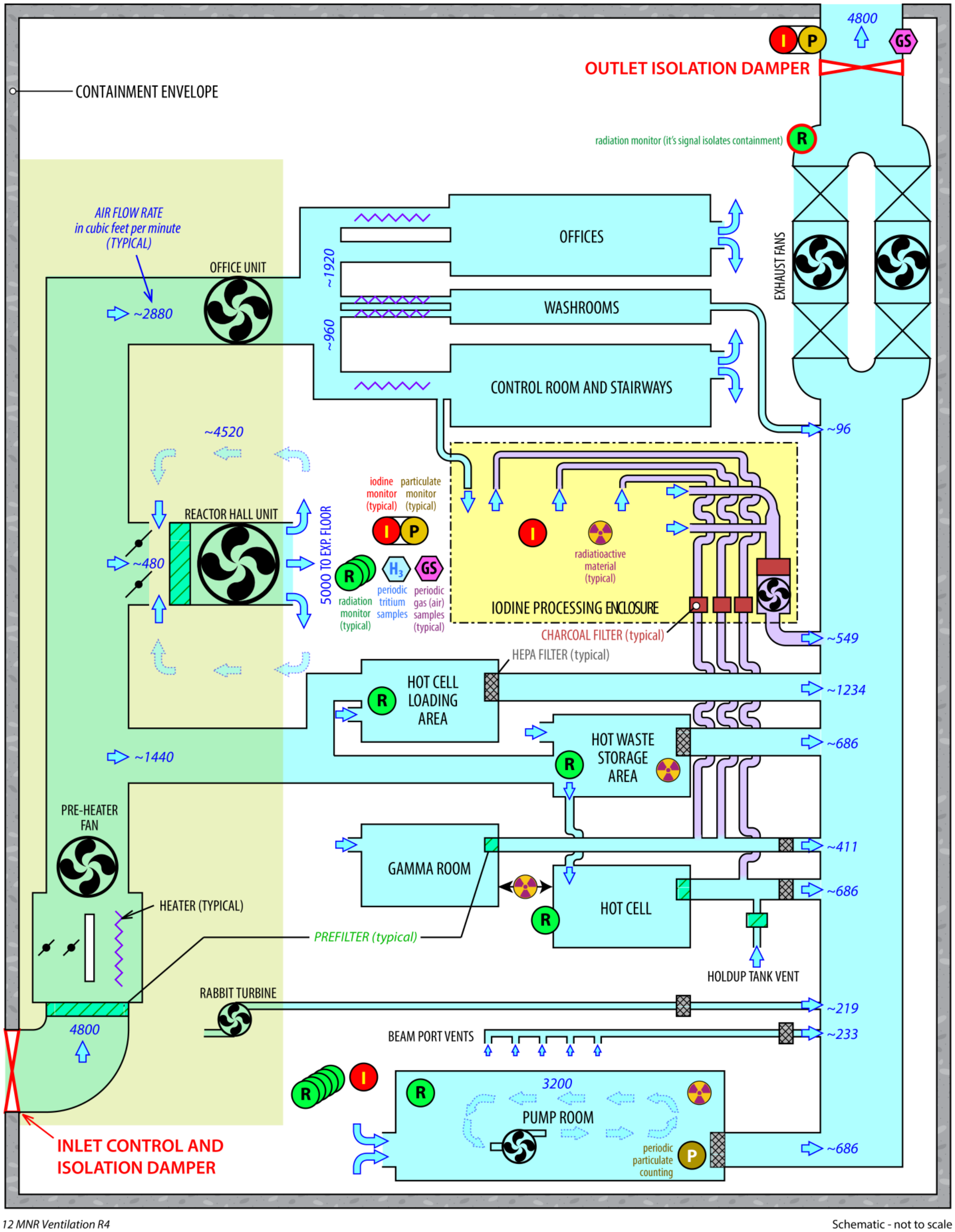

Figure 11: Schematic of ventilation system in MNR building

Updated Figure 3-7 in [17] and Figure 4-7 in [3].
The inflow/outlow rates are updated; the flow distribution is approximate. The ductwork layout in the Iodine Enclosure is updated. Approximate locations of radiation sources and monitoring provisions are illustrated.

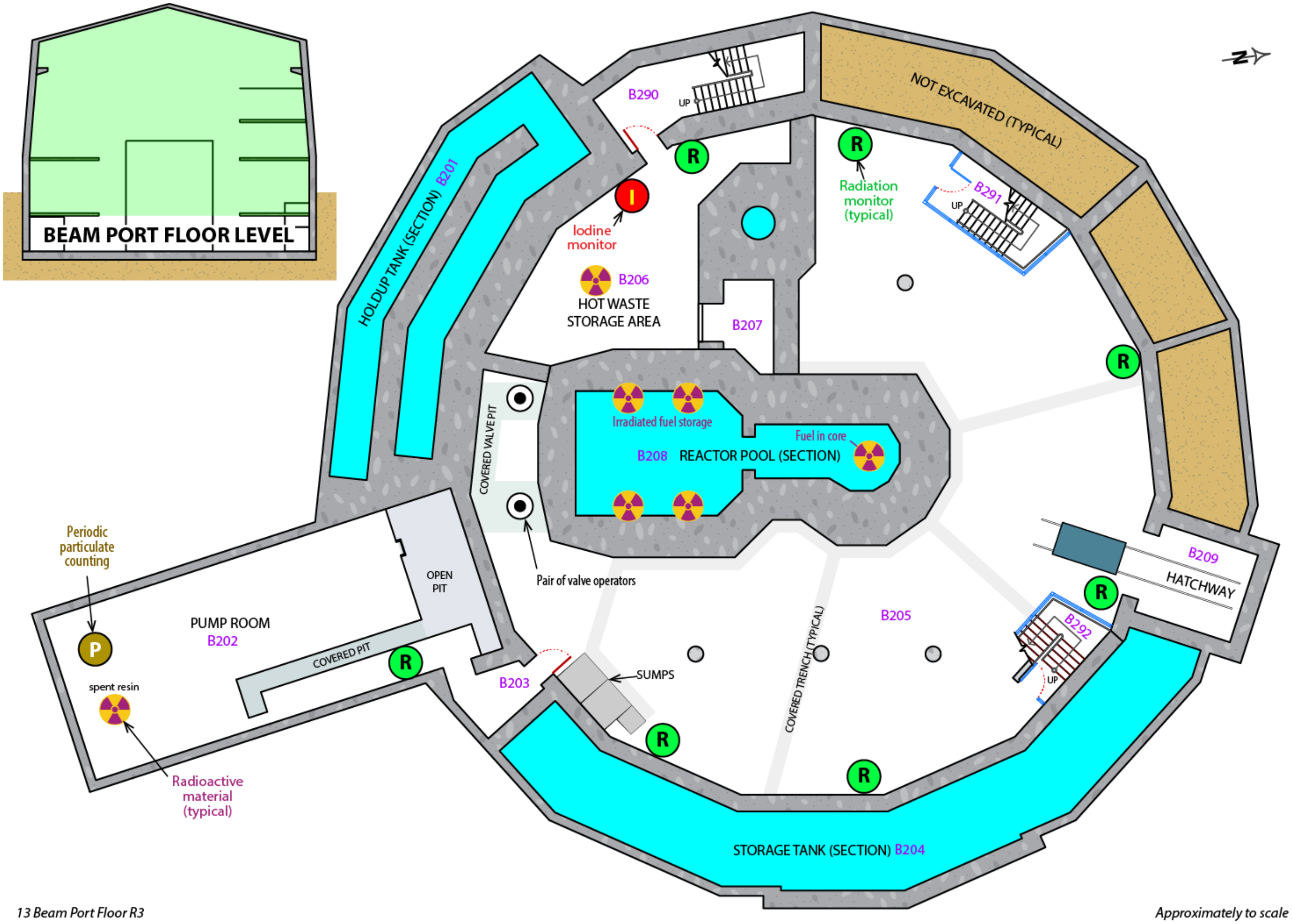

Figure 12: Beam floor of MNR building

Updated Figure 3-3 in [17]. Approximate locations of radiation sources and monitoring provisions are illustrated.

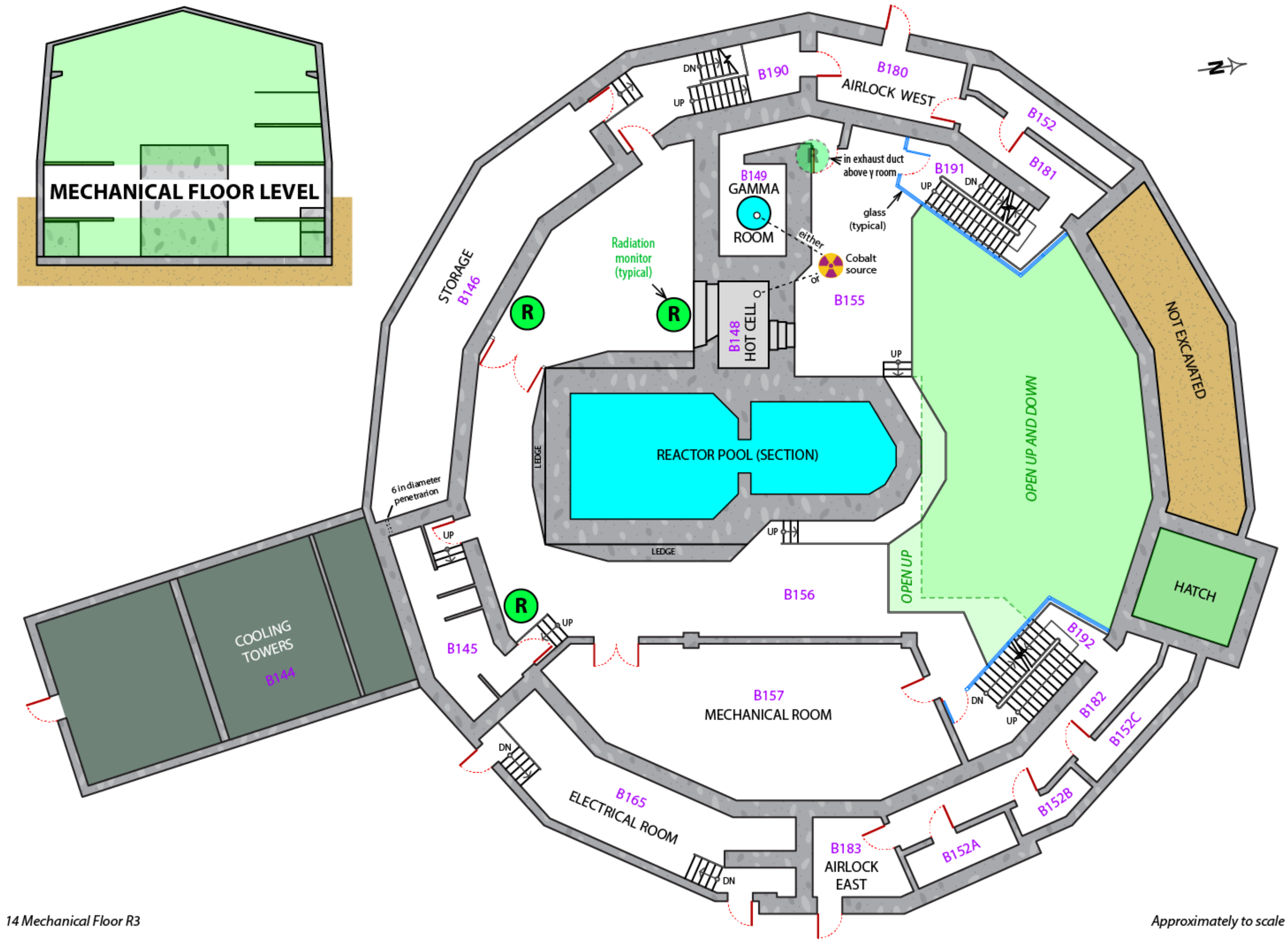

Figure 13: Mechanical floor of MNR building

Updated Figure 3-4 in [17]. Approximate locations of radiation sources and monitoring provisions are illustrated.

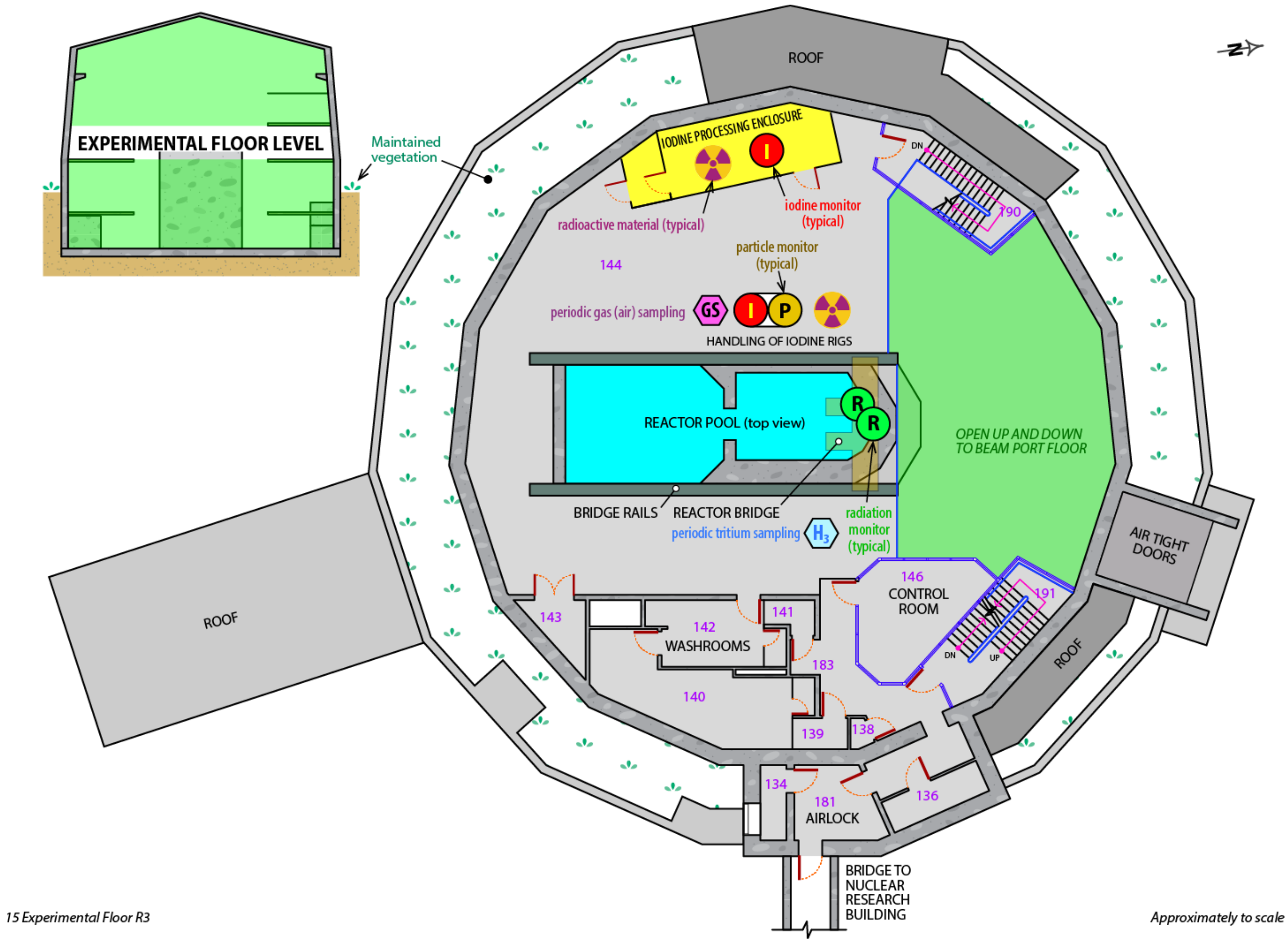

Figure 14: Experimental floor of MNR building

Updated Figure 3-5 in [17]. Approximate locations of radiation sources and monitoring provisions are illustrated..

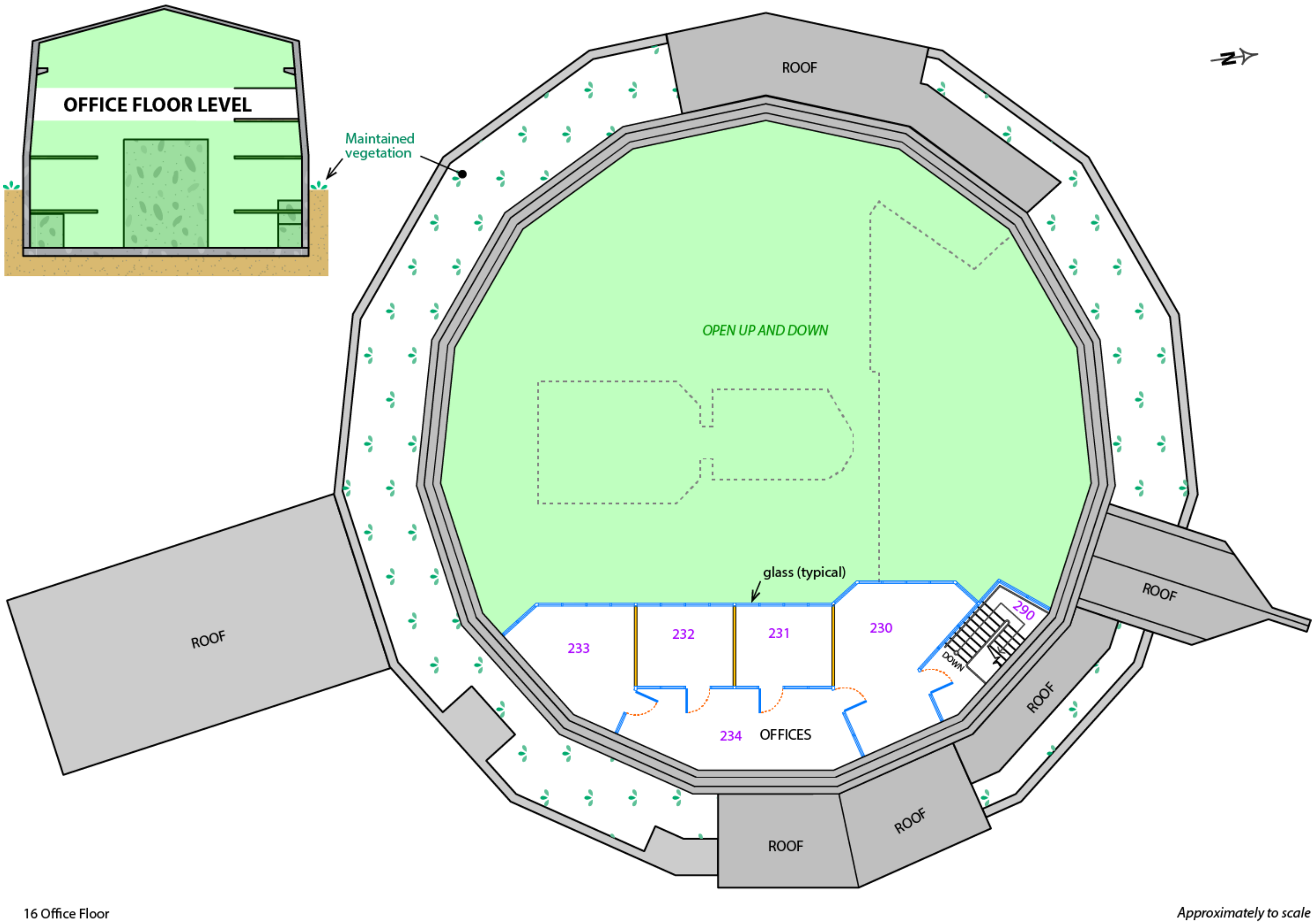

Figure 15: Office floor of MNR building

Updated Figure 3-6 in [17].

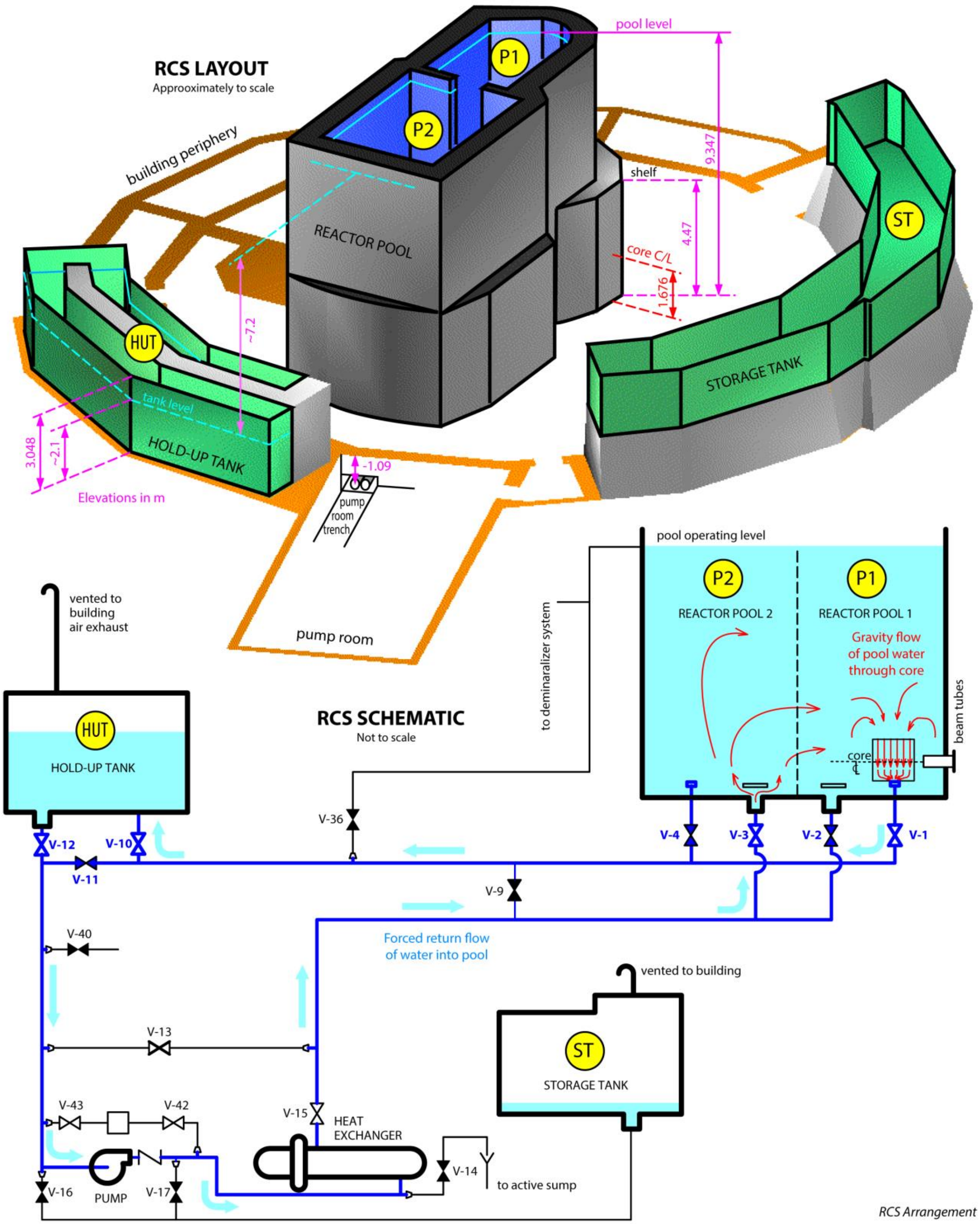

Figure 16: Reactor Pool and Reactor Cooling System arrangement in normal operation

Table 3: General Reactor Specifications
(Table 3-1 in [4])

Maximum power	5 MW (thermal)
Fuel Materials	UAlSi meat in aluminium cladding
Critical core loading	5.3 kg at 5 MW
Lattice	54 holes in 6 x 9 grid; 36 fuelled locations (typical)
Average thermal flux	$2x10^{13}$ $n \cdot cm^{-2} \cdot s^{-1}$ at 5 MW
Moderator	H_2O
Reflector	H_2O, graphite, beryllium
Shielding	H_2O, lead, barite ($BaSO_4$) and regular concrete
Primary Cooling	Primary H_2O to heat exchanger
Secondary Cooling	Heat exchanger to secondary H_2O to atmosphere
Primary H_2O purification	Continuous demineralization at pool surface
Control	Fine: 1 stainless steel regulating rod
	Coarse: 5 Ag-In-Cd shim-safety rods
Irradiation Facilities	Beam tubes; capsule irradiation assemblies; Reactor Irradiation Facilities for Large Samples (RIFLS); drypipe, various medical isotope production sites.

4. STRESSOR CHARACTERISTICS

A stressor is a chemical or biological agent, environmental condition, external stimulus or an event seen as causing stress to an organism. In plain language, it is an adverse interaction of MNR with humans and environmental biota.

MNR has only a small inventory of radioactive relative to the operating power reactors as illustrated in Figure 17. This means that there is only a small potential for harm to the public and the environment. Sections 4.1 and 4.2 describe the relevant radiological stressors and Section 4.3 discusses the physical stressors.

4.1 Airborne Emissions

In normal operation, there is a forced inflow of fresh outside air into the Reactor Building as outlined in Section 3.1. This air is circulated within the building, filtered in the exhaust duct and then discharged from the top of the Reactor Building. The outflowing air is continuously monitored for radioactivity (Section 5.1.3). The fail-safe[29] building dampers (both inlet and outlet) automatically close if the radioactivity of the discharged air was to reach ≥ 5 mR/hr (50 μSv/hr) (Table 2 in [18]). This automatic closure is backed-up by the manual damper closure on Multiple High Radiation Alarm (see Section 5.1.3). Closing the dampers isolates the containment envelope and stops the fan-driven air discharge.

The isolated Reactor Building (i.e., the isolated containment) is designed for low air leakage. Building access is through interlocked doors in several air-locks; this maintains continuity of the containment envelope. The building leakage test is performed at least annually (Section 8 in [18]). Only a small air leakage from the unattended containment could eventually occur following a slow depletion of the sub-atmospheric pressure margin in the containment envelope which exists at containment isolation[30]. The contained air heats up slowly due to a slow heat-up of the reactor pool at decay power levels since the Reactor Cooling System (RCS) is turned off after the reactor is shut down (i.e., prior to containment isolation). In the context of environment and public safety, this tiny and temporary leakage from the unattended Reactor Building is not considered to be a significant emission.

Insight: Normal emissions of airborne radioactivity from the MNR are minimized to as low as reasonably achievable (ALARA) magnitudes. The concentrations of these emissions are enumerated in Section 5.

4.2 Liquid Effluents

The MNR collects liquids in either of two sumps (pits) on the Beam Port floor with individual capacities of 1,600 litres (see location in Figure 12). The collected water is transferred to a cleanup system or a storage tank. The practice is to treat all collected water and return it to the RCS. Should a discharge to the city sewer be necessary, the water would be sampled and analyzed for activity[31]. Such discharge would only be made following an incident or mechanical failure which makes waste-water cleanup impractical. There have been no liquid releases to the city sewer since 1988 (i.e., for more than 35 years).

Insight: There are no hazardous liquids released from the Reactor Building during normal MNR operation. Thus, there are no effects of liquid effluents on the public or the environment.

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[29] The damper closure is automatically actuated on fault; the damper operation is checked at least weekly.
[30] Based on experience, the sub-atmospheric margin is not depleted during normal reactor shutdowns over the weekend.
[31] Regulatory and internal limits which apply to liquid effluent releases are in Table 12-7 of [3].

4.3 Other Physical Stressors

Physical stressors are defined in Section 1.5 of CSA N288.6-22 [2] as “noise, heat, wildlife-vehicle/bird-structure mortalities, and intake cooling water withdrawal”. None of these stressors is relevant to MNR other than a heat release into the atmosphere in the immediate proximity of the Reactor Building (see Cooling Towers in Figure 6). The carbon-free (i.e., non-polluting) heat release during normal operation is approximately equal to the reactor’s thermal power (currently licensed to ≤ 5 MW). No adverse effect of the heat release have been observed in many decades of MNR operation. The secondary water is cooled by air in the cooling towers (i.e., there is no ‘intake cooling water’). The reactor is shutdown following a loss of secondary side cooling in the towers and the fuel at decay power is then cooled by the natural circulation of pool water (Section 16.5.4.3 in the MNR SAR [3]).

The MNR is located in the urban environment. Hence, any wildlife-vehicle mortalities can only be similar to, or lower than, those in the City of Hamilton. In other words, the MNR does not affect the normal wildlife mortalities. Similarly, the bird/structure mortalities do not differ from, or are lower than, those of the surrounding urban environment.

Insight: Based on experience, the heat release does not have any noticeable impact on the environment or the public. A detailed engineering study and design is currently underway to capture this thermal energy in a tertiary loop and use it in local building Heating, Ventilation, and Air Conditioning(HVAC) systems.

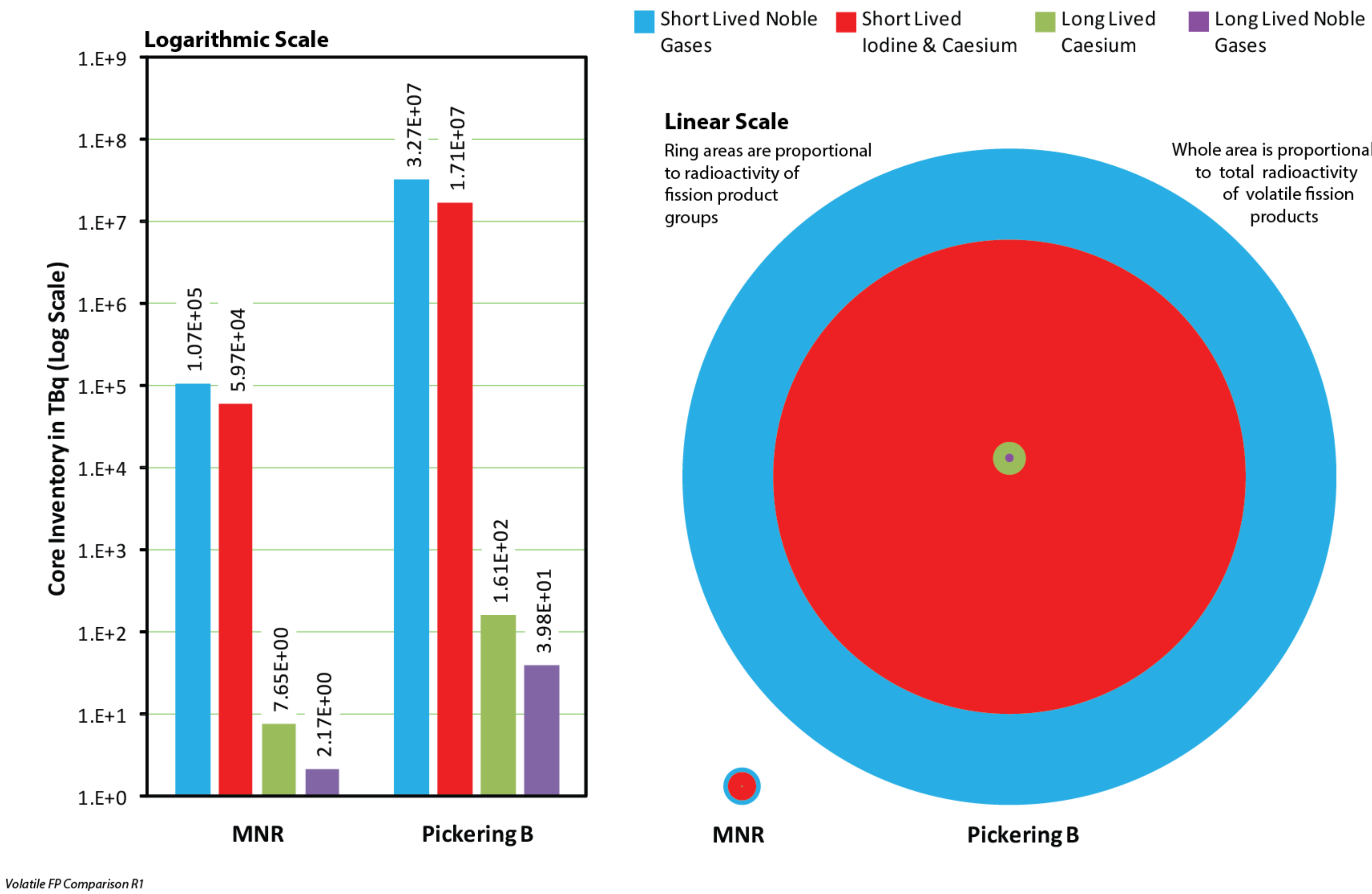

Figure 17: Inventories of important radioactive products in MNR and CANDU Reactor

Based on Figure 7-3 in [4]. MNR values are for a continuous operation at 5 MW; the values for the actual 3 MW operation are much lower.

5. MONITORING PROVISIONS

The requirement of REGDOC-2.9.1 [1] is that the report describes measures for "avoiding harmful releases into the environment and for confirming that the existing measures are effective"[32]. This section describes the provisions for monitoring of radioactivity at MNR and the monitoring results used to confirm the effectiveness of the measures.

The monitoring during normal operation focuses on mobile radioactivity[33]. The environmental monitoring (i.e., monitoring of the outside environment) is the confirmatory activity (i.e., the purpose is to verify that existing measures are effective). The internal environment within the Reactor Building is monitored to ensure safe working conditions for the staff[34], to activate the containment boundary isolation in case of an event and to provide information on the performance of MNR systems for adjustment and maintenance purposes.

5.1.1 Monitoring of External Atmosphere

Locations of monitoring stations for the outside atmosphere operated by the McMaster Health Physics Department are shown in Figure 18. Each station consists of a continuously-operating air sampler with a particulate filter and charcoal cartridge in series. The particulate filters are collected and analysed weekly to determine the concentrations of β-emitting activity in the particles. The charcoal cartridges are collected monthly and analyzed for the γ-emitting I-125 content. Historical measurements of environmental concentrations are shown in Figure 19 (particles) and in Figure 20 (I-125). No grab samples of local atmosphere are taken upon collections of filters/cartridges. Hence, no data on Ar-41 is available from these monitoring stations.

An independent monitoring station located in close proximity to the MNR is operated by Health Canada since early 2015 (see Figure 18 for the location). The data on Ar-41 in the outside atmosphere are reported by Health Canada as absorbed doses (in nGy/kg per month) [20]. A calibration factor converts the signal measured by the detector to an absorbed dose rate. The concentration of Ar-41 required to produce these dose rates are calculated in Appendix B, and the calculated concentrations are plotted at the bottom of Figure 21. Actual Ar-41 exhaust concentrations measured at the MNR are plotted at the top of the figure.

5.1.2 Monitoring of External Water

Any aqueous release to the environment would be a batch release into the city sewers (see Section 4.2). This water would beforehand be confirmed as safe (i.e., water would be be below the limits in Table 12-7 of [3]). Threrefore, during the normal operation, monitoring of water outside of the MNR building is not required and is not performed.

5.1.3 Monitoring of Internal Atmosphere

The Radiation Safety Program at MNR is documented in [21]. The routine internal surveillance covers the radiation field monitoring, the surface contamination monitoring, the airborne contamination monitoring and the reactor water analysis.

The Reactor Building is monitored at all times. Locations and types of monitors are identified in Table 4 and in the figures cross-referenced in this table. The radiation monitor in the exhaust stack

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32 See the 3rd (third) bullet of Section 1.

33 The immobile radioactivity is contained in solid structures (such the irradiated fuel) or in closed containers (such as the radioactive waste); it is not of environmental concern while being stored in the Reactor Building.

34 The Reactor Building is accessible and occupied in the 'attended' state.

(R in Figure 11) automatically isolates the containment envelope[35] should the radioactivity in the gaseous emission exceed the set-point. The automatic containment isolation is backed by the manual containment isolation upon the Multiple High Radiation Alarm (MHRA), which is triggered when any two area monitors (i.e., local radiation field monitors) in Table 4 exceed their set-points.

Examples of data from the internal atmosphere monitoring are given in Figures 22 to 24. History of the readings by the radiation field monitors is available but not in a format that can be readily plotted.

5.1.4 Monitoring of Internal Water

Pool water is continuously monitored for fission product activity during high power (>110 kW) operation. Furthermore, weekly samples of water are collected and analyzed from the pool and from the demineralising, secondary, and sump systems (Section 12.4.4.4 of the MNR SAR [3]). The pool water (i.e., the primary water) is analyzed for tritium, short-lived gross beta activity and long-lived gross beta activity. The other water samples are not analyzed for tritium. An isotopic analysis for long-lived gamma-emitting radionuclides is performed annually. Figure 25 illustrates the history of radioactivity in the pool water.

Section 5.1 insights: MNR has multiple hazards-monitoring provisions available which are coupled with the comprehensive program [21] for avoiding harmful releases into the environment as well as any harm to the operating staff. Large databases of measurements and derived doses illustrates that the existing measures are effective[36].

[35] The containment envelope is isolated when the intake and outlet dampers are closed and the fans are shut down.
[36] The concentration values are acceptable and their long-term trend is steady or decreasing.

Figure 18: Locations of stations for monitoring of external atmosphere

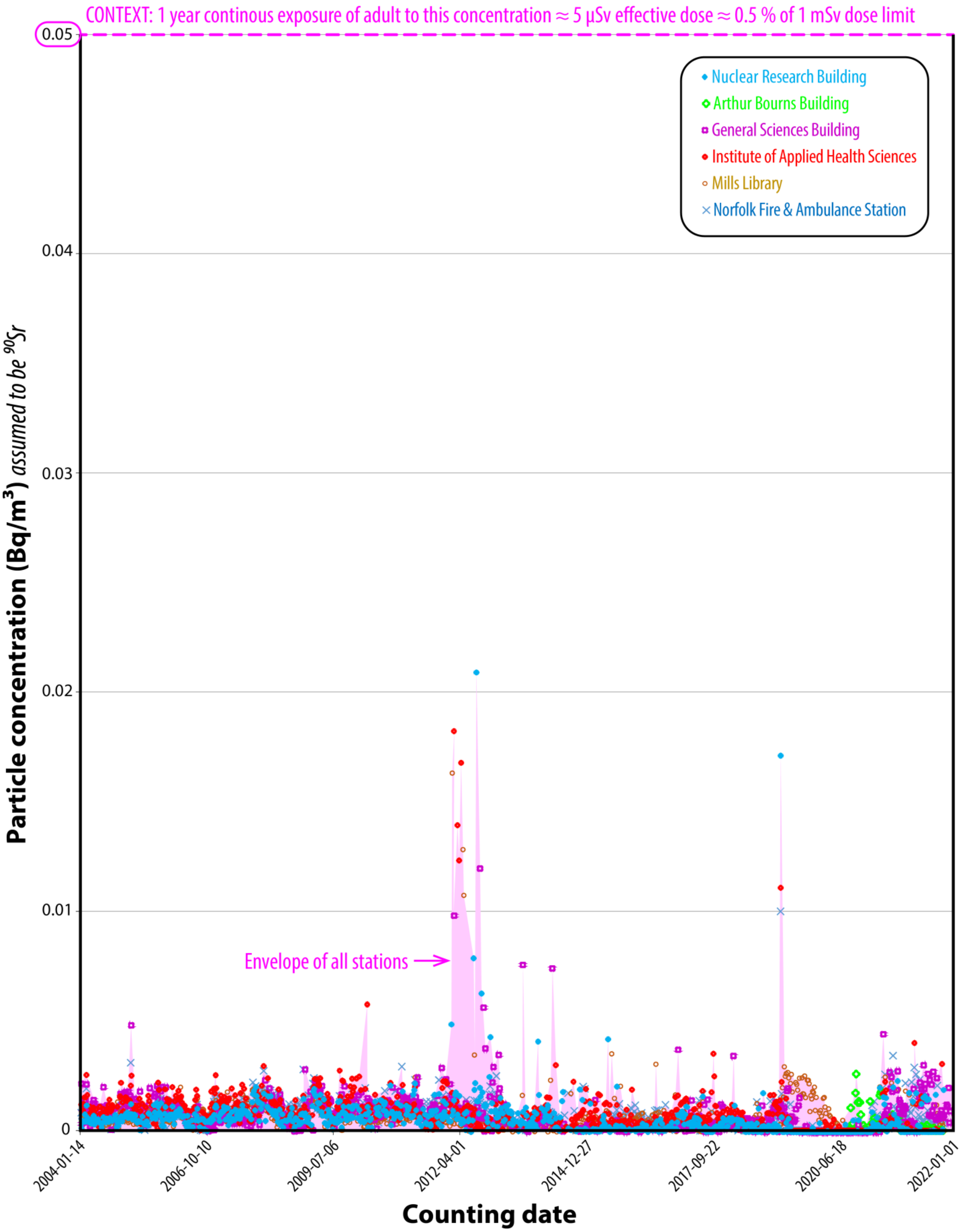

Figure 19: History of β-emitting particles measured in filters of external stations

See Figure 18 for measurement locations. Sample accumulated for weekly counting.

Numerical data of this figure for the past 5 years are in Addendum to MNR ERA.

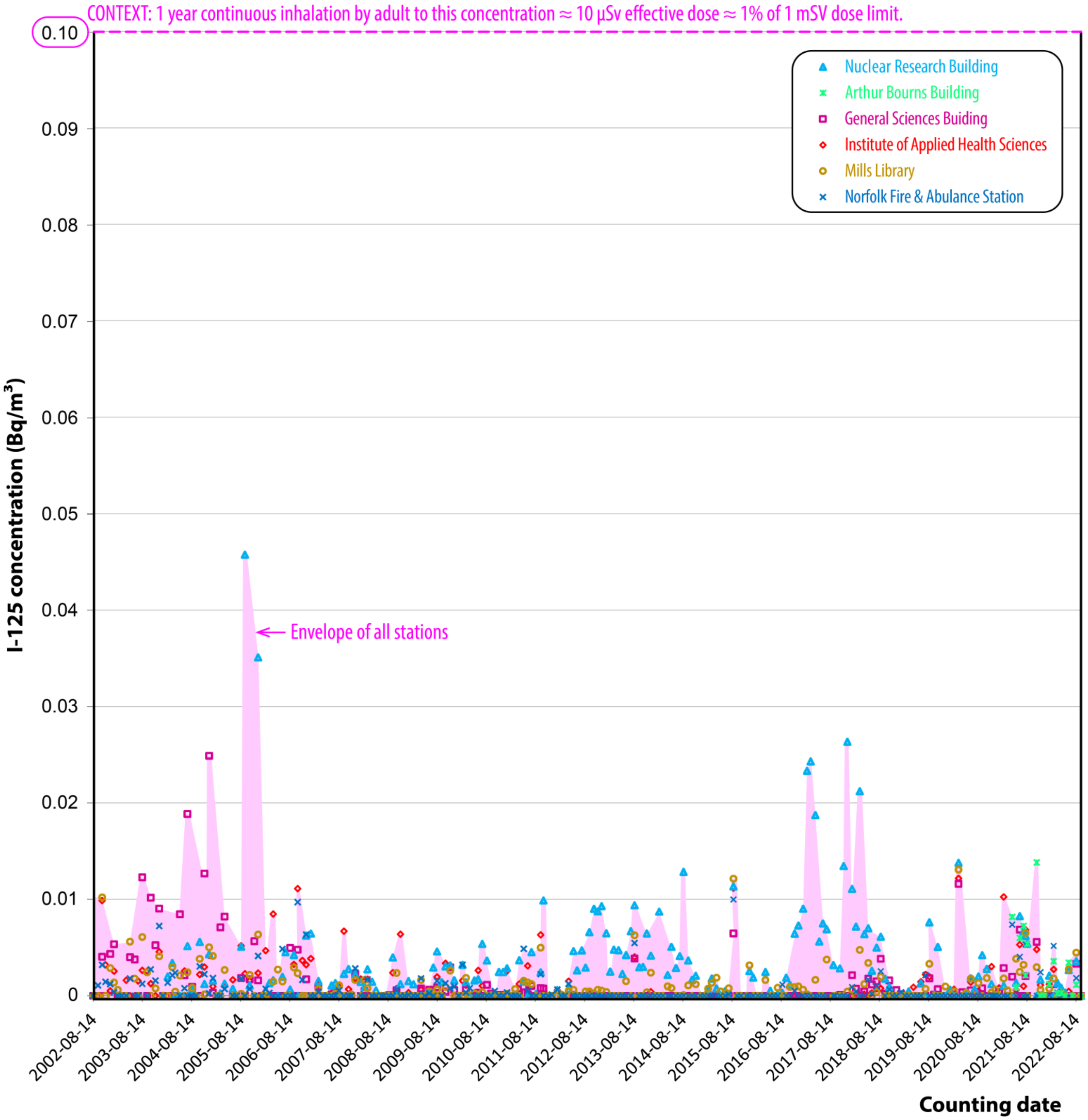

Figure 20: History of soft γ-emitting I-125 measured in charcoal cartridges of external stations

See Figure 18 for measurement locations. Not adjusted for I-125 decay during 1 month sample accumulation.

Numerical data of this figure for the past 5 years are in Addendum to MNR ERA

Some of the airborne iodine is likely in the form of the aerosols. The I-125 particles tend to be removed by the upstream interactions with the structures and by the particulate filter. Thus. the charcoal cartridges likely measure only a portion of the airborne Iodine.

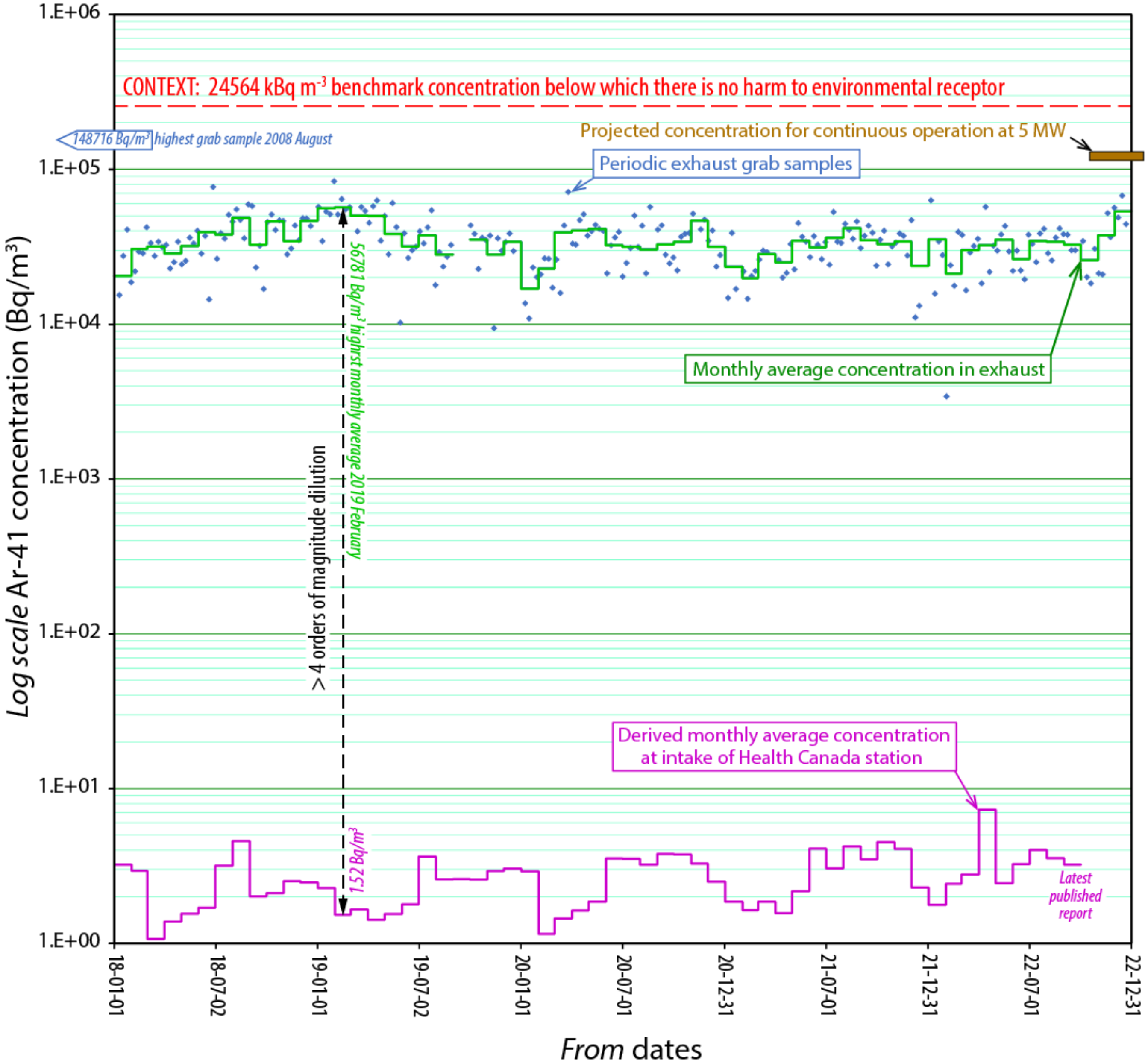

Figure 21: History of β and γ-emitting Ar-41 in outside atmosphere and exhaust

Health Canada (HC) reports doses in nGy/month [20]. Doses are converted to concentrations in Bq/m^3 in Appendix B.

See Figure 6 or 18 for location of HC monitoring station. HC data is direction specific as explained in Appendix B.

Projected concentration for potential 24/7 operation from [33].

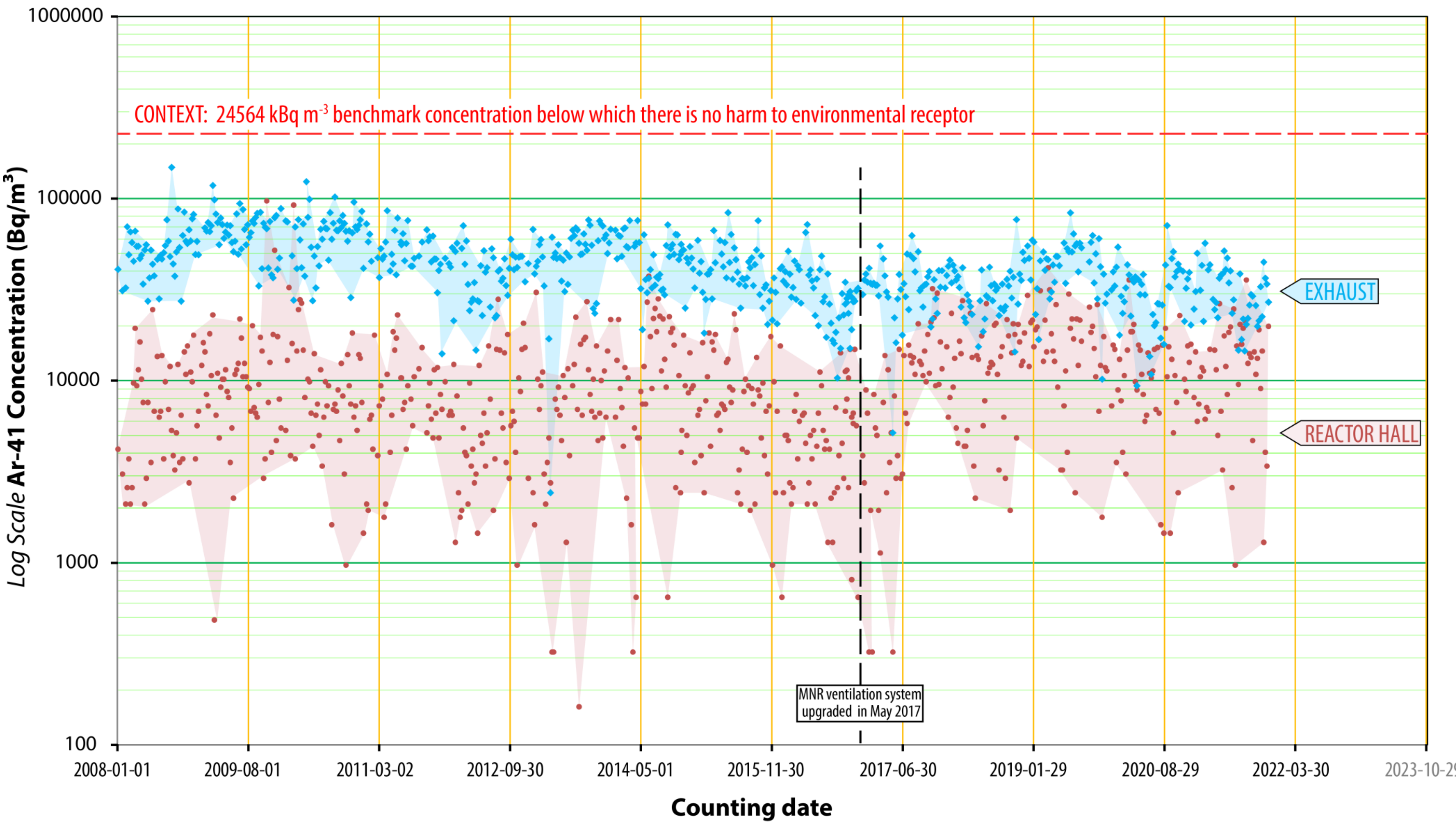

Figure 22: History of β and γ-emitting Ar-41 gas in Reactor Hall and Exhaust Duct

Records of air grab samples taken on the Experimental Floor (Figure 14) and in the exhaust (Figure 11).
Data from Health Physics from 2008-01-03 to 2021-12-01.
Benchmark concentration enumerated in Appendix A.

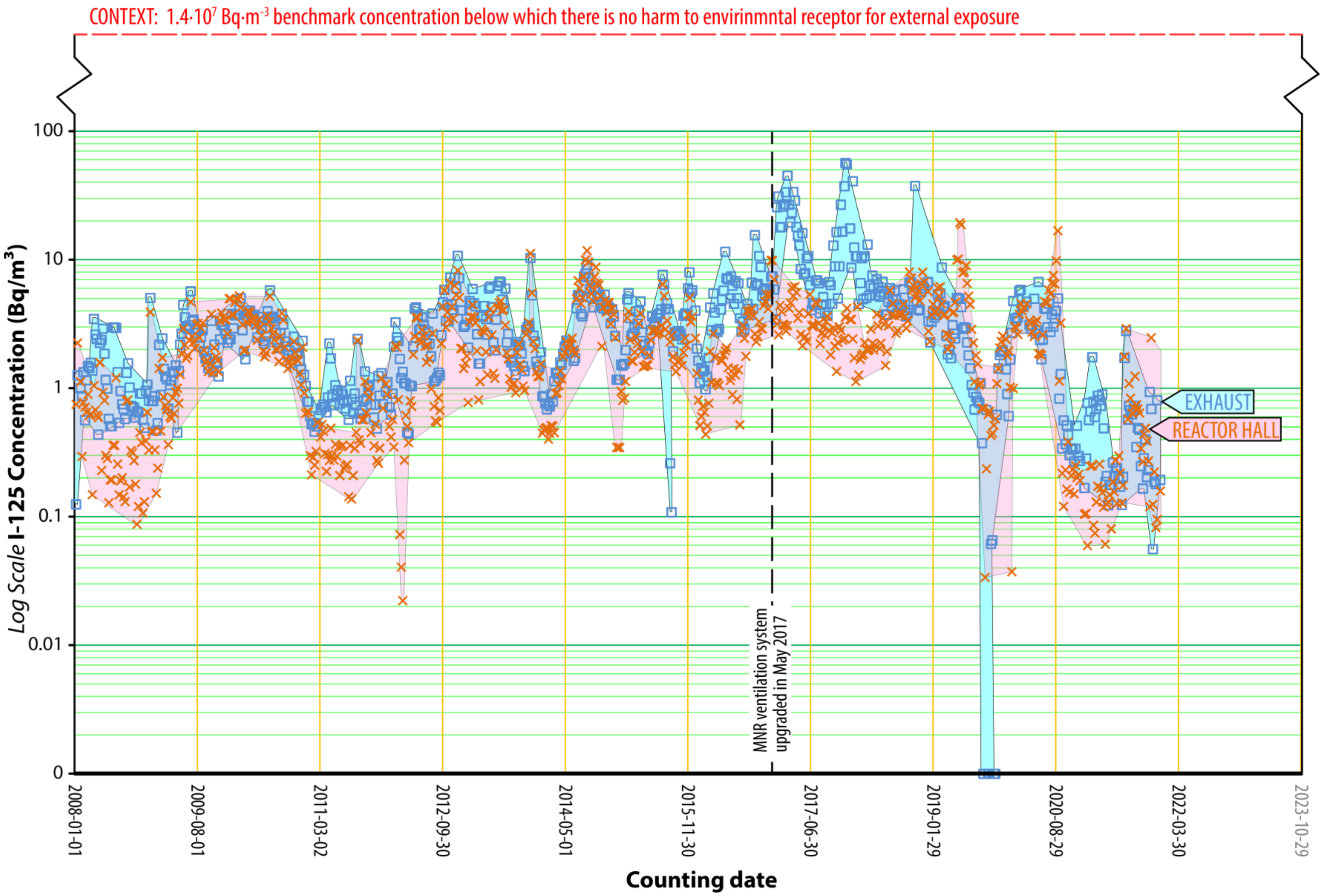

Figure 23: History of airborne, soft γ and X-ray-emitting I-125 in Reactor Hall and Exhaust Duct

Records of air grab samples taken on the Experimental Floor (Figure 14) and in the exhaust (Figure 11).
Health Physics records from 2008-01-07 to 2022-01-03. Benchmark concentration enumerated in Appendix A.

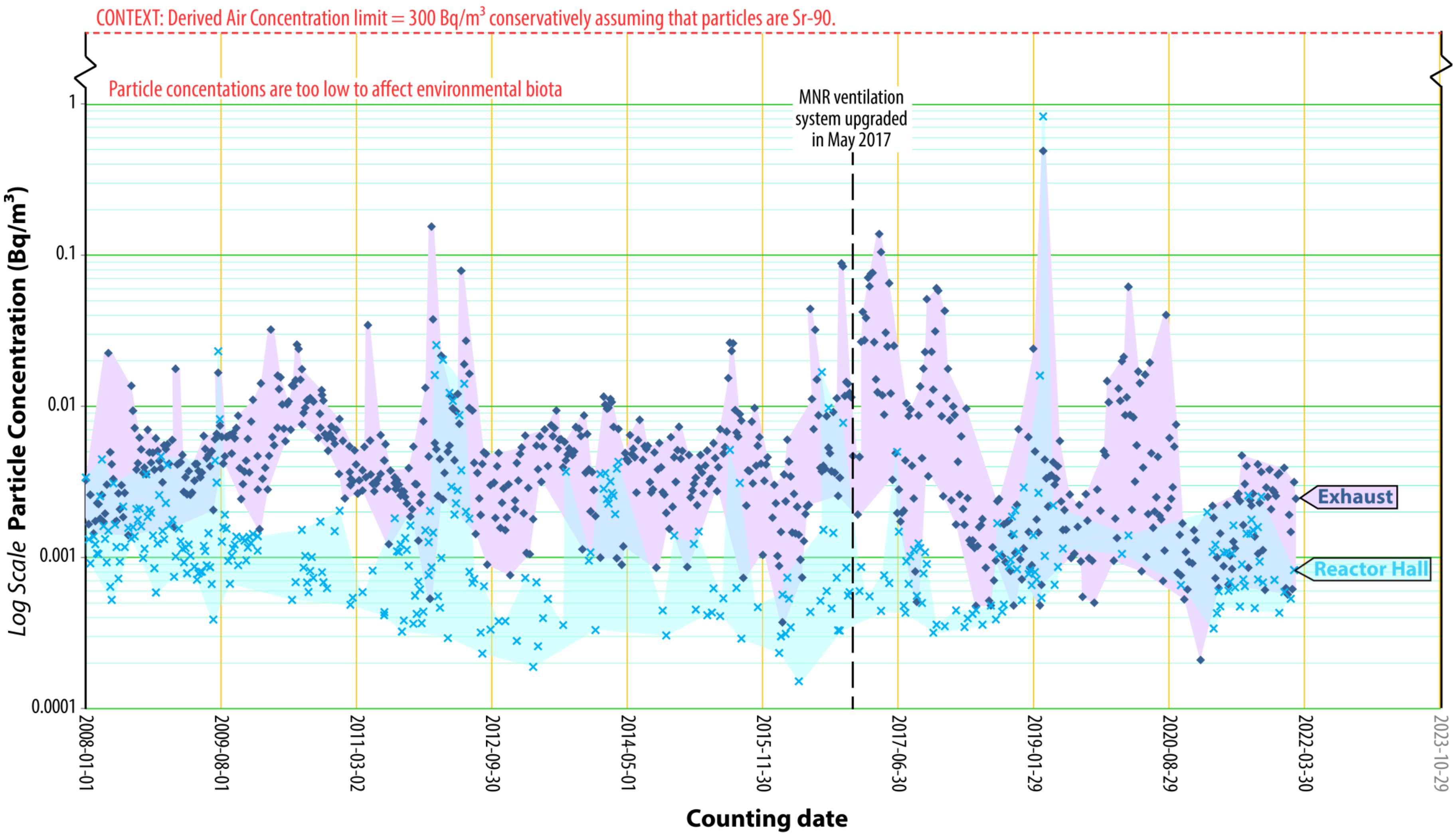

Figure 24: History of airborne, hard β-emitting particles in Reactor Hall and Exhaust Duct

Records of air grab samples taken on the Experimental Floor (Figure 14) and in the exhaust (Figure 11). Health Physics records from 2008-01-02 to 2022-02-22

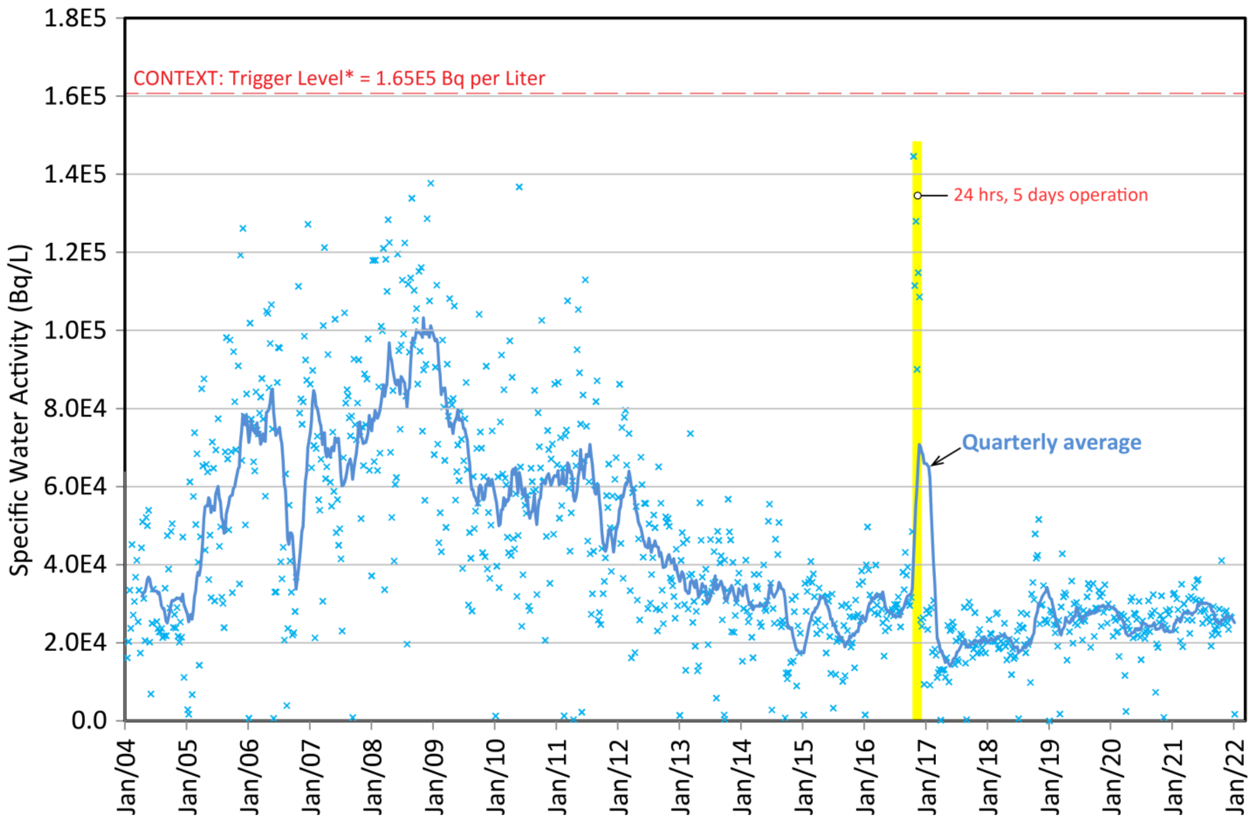

Figure 25: History of radioactivity in primary water

Records of weekly pool water grab samples

* Trigger Level is a MNR-specific parameter which defines when the investigation and follow up are mandatory (equivalent to Action Level in [29]). The illustrated limit value is currently being updated to a higher value.

Table 4: Internal Radiation Monitoring and Sampling

CM	Continuous monitoring
CMS	Continuous monitoring and sampling, periodic analysis of samples
CS	Continuous sampling, periodic analysis of samples
PS	Periodic sampling and analysis of samples

Location			**Type of Monitoring**	
RB exhaust	Figure 11	I P	Iodine & Particles	CMS
		P	Particles	CMS
		GS	Ar-41	PS
		R	Local radiation field	CM
Beam port floor	Figure 12	7 R	Local radiation field	CM
		I P	Iodine & Particles	CMS
		P	Particles	CS
Mechanical floor	Figure 13	3 R	Local radiation field	CM
Experimental floor	Figure 14	2 R	Local radiation field	CM
		3 I P	Iodine & Particles	CMS
		P	Particles	CMS
		GS	Ar-41	PS
		H_3	Tritium	PS

Information on internal monitoring is comprehensively documented in Section 6 of [21].

6. RISK-RELATED CRITERIA

As noted in Section 1, this report is the ERA for the small, research reactor with the small inventory of hazardous substances, many decades of safe operation history and the ample data on the performance of existing physical and administrative provisions. REGDOC-2.9.1 [1] as well as CSA N288.6 [2] note that the graded approach (e.g., [21] to [23]), which uses the existing information, is suitable for this report. The risk-related criteria used in the past for small, non-power reactors are summarized in the following subsections..

The following information is based on Section 2 in the MNR SAR [3].

6.1 Radiological Protection Criteria

The current limits on the maximum permissible doses to humans are listed in Table 6. Radioactivity releases that cause doses which are lower than the Regulatory Limits are recognized as inconsequential.

The relevant radioactive nuclides[37] released from the MNR in normal operation are Ar-41[38] and I-125[39]. The MNR is operated such that releases during normal operation of these radio-nuclides are less than the Derived Emission Limits (DELs) in Table 7. This table specifies the amount of radiation that may be released from the MNR in a calendar year. The reactor is actually operated such that the arbitrary and lower Administrative Control Limits for emissions (labelled as 'Admin. Control Limits' in Table 7) are not exceeded.

Note that the above mentioned limits are the reference values. In practice, the '<u>a</u>s <u>l</u>ow <u>a</u>s <u>r</u>easonably <u>a</u>chievable (ALARA)' principle [26] [30] is rigorously applied to all doses and emissions.

For emergency actions (e.g., in responses to accidents for rescue and lifesaving), an individual operator dose of up to 1 Sv is permissible [21].

6.2 Environmental Protection Criteria

No quantitative, regulatory criteria are currently defined for biota[40] exposures in the environments which surrounds the MNR. The common understanding is that protecting humans (evaluated in Section 7) also protects the environment (e.g., [27] [28]). The international consensus is that "*it is highly probable that limitation of the exposure of the most exposed humans (the critical human group), living on and receiving full sustenance from the local area, to 1 mSv·a^{-1} will lead to dose rates to plants and animals in the same area of less than 1 mGy·a^{-1}. Therefore, specific radiation protection standards for non-human biota are not needed*" [27].

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37 The airborne particles are also monitored but their concentrations are too low to be significant (Figures 19 and 24).

38 Ar-41 is produced by irradiation of pool water. It decays by β^- radiation with half life ($t_{1/2}$) of 1.83 hrs to stable K-41.

39 I-125 is the medical isotope produced in sealed rigs within the reactor pool and handled/packaged on the Experimental Floor of the Reactor Building (see Figures 11 and 14). Its $t_{1/2}$ is 59.49 days. It decays by electron capture to an excited state of Te-125, which decays immediately by γ decay with a maximum energy of 35 keV.

40 Animals and plants.

Table 5: Risk Tolerable Frequency of Human Doses

Legacy criteria from Table 2-1 in MNR SAR [3] for normal operation and plausible accidents

Frequency (occurrences per reactor-year)	**Individual Limit** (mSv)	**Public Limit** (person-Sv)
$f \geq 3\times10^{-1}$	0	0
$3\times10^{-1} > f \leq 3\times10^{-2}$	0.5	1
$3\times10^{-2} > f \leq 3\times10^{-4}$	5	10
$3\times10^{-4} > f \leq 1\times10^{-6}$	100	100

Table 6: Current Human Dose Limits

Regulatory limits from [30]for individual member of the public.

Dose	**Time Period**	**Regulatory Limit (mSv)**
Whole Body	One calendar year	1
Skin		50
Hands and Feet		50
Lens of the Eye*		15

Table 7: Derived Emission Limits for MNR

Also called Derived Release Limits. Updated Table 2-3 in MNR SAR [3].

Isotope	**Half Life**	**Derived Emission Limits (Bq per week)** [15] & [21]	**Admin. Control Limits (Bq per year)** [21]
Ar-41	109.6 min	$9.20\cdot10^{12}$	$1.6\cdot10^{13}$
I-125	59.5 day	$7.56\cdot10^{10}$	$1.0\cdot10^{10}$
Gross β (particles)		not defined	$5.0\cdot10^{8}$

7. HUMAN HEALTH RISK ASSESSMENT

This section covers the topics (clauses) in Section 6 of CSA N288.6-22 [2]. The same subsection structure and labels are used here to simplify reviews of conformance with the applicable standard.

7.1 General

Label of Section 6.1 in [2]

7.2 Problem formulation

Label of Section 6.2 in [2]

7.2.1 General

Label of Section 6.2.1 in [2]

7.2.2 Site characterization

Topic in Section 6.2.2 of [2]

A detailed description of the MNR site and its operations is provided in Sections 2 and 3. The contaminants and the physical stressors are identified in Section 4. Receptors associated with past, present, and anticipated future activities is the Hamilton population described in Section 2.1.

7.2.3 Receptor selection and characterization

Topic in Section 6.2.3 of [2]

The receptor is selected and described in Section 4 of [15]. It is an adult, non-Nuclear Energy Worker who is occupationally exposed within the neighbouring Nuclear Research Building (NRB) that has one of its air intakes located approximately 30m from the airborne emission from the MNR exhaust damper (see Figure 6). The receptor is thus a conservative representation of persons exposed anywhere in the University campus. This adult receptor is assumed to be present within the NRB for half of the day (12 hours) for a full year (including weekends and holidays)[41]. Previous Human Health Risk Assessments (HHRA's) used an approach in which a vulnerable member of the public (an infant) was assumed to be present outdoors 24 hours per day for the full year at a location of the maximum ground level exposure. The present receptor treatment avoids the physically impossible infant assumption while using conceivable receptor exposure boundary conditions. The present treatment produces a more conservative (higher) Boundary Dose estimate (see Figure 27).

7.2.4 Assessment and measurement endpoints

Topic in Section 6.2.4 of [2]

For HHRAs, the assessment and measurement endpoints are the same: to show no meaningful health effects on individual human receptors. As a result, there is no need to translate measurement endpoints into different yet applicable assessment endpoints.

7.2.5 Selection of chemical, radiological, and other stressors

Topic in Section 6.2.5 of [2]

Relevant stressors are identified in Section 4 based on multi-decade operating experience and monitoring. There are no chemical stressors.

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[41] Most individuals in the NRB work around 40 hours per week.

7.2.6 Selection of exposure pathways

Topic in Section 6.2.6 of [2]

The exposure pathways involve immersion in and inhalation of the contaminated air within the NRB [15].

7.2.7 Human health conceptual model

Topic in Section 6.2.7 of [2]

The model is described in [15].

7.3 Exposure assessment

Label in Section 6.3 of [2]

Only indoor exposures within the NRB are relevant [15].

7.4 Toxicity assessment

Label in Section 6.4 of [2]

There are no chemical contaminants released from MNR. Thus this topic is not applicable.

7.4.1 Radiation dose limits and targets

Label in Section 6.4.6 of [2]

Throughout the long operating history of MNR, radiation exposure levels have been consistently safe and well below applicable limits on doses. This section summarizes dose history due to reactor operation up the last year for which complete data are available.

External doses to operations staff are mainly determined by operating time and power of the reactor and the number and type of irradiation samples handled. The highest routinely encountered external dose rates are in the Pump Room. Localized dose rates as high as 20 mSv/h (2 rem/h) are in the pump pit. The most recent building survey (2022-12-05) measured the highest value of 850 mrem/h at valve 10[42]. The combination of time spent in the Pump Room and the local radiation field determines the dose to the operator. The history of effective doses acquired by operations personnel is shown in Figure 26. The average (mean) and the maximum doses in the past 25 years were 0.71 and 3.11 mSv, respectively. These are small fractions of the regulatory dose limit. Extremity exposures to operations staff have consistently been less than 5 mSv annually[43].

Internal doses to operations staff resulting from routine operations are very small. Historic whole body counts have consistently not detected any evidence of intakes of radio-nuclides by operations personnel. I-125 is the only radionuclide that is detected for operator intakes. The operators self-test their thyroids for activity on weekly basis. Only a very low presence of I-125 is routinely detected which is insignificant (i.e., well below levels at which 'assigning' the worker doses to the National Dose Registry is warranted).

Boundary Dose is a MNR term for the largest conceivable dose to a most vulnerable individual member of the public[44] due to the routine discharge of the mildly contaminated air by the Reactor Building

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42 See Figure 16 for valve numbers.

43 A single outlier is the 5.87 mSv extremity dose in 2020.

44 An infant postulated to be outside for the whole year at a location with the highest ground-level concentration of Ar-41. This receptor type and residence time are impossible in reality.

Ventilation System [15][45,46]. Figure 27 shows the calculated annual boundary doses due to the MNR effluents in the past 20 years. A projection for a potential future operation up to the maximum reactor power permitted by the operating licence is also illustrated.

Insight: Historical data confirms that doses to the operating personnel are small (well below the regulatory limits). The public doses are orders of magnitude below the regulatory limit which delineates the safe doses. This means that there is no human health risk stemming from the MNR operation.

7.5 Risk characterization

Label in Section 6.5 of [2]

The risk posed to receptors resulting from exposure to contaminants and physical stressors in the environment is to be quantified by integrating the results of the exposure assessment and toxicity assessment (Section 6.5 of [2]). This integration is not relevant since there are no physical stressors affecting the public (Section 4.3) and non-radiological toxic substances are not released from the MNR,

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45 The ground concentration is calculated by a modified Gaussian plume model in [31] using the wind data from the Royal Botanical Gardens (Figure 7), choosing the wind properties which produce the highest ground-level concentration (regardless of wind direction), assuming that this wind prevails for the whole year, and neglecting any obstructions in the plume path which would dilute the concentration. Hence, highly stylized boundary conditions of contaminated plume behaviour are defined, which are physically impossible at the MNR site.

46 At the time of ERA report writing, [15] is in the process of being updated.

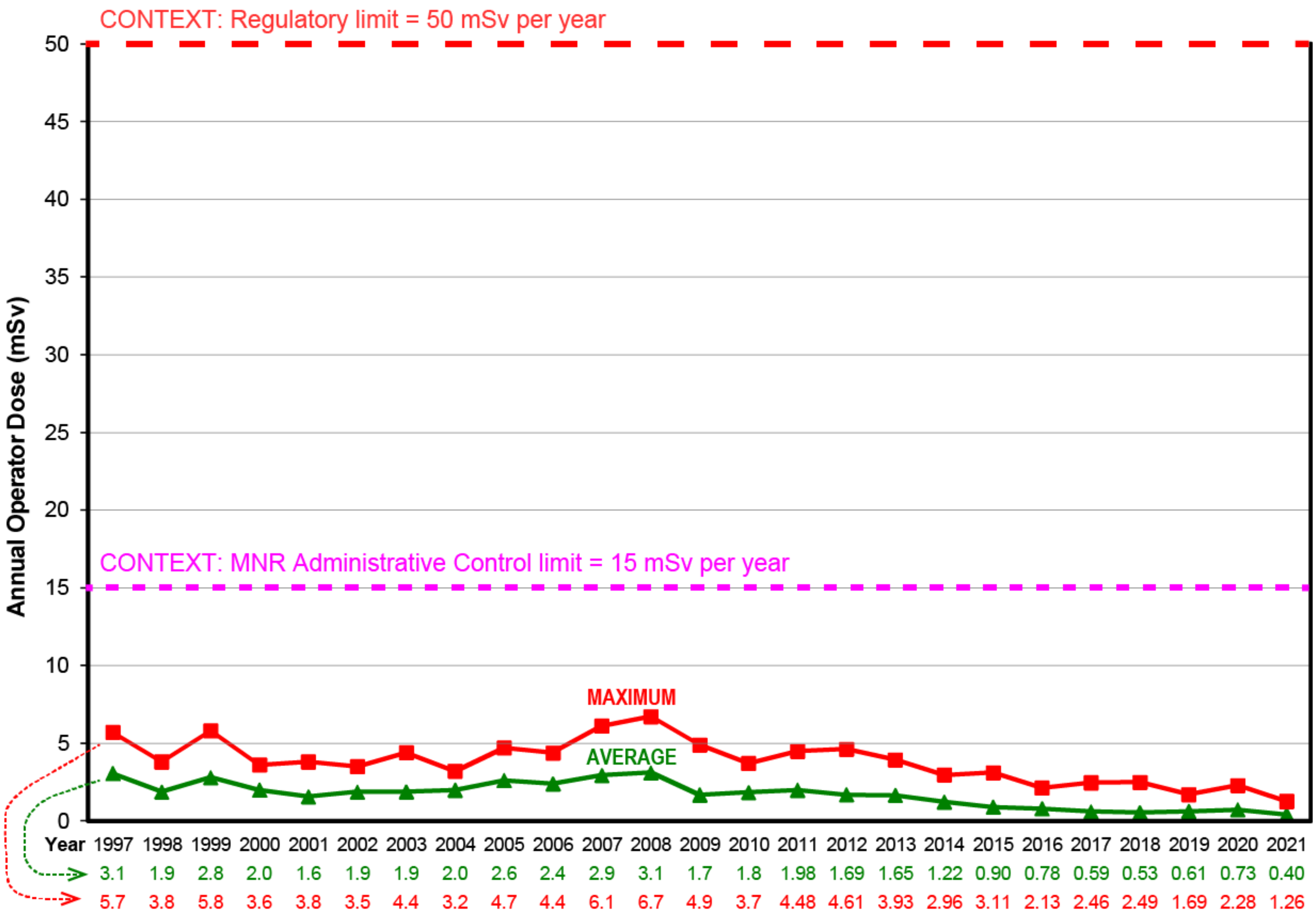

Figure 26: History of MNR Operations Personnel Doses

Whole-Body Effective Doses from Health Physics records. Dose limits see Table 6

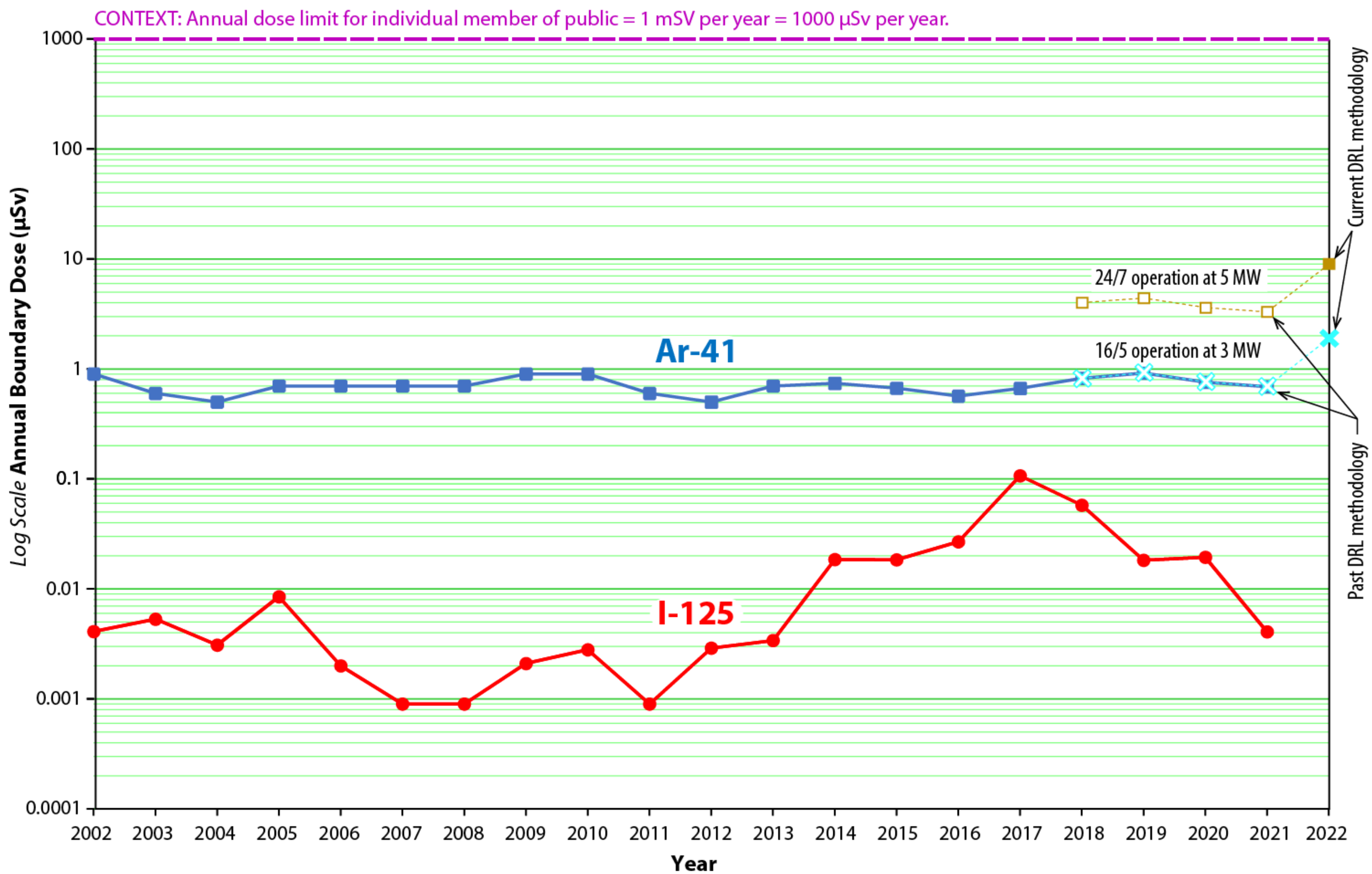

Figure 27: History of MNR Boundary Dose

Data to 2021 from Health Physics records. Data points for the past 5 years (covering a potential operation at 5 MW permitted by the operating license) from [33][47]. Past DRL methodology and calculation are documented in [14]. Current (updated) DRL methodology and calculation are documented in [15]. See Table 6 for the annual dose limit. *This limit is lower than the Canadian average effective dose from natural sources (background radiation) of 1.77 mSv [34].*

[47] Tabular data for these points is recorded in [33].

8. ECOLOGICAL RISK ASSESSMENT

This section covers the topics (clauses) in Section 7 of CSA N288.6-22 [2]. The same subsection structure and labels are used here to simplify reviews of conformance with the applicable standard. However, the CSA structure of the topics is not editorially optimal for compact and coherent explanation of the assessments performed in this ERA.

8.1 Problem formulation

Label of Section 7.2 in [2]

8.1.1 Site characterization

Topic of Section 7.2.2 in [2]

The MNR site is described in Section 2.1. As illustrated in Figures 2 and 4, the environments surrounding the reactor include:

a. The human-populated urban and industrial areas. This urban environment is assessed by the Human Risk Assessment in Section 7.

b. Lands with the terrestrial biota which are sparely populated by humans. This environment is described in Section 2.2.1.

c. Water-filled areas with the aquatic biota. This environment is described, and its flora and fauna are identified in Section 2.2.2. This biota is not affected by routine emissions from the MNR as explained in Section 2 of Appendix A and in Section 8.1.5 below. Thus, it is not examined further in this ERA.

8.1.2 Receptor selection and characterization

Topics of Section 7.2.3 in [2]

A small terrestrial bird is chosen in Table 1 of Appendix A as the limiting receptor[48]. No taxonomic properties are published for the bird. Its properties (mass and size) are reported to be closely similar to the properties of a small mammal. They are stylized as the properties of Reference Rat [35] with the mass of 0.314 kg,

8.1.3 Assessment and measurement endpoints

Topics of Section 7.2.4 of [2]. "Assessment endpoints are explicit expressions of the environmental values ... should be defined at population or community levels".

Regulatory limits are not defined for the environmental parameters.

Endangered, threatened, and vulnerable species potentially living in MNR vicinity are identified in Table 2 of Appendix A, based on locations of such species in "Species at risk in Ontario" [36]. The species in this table are taken to be of 'environmental value'.

8.1.4 Selection of chemical, radiological, and other stressors

Topics in Section 7.2.5 of [2]

Environmental stressors during normal MNR operation are described in Section 4.1. The relevant stressors are:

- small emissions of noble gas isotope Ar-41 into the outside atmosphere; and
- extremely small emissions of I-125 vapour and radioactive particles into the outside atmosphere.

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48 Limiting receptor = a community of potentially endangered animals with the highest potential for harm by exposure to radiation in the surrounding air.

8.1.5 Selection of exposure pathways

Topics in Section 7.2.6 of [2]

All exposure pathways to the biota involve the airborne transport and its associated dispersion (dilution) of MNR emissions. These two variables are governed by the time-dependent, local weather and by the locations of the biota habitats relative to the airborne emission plume.

Pathways to the aquatic biota entail additional transport variables, i.e., the dissolution of gases in water and the dilution of isotope concentrations in liquid water. Given the composition of MNR emission, these latter parameters are the governing parameters for the exposure of aquatic biota to radiation as explained below. For Ar-41 gas, a contaminated plume stream comes into contact with surfaces of water that has a natural equilibrium concentration of Argon. The atmospheric Ar-41 gas transfers into water by the concentration-driven diffusion process which is very slow and which competes with the fast decay of Ar-41[49] to the non-radioactive K-41. For I-125 vapour or aerosols, both forms are slightly and slowly soluble in water[50]. In conjunction with a rather fast I-125 decay[51] and with the natural turbidity of water in Dundas marsh and connected water steams [52], it is not credible that the aquatic biota living within water would be exposed to any appreciable, sustained I-125 liquid concentration. In other words, there is not a plausible pathway to expose the submerged biota to an appreciable radiation from the MNR emission gases.

Similarly, all pathways to the terrestrial biota living mainly below the ground surface are constrained by an access of the contaminated air into the soil. There is not a plausible pathway to directly expose of the underground biota to the MNR emission gases.

8.1.6 Ecological conceptual model

Topic in Section 7.2.7 of [2]

Based on preceding considerations, this ERA only assesses exposures of the terrestrial biota residing above ground to Ar-41 and I-125 gases.

8.2 Exposure assessment

Label of Section 7.3 in [2].

8.2.1 Exposure points/locations

Topic of Section 7.3.2 in [2]

Populations of wild, terrestrial flora and fauna are located in WNW to ENE directions from the MNR building (green spaces in Figure 7) on the lands below the cliff of the Niagara Escarpment. The largest radiation exposures of biota populations invariably arise at shortest distances of biota habitats from the source of radioactive emission. Figure 28 illustrates the relevant areas as the hatched spaces. The closest distance to the potential receptor habitat is approximately 500 m from the MNR. There is no doubt that the exposures will be negligible at distances beyond 1 km. This figure also illustrates the worst (limiting) wind direction for the transport of radioactivity to the biota habitat, which is relevant to the topic covered in Section 8.2.6.

8.2.2 Exposure frequency, duration, and averaging

Topics in Section 7.3.3 of [2]

These three topics are addressed by conservative (bounding) assumption listed below:

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49 Ar-41 has β^- decay with half life ($t_{1/2}$) of 109.34 minutes.

50 Iodine solubility is 0.34 gm per kg of water (e.g., https://onlinelibrary.wiley.com/doi/abs/10.1002/047084289X.ri005)

51 I-125 decays with $t_{1/2}$ of 59.49 days. It emits soft γ radiation and x-rays (max. energy ~ 35 KeV).

52 See the description of Aquatic Environment in Section 2.2.2.

- The receptor (i.e., the nesting bird) is continuously and perpetually exposed to the contaminated plume of MNR emission passing through its habitat.

This means the 100% exposure frequency, the continuous and indefinite duration of exposure, and no averaging of the exposure boundary conditions. These are unrealistic but bounding assumptions, especially for the bird receptor which is stationary (i.e., remains in a nest = stays continuously in the exposure locations) only for a few weeks in a year.

8.2.3 Dose calculation methods

Topic in Section 7.3.4 of [2]

Doses to receptors need not be, and are not, explicitly enumerated in order to examine the impact of MNR emissions on the biota. The approach in this ERA is:

a) Use the benchmark dose (i.e., the highest chronic dose that does not adversely affect the receptor) from United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2008 [37][53].
The UNSCEAR doses for taxonomic families of biota are extracted into Table 3 of Appendix A.

b) Convert the above benchmark dose to the benchmark concentrations of relevant isotopes (Ar-41 and I-125) in the air that surrounds the limiting receptor (the terrestrial bird) using the Dose Coefficients in BiotaDC database [38] of International Commission on Radiological Protection (ICRP) 136 [39].
These coefficients are listed in Table 4 of Appendix A. The benchmark concentrations are enumerated in the Attachment to Appendix B at $2.56 \cdot 10^5\ Bq \cdot m^{-3}$ *for Ar-41 and* $1.4 \cdot 10^7\ Bq \cdot m^{-3}$ *for I-125.*

c) Graphically compare the benchmark concentrations with the measured concentrations in the emission from the MNR (i.e., the source concentrations, Figures 22 and 23) and with the conservatively calculated concentrations in the emission plume as the function of distance from the source (Figure 29).
Figure 29 is derived in the Attachment to Appendix B. The source concentrations in this figure are the highest concentrations measured in frequent, periodic grab samples of MNR exhaust (i.e., they are not the averaged concentration measurements).

8.2.4 Transfer factors, exposure factors, and dose coefficients

Topics in Section 7.3.5 of [2]

Dose coefficients used in this ERA are the internationally recommended ‘external’ dose coefficients defined and described in the preceding section.

Note that the ‘internal’ I-125 dose in the thyroid of the bird is not enumerated. Common concerns regarding the thyroid dose are mainly due to exposures to the long lived I-131 (a fission product) during open-air atomic bomb testing in the 1950s and daring severe nuclear power plant accidents such as Chernobyl and Fukushima. These concern are not applicable to the medical isotope I-125 but no information could be located on the I-125 benchmark thyroid dose or the corresponding concentration for any environmental fauna. A conservatively calculated (i.e., overestimated) I-125 concentrations as the function of distance show very low concentrations in the receptor habitat (Figure 29). These concentrations do not credit the removal of iodine from the plume by its reactions with surfaces of metallic and cementitious materials and by other applicable removal mechanisms. Thus, it is reasonable not to enumerate the thyroid dose to the bird receptor given that this would be an effort-intensive endeavour based on unrealistic, calculated concentrations. The judgements are that the actual I-125

[53] As prescribed in Section 7.4.2 of the applicable standard [2].

concentrations would be even lower than those in Figure 29 and that the thyroid doses would be negligible.

8.2.5 Modelled versus measured exposure concentrations

Topic in Section 7.3.6 of [2]

Concentrations of the release source (exhaust) are routinely measured and their magnitudes are consistently below the benchmark concentrations (Figures 22 and 23). Thus, the external exposure of the receptor to the undiluted emission would not harm it. However, it is desirable to have information on the concentrations at locations of the biota habitats, for which no measured data exists. In order to fill the data gap, a simple plume transport model is defined and used in the Attachment to Appendix B as discussed below.

8.2.6 Models

Topic in Section 7.3.7 of [2]

The atmospheric transport is a very complex topic. Complex, sophisticated calculations of contaminated plume behaviour are possible, but they are effort intensive as well as laden with uncertainties in the many assumptions required for such calculations. For practicality, a simple (textbook) and conservative model is documented in the Attachment to Appendix B which presumes the worst conceivable transport path for the contaminated plume (illustrated in Figure 28) that prevails continuously and indefinitely. These are, of course, stylized and unrealistic conditions which exaggerate the receptor exposure to radiation. The results (Figure 29) are not realistic but they delineate the highest conceivable radioactivity concentrations to which the terrestrial biota receptor might be exposed. The calculated bounding concentrations are sufficient for demonstrating that the routine MNR emission cannot adversely affect the environment but they do not represent the expected concentrations which a lower.

8.2.7 Exposure point concentrations and doses

Topics in Section 7.3.8 of [2]

Relevant concentrations are shown in Figure 29. Relative to the source concentrations, the conservatively calculated exposure point concentrations are ~ 3 orders of magnitude lower. The actual exposure point concentrations are expected to be > 5 orders of magnitude lower given the real-world variability of weather at the MNR site. In plain language, the exposure concentrations are small. For I-125, they will likely be below the detectable concentration.

8.3 Effects Assessment

Label of Section 7.4 in [2]

8.3.1 Radiological benchmarks

Topic in Section 7.4.2 of [2]

The benchmark for the chronic exposure prescribed in [2] and defined in [37] is used in this ERA (see Section 8.2.3).

8.3.2 Toxicological benchmarks

Topic in Section 7.4.3 of [2]

Only the prescribed radiological benchmark is used. This benchmark (expressed as benchmark concentrations in Figure 29) is not exceeded. Hence, no interpretation of adverse effects when the benchmark is exceeded needs to be performed. Uncertainties in the benchmark dose from [37] and in the coefficients used to interpret it as the benchmark concentrations in Figure 29 are not examined.

The benchmark dose from [37] is the most recent value available. No significant, non-radiological stressors are caused by MNR operation (Section 4). Hence, site-specific benchmarks, or benchmarks for short term (acute) exposures, are not required.

8.3.3 Thermal benchmarks

Topic in Section 7.4.4 of [2]

No thermal benchmarks are required for, or used in, this ERA.

8.4 Risk characterization

Label of Section 7.5 in [2]

8.4.1 Risk estimation

Topic in Section 7.5.2 of [2]

Hazard Quotients (HQs) are to be calculated and presented for each ecological receptor in each exposure area, for each ‘Contaminant and Stressor of Potential Concern’ in that area. This ERA is not an all-encompassing, probabilistic study but the conservative, bounding assessment focussed on enumerating the worst conceivable impact that routine MNR emission releases might have on the surrounding environment. In this context, only the worst conceivable risk is estimated for only one ecological receptor (i.e., the limiting receptor defined in Appendix A, see Section 8.1.2) who is located in the single area with the highest potential for receptor exposure (see Section 8.2.1 and the plume path in Figure 28).

The Hazard Quotients for Ar-41 and I-125 and a given receptor are enumerated as follows:

$$HQ = \frac{concentration\ @\ specified\ distance\ to\ which\ receptor\ is\ continuously\ exposed}{benchmark\ concentration\ that\ receptor\ can\ withstand\ without\ harm}$$

The input values are recorded in Figure 29. The HQ values are enumerated in the Attachment to Appendix B as follows:

Table 8: Hazard Quotients at different distances from MNR exhaust

HQ at distance → for isotope ↓	40 m[54]	500 m	1 km
Ar-41	0.02	$2.13 \cdot 10^{-4}$	$1.07 \cdot 10^{-4}$
I-125	$1.44 \cdot 10^{-7}$	$1.31 \cdot 10^{-9}$	$6.56 \cdot 10^{-10}$

All HQs are well below the value of 1, including those in the close proximity to the source. This means that additional clauses in Sections 7.5.2.2 through 7.5.2.6 of [2] are irrelevant. As discussed in Section 8.2.4, the I-125 emission would result in a negligible thyroid dose. The HQ for the thyroid dose need not be enumerated.

8.4.2 Other lines of evidence

Topic in Section 7.5.3 of [2]

No other lines of evidence are available or are needed.

54 40 m is approximately the distance to the intake of Health Canada monitoring station, see Figure 18.

8.4.3 Thermal effects

Topic in Section 7.5.4 of [2]

These effects are pertinent to boundary conditions when the HQs are ≈ or > 1; they are not pertinent to the MNR conditions and are not examined in this ERA.

8.4.4 Wildlife-vehicle and bird-structure mortalities effects

Topic in Section 7.5.5 of [2]

Refer to Section 4.3 for an explanation of how the MNR does not affect normal wildlife mortalities.

8.5 Uncertainties of Ecological Risk Assessment

Topic in Section 8 of [2]

Important uncertainties are to be evaluated qualitatively or semi-quantitatively and discussed in the ERA report [2]. Approaches or parameters used in the assessment that lead to an overestimation or underestimation of exposure, toxicity, or risk are to be identified and judgments about the degree of over- or underestimation are to be provided, if possible [2].

This ERA is the bounding assessment. Thus, the exposure is undoubtedly overestimated. The reason for using this bounding approach is mainly the variability of local weather (and the associated variability of local winds), which govern the transport and dispersion of airborne radioactivity in the environment. Limited data on measured concentrations of pollutants in the environment is available (Section 5.1.1) but this data is not directly usable in the ecological risk assessment as explained in Appendix B. The conservative modelling of the plume transport and the calculation of the concentrations away from the MNR (Section 8.2.6) are used to quantify the concentrations. Based on the experience with modelling of atmospheric dispersions following nuclear reactor accidents, the transport treatment in the Attachment to Appendix B results produces a > 2 orders of magnitude (> factor of 100) over-estimate of the diluted concentrations within the receptor habitat.

The related bounding assumption is that the receptor (i.e., a nesting terrestrial bird) remains within the contaminated plume continuously and indefinitely (Section 8.2.2). This assumption is consistent with the conditions for which the benchmark dose in [37] (and the derived benchmark concentration) are defined. The actual bird residence in the contaminated plume is variable and unknown. Benchmark concentrations would be higher for an intermittent receptor residence within the plume.

Of potential concern is that casual readers may miss or ignore the bounding nature of the results and misunderstand (undervalue) the margins to impacts on the environment with which the MNR operates.

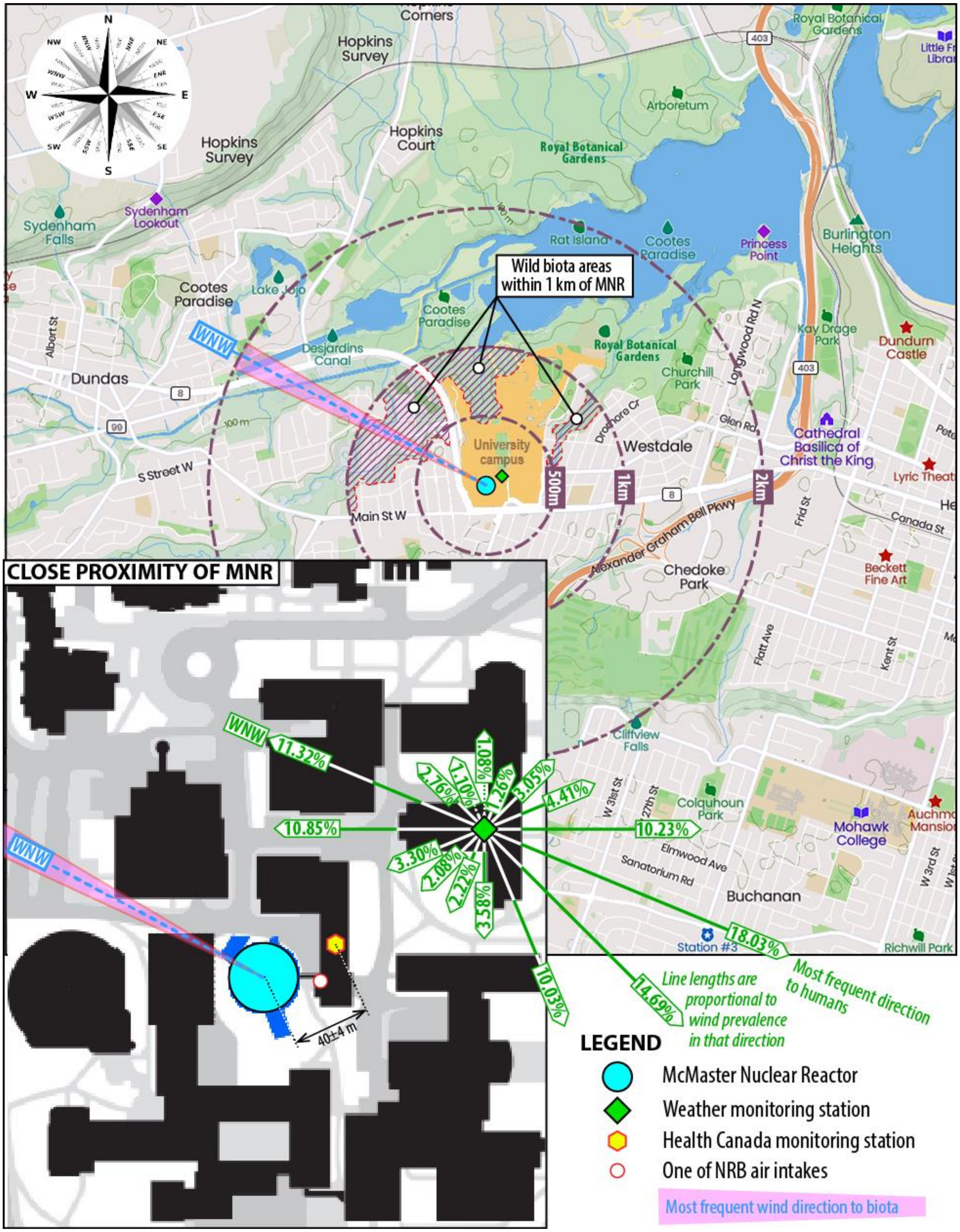

Figure 28: Biota location and wind direction for analysis

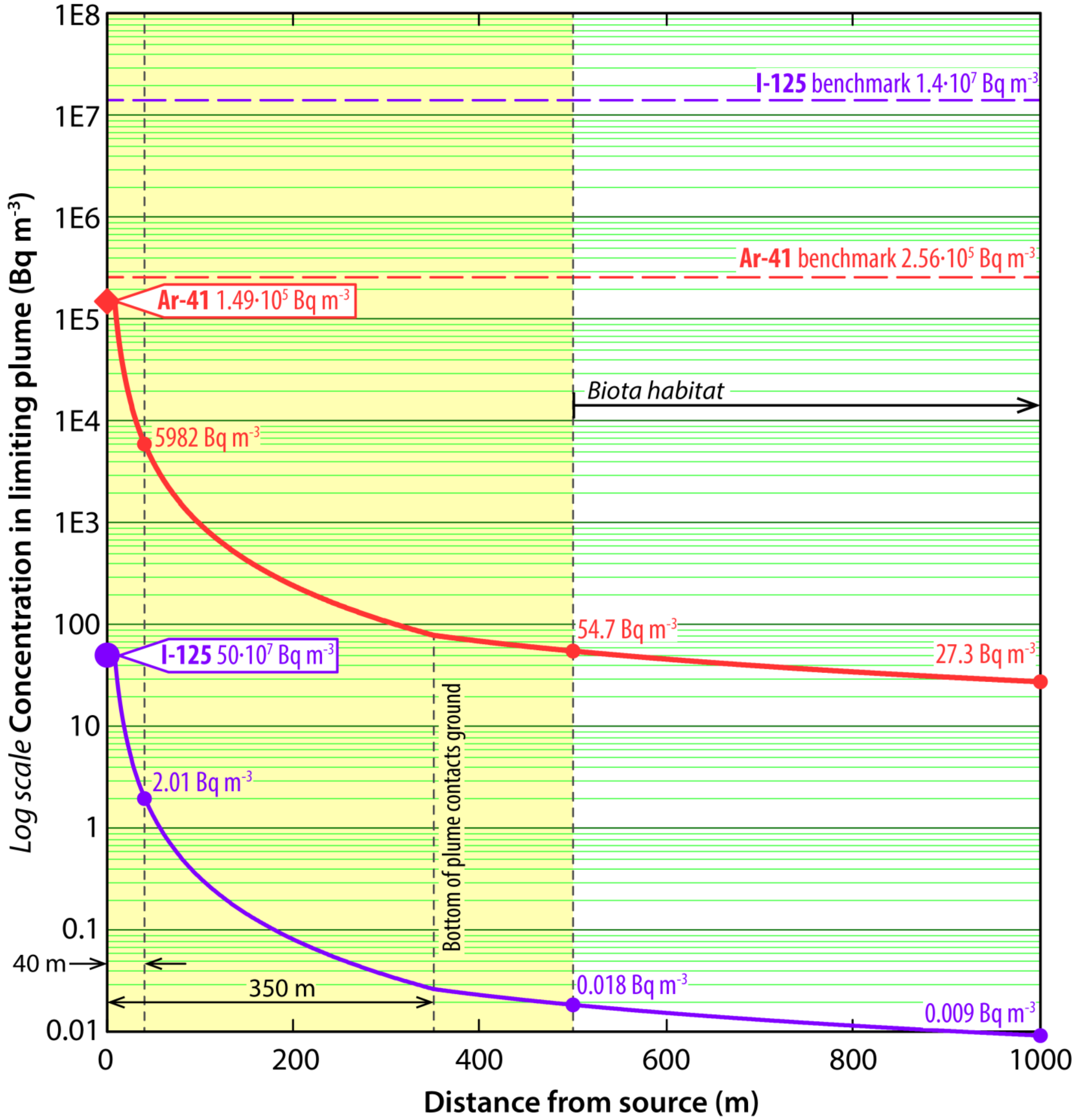

Figure 29: Concentrations in limiting plume as function of distance from source

Calculated in Attachment to Appendix B

9. EVALUATION OF UNCERTAINTY

Topic in Section 8 of [2]

9.1 Uncertainties of Human Risk Assessment

A requirement of CSA N288.6-22 standard is that "the important uncertainties shall be evaluated qualitatively or semi-quantitatively and discussed in the ERA report" (Sections 8.1 and 8.2.2 of [2]). This topic is covered below.

For normal operation, the health risks to nuclear workers (operating staff) are assessed from the extensive records of measured exposures to radiation. The health risks to population are assessed from data provided by various sensors (i.e., radioactivity concentrations, emission flow rates, etc.) in combination with conservative assumptions on the exposure pathways (i.e., the weather) and the receptor locations.

The instruments are routinely calibrated [21] and the trends of measured data are continuously monitored by the Health Physics as well as the Operations staff. Any anomaly is promptly investigated and resolved.

Insight: The nuclear workers doses are realistic. The public doses are conservative (i.e., overestimated).

10. RISK-BASED RECOMMENDATIONS

Topic in Section 9 of [2]

This ERA confirms that the normal operation of MNR does not adversely affect the environment. Thus, no recommendations are made for modifications of, or adjustments to, existing provisions and practices related to MNR handling and management of radioactive materials.

This said, optional refinements related to environmental monitoring can be identified. While an extensive program for monitoring of outside atmosphere is in place (Section 5.1.1), the measured data seems to be used only for confirming that no detrimental changes in the data trends are occurring. The existing provisions do not measure the Ar-41 gas content in the outside air, which is the largest source of the very small environmental risk as illustrated by the Hazard Quotients in Table 8. The Ar-41 concentrations are not of safety concern. The lacking data would be useful for verification of environmental transport models. Similarly, provisions for monitoring I-125 concentrations do not recognize that iodine may be present in 2 physical forms (i.e., the vapour and the aerosol particles). Again, this aspect is not a safety issue; it pertains to completeness of understanding the nature of the pollutant. It might be worthwhile (but not essential) to re-examine all radioactivity monitoring provisions at, and around, the MNR in view of all potential data applications to ensure that the maximum value is provided for all potential uses of the data.

Site surveys are performed periodically. However, the measurements taken in these surveys do not seem to be adequately archived. The survey data is useful not only for confirming the current conditions. It is also a valuable commodity for future analyses and modelling.

11. QUALITY ASSURANCE AND CONTROL

Topic in Section 10 of [2]

McMaster Nuclear Operations and Facilities employs a Quality Management System (QMS) that is compliant with CSA N286-12 [41] which governs document creation, approval, revision, and control. This ERA is drafted and finalized following AP-1000 MNR Policy Manual [42] and AP-1215 MNR Document Control [43], which are in compliance with CSA N286 [41]. The review included technical experts as well as editorial review. All review comments were resolved and incorporated. The document control process [43] involves ongoing reviews of the ERA document. The document will be reviewed for adequacy by appropriate personnel, at a minimum of every three years.

Many of the reported data pertains to monitoring by the Health Physics Department. HP-9000 MNR Radiation Safety Program [21] defines the requirements for radiation safety, which covers safety precautions and monitoring that ensure safety for the human stakeholders and the environment. All monitoring equipment is used and maintained in accordance with HP-9005 Quality Assurance Program for Radiological Safety Instruments [44]. The measurements of airborne radiation are undertaken in accordance with multiple procedures ([45] to [56]).

12. SUMMARY

This assessment confirms that the McMaster Nuclear Reactor (MNR) is a Class 1 facility with a very low release of pollutants into the environment. The routine releases are small airborne emissions of

- Ar-41 (non-reactive noble gas produced mainly by irradiation of pool water) and minuscule emissions of
- I-125 vapour or aerosols (medical isotope produced in sealed rigs within the reactor pool and handled/packaged on the Experimental Floor of the Reactor Building); and
- Radioactive particles (dust of undefined source).

The radioactive particles suspended in the air are monitored as the matter of principle (defence-in-depth). Their concentrations are close to, or below, the minimum detectable value and they are insignificant in terms of environmental impact.

There are no liquid effluents from the MNR. Solid radioactive materials are stored within the Reactor Building (i.e., within the MNR containment envelope) and are periodically transferred to facilities which are certified by the CNSC for disposal. Thus, the MNR is a low hazard facility.

Radioactivity is comprehensively monitored within as well as outside of the MNR. The monitoring records are routinely examined by the MNR operators and by the Health Physics authorities for anomalies and corrective actions are taken if needed. These records are reported to the CNSC in Annual Compliance Reports for independent assessments.

Historical trends show a decline of airborne radioactivity concentrations within the Reactor Building at the beginning of MNR operation (more than 60 years ago) followed by the maintenance of low concentrations thereafter (up to now). These records unambiguously confirm that the existing MNR provisions for controlling radioactivity in normal operation (physical as well as administrative) are effective.

The MNR rigorously applies the as low as reasonably achievable (ALARA) principles to all radiological parameters. Worker and public doses (historical and current) are well below the regulatory limits as well as below the more stringent MNR Administrative Control limits. Environmental effects of the small radioactivity releases into the atmosphere were not explicitly assessed until this report. Such assessment was deemed unnecessary based on the domestic and international consensus that adequately protecting the humans also adequately protects the environment (e.g., [27] [28). The assessment in this report corroborates the international consensus. It is performed to fulfil recently updated regulatory requirements in REGDOC-2.9.1 [1]. It follows the guidance of Canadian Standards Association (CSA) standard N288.6-22 [2] to the extent possible given the unique features of the MNR.

Realistic estimates of MNR interactions with the environmental biota are not feasible at this time, but they are not essential for demonstrating that the MNR has no noticeable impact on the environment. Conservative (bounding) assessment is performed, which enumerates the worst conceivable impact (i.e., the upper bound of potential impacts range). Even for this extreme, it is shown that the largest current MNR emissions to the atmosphere (resulting from current and past reactor operation at 3 MW) would not affect the limiting biota receptor (i.e., the most vulnerable receptor in terms of radiation effects) with a large margin to spare. A predictive assessment shows that this conclusion holds for a potential, future operation of MNR at 5 MW (i.e., at the maximum power permitted by the operating license).

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MNR ERA Appendix A

TERRESTRIAL BIOTA PARAMETERS

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ACRONYMS AND UNIT SUMBOLS

Ar-41	Argon isotope (noble gas)
CSA	Canadian Standards Association
DC	Dose Coefficient
ERA	Environmental Risk Assessment
hr	hour = unit of time
MNR	McMaster Nuclear Reactor
I-125	Iodine isotope (vapour and/or aerosol)
ICRP	International Commission on Radiological Protection
Gy	Gray = SI unit of ionizing radiation = absorption of 1J energy per kg of matter
μGy	MicroGray = $Gy \cdot 10^{-6}$
SI	International System of Units
α	Alpha = type of radiation involving particles
β	Beta = type of radiation involving electrons or positrons

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1. INTRODUCTION

Ecological risk assessment covers the lands with the terrestrial biota which are sparsely populated by humans and the water-filled areas with the aquatic biota. Figure 1 illustrates locations and types of areas surrounding the McMaster Nuclear Reactor (MNR). Should any wild biota be adversely affected by contaminated effluents from the MNR, the most noticeable impact would be within 1 km of the effluent source. Figure 2 shows the potential areas of interest. The wild biota only resides in North direction from the MNR in the Dundas (or Cootes Paradise) valley.

Section 2 summarizes information on relevant stressors. Section 3 compiles information on the biota parameters needed for the assessment. Section 4 compiles information on radiological benchmarks (screening criteria) needed for interpretation of assessment results.

2. STRESSOR FEATURES

A stressor is a chemical or biological agent, environmental condition, external stimulus or an event seen as causing stress to an organism. Information on the stressors is provided in Section 4 of the main report. Stressors relevant to this ERA are:

- Airborne release of Ar-41; and
- Airborne release of I-125.

Small amounts of beta-emitting particles are also discharged as part of the MNR effluent. However, these amounts are so small that they need not be explicitly considered.

These gaseous stressors interact differently with terrestrial and aquatic biota. Radiation exposures of the terrestrial plants and animals residing above the ground are directly related to the weather-affected concentrations of the two airborne isotopes at the locations of these biota. This is not the case for the aquatic plants and animals which are submerged in water. An additional parameter, which most likely governs (or at least strongly affects) the radiation exposures of aquatic biota, is the transfer of Ar-41 and I-125 from air into water.

Consider a flowing plume stream with a small Ar-41 mass content coming into contact with a stationary water surface. This water has a pre-existing equilibrium concentration of natural Argon. The transfer of an additional Ar-41 gas into the Argon-saturated water is by the concentration-driven diffusion process which is extremely slow given the small mass concentrations Ar-41 in the contaminated plume stream. This slow diffusion rate is further reduced by the Ar-41[1] decay into the non-radioactive K-41.

Iodine is slowly and slightly soluble in water[2]. Thus, the dissolution of the airborne I-125 (vapour or aerosol) in the stationary water pool can also only be very slow.

Local concentrations of both stressors in water are continuously reduced the natural turbidity of water in potential receptor locations[3]. Hence, it is not credible that the aquatic biota living within water would be exposed to any appreciable, sustained concentrations of Ar-41 or I-125 in liquid water. In other words, there is not a plausible pathway to expose the submerged biota to any significant radiation from the MNR effluent gases. Similarly, pathways to the terrestrial biota living below the ground surface are severely constrained by the access of the gaseous stressors into the soil.

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1 Ar-41 has β^- decay with half life of 109.34 minutes.
2 Iodine solubility is 0.34 gm per kg of water (e.g., https://onlinelibrary.wiley.com/doi/abs/10.1002/047084289X.ri005)
3 See description of Aquatic Environment in Section 2.2.2 of the main report.

In plain language, any appreciable exposures of submerged or underground biota to the MNR effluent gases are not credible. This insight is used for screening of potential receptor choices in Table 1.

3. RECEPTOR FEATURES

The terrestrial biota in proximity of MNR is described in Section 2.2.2 of the main report. Based on insights of Section 2, only the wild, terrestrial biota located on the lands marked in Figure 2 needs to be considered.

CSA N288.6-22 Standard recognizes that "it is not practical or necessary to specifically assess all species present or likely to be present on a site" (Section 7.2.3.2 of [7]). It is also noted that "a receptor is not necessarily a particular species and can be defined at a higher taxonomic[4] or community level" (Section 7.2.3.3 of [7]). The International Commission on Radiological Protection (ICRP) has defined reference plant and animal *families* on the taxonomic level [8] as listed in the 1st column of Table 1.

3.1 Choice of Receptor

As already noted, only the plants and animals living on the ground surface are the potential receptors for this ERA. An additional screening consideration is that the plants are less affected by exposures to radiation then the animals are (Table 3). The terrestrial plants would not be adversely affected by exposures to low radiation levels which are prototypic of the MNR site. In fact, plant irradiations may have a positive effect on plant growth at low radiation levels and harmful effects only at high radiation levels (e.g.,[10] [11]). Chronic doses to the plants can only be low under MNR normal operating conditions, possibly enhancing the plant growth. Thus, neither the submerged aquatic biota nor the terrestrial plants are chosen as the receptors in Table 2.

A considerable amount of research was (and still is) performed on irradiating insects for purposes of agricultural pest control. It is observed that insects are more resistant to ionizing radiation than vertebrates[5]. While very high doses reduce an insect lifespan, lower doses can enhance the lifespan (e.g., [12][13][16]). However, the radiation resistance is not uniform throughout the insect family [14] (i.e., there are variations in what constitutes 'high doses'). Few insects-at-risk which are not agricultural pests may or may not be present at the MNR site (Table 2). For practicality, they are not chosen as receptors.

The bounding hypothesis is that radiological consequences of all terrestrial biota are ≤ the consequences for a small terrestrial bird. This bird is represented by a small terrestrial mammal, which is represented by the Reference Rat. Thus, the 'Reference Rat' is the chosen as the bounding receptor in Table 2 on behalf of the small bird. This rat has the same radiological properties as the bird (i.e., the mass, shape, etc.) but not the same habitat (i.e., exposure) conditions.

4. RADIOLOGICAL BENCHMARKS FOR ENVIRONMENTAL BIOTA

Regulatory limits on acceptable doses to the environmental biota are not defined. CSA N288.6-22 standard [7] states that "radiation dose benchmarks for quantitative effects assessment should follow UNSCEAR (2008). Table 3 collects the benchmarks in Annex E of UNSCEAR (2008) [16].

[4] Taxonomy is the science of naming, describing and classifying organisms.
[5] Animals with a backbone or spinal column, including mammals, birds, reptiles, amphibians, and fishes.

For the chosen receptor (i.e., a small terrestrial bird represented by the Reference Rat in terms of its mass, shape, etc.), the Benchmark Dose (i.e., the acceptable dose at which no detrimental endpoints have been observed) is < 100 μGy/hr. This is the biological effects parameter. The dose is acquired by the immersion of the animal in radioactive gases emitted from the MNR stack, which in turn produce a cloud at the receptor location with some Ar-41 and I-125 concentrations in the air.

For the ERA, it is practical to express the above biological effects threshold in terms of a maximum concentrations (which are the physical parameters) to which the chosen receptor can be continuously exposed without harm.

ICRP 136 [19] provides a computerized database (BiotaDC [20]) which facilitates a lookup of available information on various terrestrial ecosystems. The information on the terrestrial fauna (animals) is provided for different exposure targets (organism mass and shape), sources of exposure (type and height) and types of radiation (parent radionuclide and treatment of decay chain). Semi-empirical Dose Coefficients (DCs) are given for the submersion in the contaminated air, which correlate the dose to the concentration of the radionuclide in the air.

Table 4 extracts the BiotaDC information for a small bird, which is the receptor chosen in Table 1. The relationship between the external dose and the Ar-41 concentration in the air at receptor location is approximately $1 Bq/m^3 \approx 3.9 \cdot 10^{-4}$ μGy/hr[6]. The benchmark external dose of 100 μGy/hr is thus equivalent to the benchmark Ar-41 concentration in the atmosphere $\approx 2.564 \cdot 10^5$ Bq/m^3. The environmental receptor can be indefinitely exposed to this and lower concentration without harm.

The external dose from I-125 is only a negligible contributor to the total external dose. The benchmark I-125 concentration $\approx 1.401 \cdot 10^7$ Bq/m^3. The receptor can thus tolerate much higher I-125 concentrations than Ar-41 concentrations for the external exposures. I-125 thus can be (and is) ignored in assessing the external receptor exposures. The internal (i.e., the thyroid) dose is also deemed to be negligible given the very small I-125 concentrations at biota locations enumerated in Figure 33 in the main report.

5. SUMMARY

This appendix documents a complex process of sorting out which irradiation target (the receptor) is to be evaluated for practical (i.e., as simple as possible) analysis. The choice of the receptor, the rationale for this choice, and the benchmark dose which the receptor can receive without harm are documented in sufficient detail to facilitate independent reviews.

6 This is the rounded value of DC in the second row of Table 4.

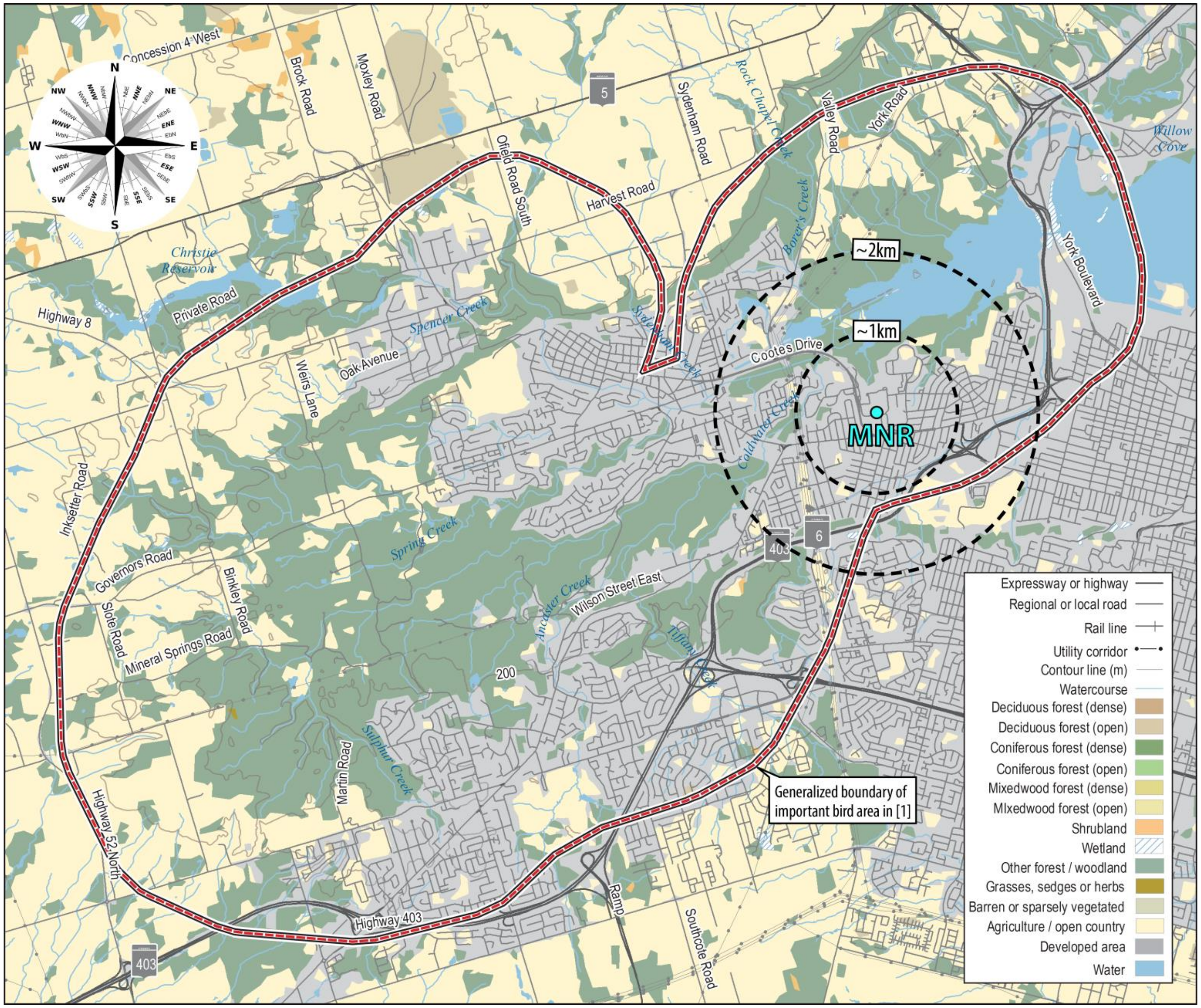

Figure 1: Map of unpopulated and urban areas around MNR

Annotated map from [1]

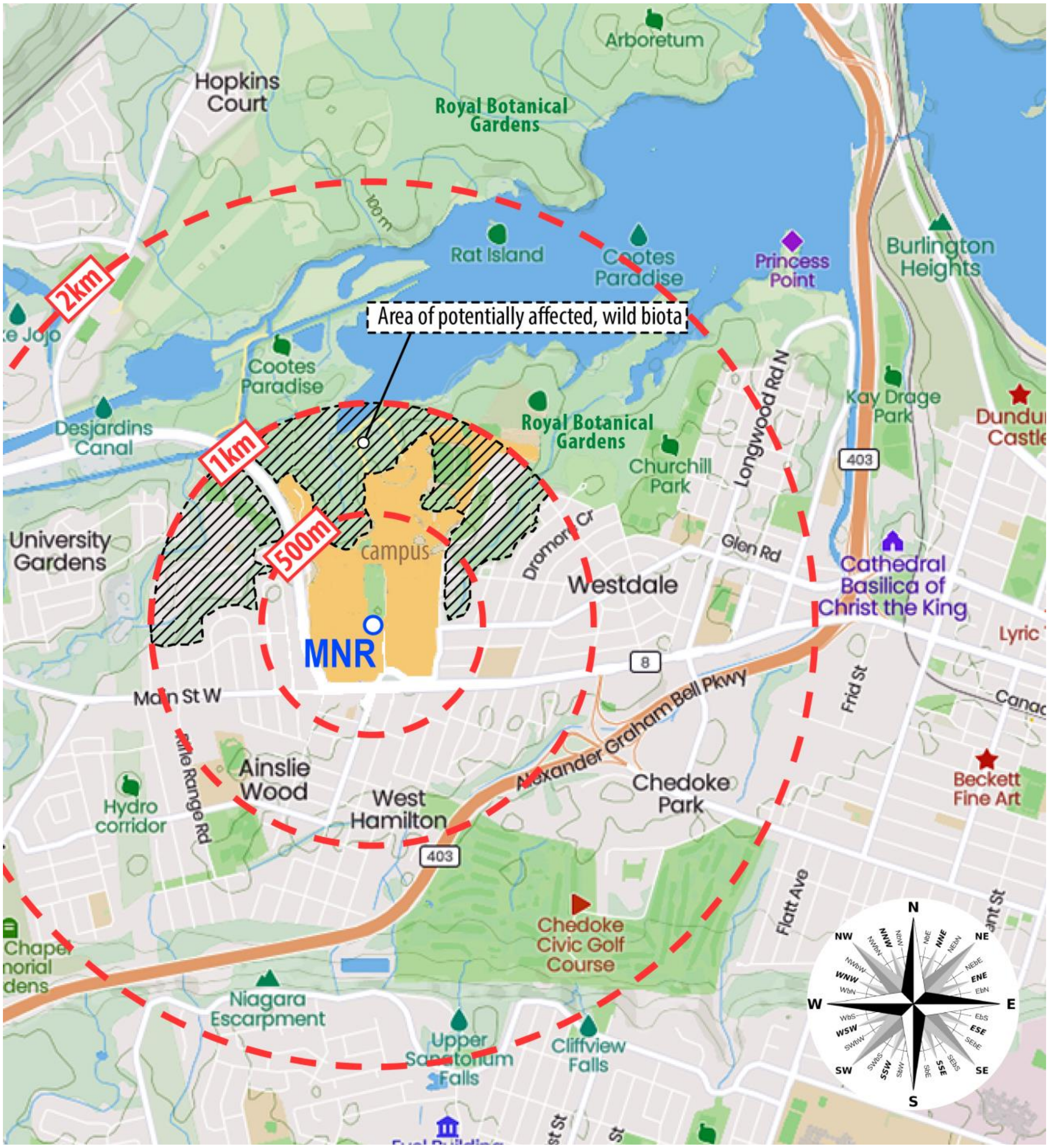

Figure 2: Area of potentially affected wild biota

Table 1: ICRP taxonomic families of biota and choices of receptor

Reference animals are defined in [8] and confirmed in [9]

Family	Reference animal ▼	Section number in [8] ▼	Note
Large terrestrial mammal	Deer	2.5.1	Large wild mammals may briefly pass through the relevant area in Figure 2 but they do not reside in it. Hence, this family is not chosen as the receptor.
Small terrestrial mammal	Rat *Similar to bird*	2.5.2	Small mammals reside around the MNR. The rats are not species-at-risk. Other small mammals which are at risk have no or limited exposure to airborne radiation by virtue of their habitat characteristics (Table 2). However, Reference Rat is **used as the receptor surrogate** by virtue of being similar to small terrestrial bird.
Aquatic bird	Duck	2.5.3	The ducks are common in the Dundas Marsh but they are not species at risk. Hence, this family is not chosen as the receptor.
Terrestrial bird	*ND** ***Chosen receptor***	*ND**	Numerous small birds are common around MNR. Thus, 'Small Terrestrial Birds' family nesting in the area shown in Figure 2 is the appropriate **receptor** with the focus on birds-at-risk (Table 2), represented by Reference Rat physical properties. A caveat is that the bird nesting season (i.e., the exposure) is not prolonged and continuous [17][18]. The birds are stationary in their nests for up to 4 weeks from mid March to late August.
Amphibian	Frog	2.5.4	Frogs are common in the Dundas Marsh but they are not species-at-risk. Locations of the amphibians at risk are examined in Table 2 and none of them lives within many km of the MNR. Thus, this family is not chosen as the receptor.
Freshwater fish	Trout	2.5.5	Submerged aquatic biota is not exposed to any appreciable radiation from air as explained in Section 2. Thus, this family is not chosen as the receptor.
Marine fish	Flatfish	2.5.6	Not relevant to MNR.
Terrestrial insect	Bee	2.5.7	The reference insect managed by bee farmers is not at risk. 3 insects-at-risk (1 moth + 2 butterflies) may or may not be present in the area through which the diluted MNR effluent passes (Table 2). The insight in the 2nd paragraph of Section 3.1 is that the insects are more resistant to ionizing radiation than vertebrates = means more resistant than Reference Rat which is the chosen receptor. For practicality, it is assumed the effects on small bird family envelope (bound) the effects on insect family. Thus, this family is not chosen as the receptor.
Marine crustacean	Crab	2.5.8	Not relevant to MNR.
Terrestrial annelid	Earthworm	2.5.9	Underground biota is not exposed to any appreciable radiation from air as explained in Section 8.1.5 of the main report. Thus, this family is not chosen as the receptor.
Large terrestrial plant	Pine Tree	2.5.10	Information in the 3rd paragraph of above Section 3 shows that exposures to low radiation fields have no effect, or positive effect, on plant growth. The fields from the diluted MNR effluent stream can only be very low. Thus, these families are not chosen as the receptors.
Small terrestrial plant	Wild Grass	2.5.11	
Seaweed	Brown Seaweed	2.5.12	Not relevant to MNR.

* ND = not defined in [8].

Table 2: Species at risk potentially living in wild areas around MNR

Identified from information in [15]

ANIMAL	HABITAT	RELEVANCE TO MNR ERA
Small Mammals		
Woodland vole (Microtis pinetorum)	Small rodent which lives below ground. One of its habitats is in Hamilton	Underground = limited exposure to airborne radiation
Tri-colored Bat (Perimyotis subflavus)	Small bat which lives in forests of southern Ontario (likely including forests in Figure 1)	Habitat not close enough to MNR
Small Birds		
Bank Swallow (Riparia riparia)	Small songbird nesting on banks of rivers and lakes in southern Ontario. It migrates south for the winter.	Cannot be precluded in Dundas Valley
Barn swallow (Hirundo rustica)	Medium songbird nesting on human-made, open structures throughout southern Ontario.	Shielded by structure = limited exposure to airborne radiation
Black tern (Chlidonias niger)	Small waterbird nesting mainly in the marshes along the edges of the Great Lakes. It migrates south for the winter.	Cannot be precluded in Dundas Marsh
Bobolink (Dolichonyx oryzivorus)	Medium songbird found in grasslands and hayfields in southern Ontario	Habitat not close enough to MNR
Common nighthawk (Chordeiles minor)	Medium bird living throughout Ontario in open areas with little vegetation. It migrates south for the winter.	Habitat not close enough to MNR
Eastern wood-pewee (Contopus virens)	Small forest bird living in southern and central Ontario at edges forests.	Cannot be precluded in Dundas Valley
Golden-winged warbler (Vermivora chrysoptera)	Small songbird breeding in areas of central-eastern Ontario with young shrubs surrounded by mature forest	Habitat not close enough to MNR
Grasshopper Sparrow (Ammodramus savannarum)	Small songbird living in open grassland areas of southern Ontario	Habitat not close enough to MNR
Least bittern (Ixobrychus exilis)	Medium bird lining wetland habitats of central and eastern Ontario. It nests above the marsh water in stands of dense vegetation	Cannot be precluded in Dundas Marsh
Piping plover (Charadrius melodus)	Small shorebird, not common, breeding along the shores of the Great Lakes	Habitat not close enough to MNR
Wood thrush (Hylocichla mustelina)	Medium songbird living in deciduous and mixed forests all across southern Ontario	Cannot be precluded in Dundas Valley.
No amphibians at risk are reported in [15] for areas adjacent to MNR		
Insects		
False-foxglove Sun Moth (Pyrrhia aurantiago)	This moth lives in dry sandy or loamy soils near the Great Lakes	Cannot be precluded in University Campus
Monarch (Danaus plexippus)	This relatively large butterfly is abundant in much of Ontario where milkweed plants are widespread. Monarchs migrate south for the winter.	Habitat not close enough to MNR
Mottled Duskywing (Erynnis martialis)	These medium butterflies live in dry habitats with sparse vegetation throughout southern Ontario.	Cannot be precluded in University Campus
West Virginia White (Pieris virginiensis)	Small and rare butterfly living in moist, deciduous woodlots of central and southern Ontario.	Cannot be precluded in Dundas Valley.
Yellow-banded Bumble Bee (Bombus terricola)	Medium bumble bee lives in mixed woodlands well as open habitats of Ontario. Nest sites are often underground.	Underground = insignificant exposure to airborne radiation

Table 3: Effects of chronic radiation exposure on plants and animals

Radiation dose ***benchmarks*** *- expanded Table 39 in [16] which explicitly includes birds and insects.*

Biota Family	Dose rate (µGy/hr)	Effects	Endpoint
Plants (terrestrial)	100–1000	Reduced trunk growth of pine trees	Morbidity
	400–700	Reduced numbers of herbaceous[7] plants	
Fish [A]	100–1000	Reduction in testis mass and sperm production, lower fecundity, delayed spawning	Reproduction
	200–499	Reduced spermatogonia[8] and sperm in tissues	
Mammals	< 100	No detrimental endpoints have been described	Morbidity mortality reproduction
Birds [B]		*Effects of radiation exposure on birds are similar to those in small mammals* [C]	
Insects [B]	≥ 100	*Reptiles and invertebrates (including insects) are less radiosensitive than birds* [C]	
Generic ecosystems (terrestrial and aquatic)	~ 80	The dose rate at which 95% of the species in the ecosystem are protected	

[A] Not applicable. Aquatic biota is not exposed to appreciable radiation from MNR effluent gases (Section 3.1).
[B] Not listed in Table 39 of [16].
[C] Citation from text on page 292 in [16].

Table 4: Dose coefficients (DCs) for nesting bird

From BiotaDC database [20] of ICRP 136 [19]

External exposure to contaminated air
Bird mass = 0.314 kg (tissue-equivalent sphere)
Bird is stationary for up to 1 month during nesting

Nuclide	Nesting Height	DC (µGy/h per Bq/m³)	*Note*
Ar-41	10 cm [E]	3.82E-04	*Only small effect of height.*
	5 m [F]	3.94E-04	
I-125	10 cm [E]	5.97E-06	*I-125 has smaller biological impact than Ar-41*
	5 m [F]	7.14E-06	

E Nest is near ground or water surface, applicable to Bank swallow, Black tern and Least bittern in Table 2.

F Nest is above ground, applicable to Eastern wood-pewee (15-45' or 4.6-13.7 m) and Wood thrush (10-15' or 3-4.6 m) in Table 2.

A stylized nesting height of 5 m is used to illustrate the insensitivity of the DC to this parameter as well as to recognize that the ground elevation (and thus the nest height) is likely to be lower than the horizontal elevation of the plume discharge from the MNR exhaust.

7 Plants that have no persistent woody stems above ground.
8 An undifferentiated male germ cell.

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MNR ERA Appendix B

AIRBORNE ACTIVITY TRANSPORT TO BIOTA LOCATIONS

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ACRONYMS AND UNITS

Bq	Becquerel = SI unit of radioactivity strength = the amount of released radiation
CNSC	Canadian Nuclear Safety Commission
ERA	Environmental Risk Assessment
KERMA	Kinetic Energy Released in Matter
MNR	McMaster Nuclear Reactor
MW	Megawatt = unit of power. For MNR, it is the thermal power.
ICRP	International Commission on Radiological Protection
Gy	Gray = SI unit of ionizing radiation = absorption of 1J energy per kg of matter
nGy	nanoGray = $Gy \cdot 10^{-9}$
SI	International System of Units
Sv	Sievert = SI unit represents the stochastic health risk of ionizing radiation.

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ATTACHMENT: AIRBORNE RADIOACTIVITY TRANSPORT TO WILD BIOTA

1. INTRODUCTION

This appendix reviews the transport of airborne radioactivity from the exhaust of the McMaster Nuclear Reactor (MNR) to nearby lands which may house populations of terrestrial receptors defined in Appendix A[1]. From Figure 1 which compares the benchmark concentration defined in Appendix A with the measured exhaust concentrations, it is known in advance that the environmental biota is not endangered by the routine effluents from the MNR operating at 3 MW thermal power. However, the MNR is licensed for operation up to 5 MW. The exhaust radioactivity concentrations of Ar-41 at 5 MW would be higher than the illustrated concentrations in Figure 1.

Information on a dilution of radioactive concentrations during the transport of effluent within the outside environment is of genetic interest. Such information would be useful for assessments of reactor powers higher than 3 MW. This appendix aims at providing insights on the dilution of concentrations as the function of distance from the source.

The atmospheric transport is a very complex topic. Sophisticated calculations of contaminated plume behaviour are possible, but they are effort intensive as well as laden with uncertainties in the many assumptions required for such calculations. For practicality, a simple (textbook) and conservative approach is adopted which assumes the worst conceivable transport path for the contaminated plume that prevails continuously and indefinitely. These, of course, are stylized and unrealistic boundary conditions that exaggerate the receptor exposure to radiation. This calculation conservatively ‘fills-in’ the information that is not available from the measured data.

Section 2 extracts from Appendix A the locations of target areas (i.e., the spaces occupied ecological receptors) relative to the source of radioactive release into the environment. Section 3 summarizes topography and meteorology conditions relevant to the atmospheric transport. Section 4 reviews the measured data on the concentrations of Ar-41 gas in the atmosphere outside of the MNR. Section 5 presents the results of calculation documented in the Attachment to this appendix. Section 6 discusses the insights gained from the assessments herein.

2. AREA OCCUPIED BY POPULATIONS OF RELEVANT TERRESTRIAL ANIMALS

The area occupied by ecological receptors is defined in Figure 2 of Appendix A which is reproduced as Figure 2 below. Of specific interest are the animals at risk. It turns out that there are no populations of mammals at risk residing within 2 km of the MNR (Table 2 in Appendix A). Several small bird species at risk may or may not nest (and thus may or may not be stationary for several weeks) in the hatched areas of Figure 2.

3. TOPOGRAPHY AND METEOROLOGY ASPECTS OF ATMOSPHERIC TRANSPORT

The topography and meteorology govern the airborne transport of radioactivity to the receptors. The MNR is located within the Dundas Valley[2] as illustrated in Figure 3. A steep escarpment on the North-West side of this valley alters wind directions within the valley as illustrated by the weather station data in Figure 4. Complex local wind patterns are one of the reasons why detailed simulations of the atmospheric plume dispersion are tenuous and their results cannot be confirmed.

[1] The limiting receptor is a small terrestrial bird.
[2] Also called the Cootes Paradise Valley.

4. MEASURED RADIOACTIVITY CONCENTRATIONS IN ATMOSPHERE

Figure 1 plots the measured Ar-41 data on airborne radioactivity and compares them to the benchmark concentration (i.e., the acceptable concentration enumerated in Appendix A). This figure implies a huge dilution of the concentration (by about 5 orders of magnitude) within a distance of only few tens of meters from the MNR stack. This large dilution is examined below.

The map insert in Figure 5 illustrated where the Health Canada station that measures the atmospheric concentration is located. This station is in operation since April 2015 as part of the 'Fixed Point Surveillance Network' [3]. In the Health Canada reports, it is identified as 'Greater Toronto Area/Lake Ontario system', 'Hamilton'. The station measures Argon-41, Xenon-133, Xenon-135 and Total Air KERMA[3] using Sodium Iodide spectrometer with a 15-minute accumulation period. The radiation doses (in nGy[4]/month) are enumerated for an adult member of the public continuously exposed to air at the location of the station. The biological effects on this human are enumerated using the effective dose rate coefficients for exposures of adults to airborne inert gases in Appendix C of ICRP 119 [4]. The coefficient for Ar-41 is 1 $Bq/m^3 = 5.3 \cdot 10^{-9}$ Sv/day = $5.3 \cdot 10^{-9}$ Gy/day.

The conversion of the Health Canada doses to the concentrations in Figure 1 uses the following formula:

$$Y\left(\frac{Bq}{m^3}\right) = X\ 5.3E^{-9}\ \frac{\frac{Gy}{month}}{\frac{\#\ days}{month}}$$

Where the number (#) of days per month varies from 28 to 31 according to the month and year of the Health Canada reports.

Examining the wind prevalence's in Figure 5 shows that the Health Canada intake is in the direction of infrequent winds[5]. This means that the MNR effluent steam bypasses the intake in more than 95% of local weather conditions. It follows that the Health Canada data in Figure 1 is not representative of the average concentration around the MNR but of the average concentration in a specific direction from the MNR.

5. CALCULATION OF RADIOACTIVITY TRANSPORT

Knowing the dilution of contaminated plume in a direction towards the receptor is desirable. A conservative calculation is performed in the attachment to this appendix to enumerate the concentrations as the function of distance from the source. The most frequent wind direction at the MNR site, and its associated wind speed, are assumed to prevail continuously and indefinitely[6]. The effluent discharge is represented by the point source as schematically illustrated in Figure 6[7]. The calculation is for a flat[8] and smooth[9] ground. At some distance from the source, the plume expands enough to touch the ground, which prevents a further expansion of plume bottom. From this distance onwards, it is assumed that the

3 'Total Air KERMA' refers to the radiation dose from all external gamma sources, not just from the three noble gases Argon-41, Xenon-133 and Xenon-135. This includes natural background radiation as well [3].

4 1 nGy = 1×10^{-9} Gy = 1×10^{-9} Sv [3].

5 Winds towards ENE.

6 This assumption is shown graphically in Figure 5.

7 The point source is very conservative for the multi-directional effluent discharge at the top of the reactor building which is built to maximize the dispersion.

8 The ground surface is slightly declining in reality (Figure 3). Relative to the assumed flat ground, the contact of plume bottom with the ground occurs at a longer distance.

9 Obstructions in plume path tend to promote the dilution of plume average concentrations.

vertical plume depth (i.e., the distance between top and bottom of the plume) remains constant and that the plume continues to expand only in the horizontal direction (i.e., only the sides of the plume expand). This is, of course, an unrealistic (bounding) representation which grossly overestimates the average concentrations of plume cross-sections.

Figure 7 shows the changes in Ar-41 concentrations as the function of distance calculated for the stylized plume flowing into the WNW direction driven by the Pasquill Stability Class D wind (neutral wind) at the speed of 3.52 m/s (i.e., the most frequent wind (54%) of all winds into the WNW direction). A significant dilution of the concentration in the close proximity of the MNR (by about 2 orders of magnitude) is calculated. This dilution increases to more than 3 orders of magnitude reduction at 500 m distance, which is the closest edge of the receptor habitat.

6. INSIGHTS

The simple, bounding assessment in this appendix is sufficient to show that the normal operation of the MNR entails very large (orders of magnitude) margins to any concerns about the radiological impact on the environment. There is no doubt that the normal operation of MNR at up to 5 MW thermal power permitted by the CNSC license does not cause any adverse effect on the surrounding flora and fauna.

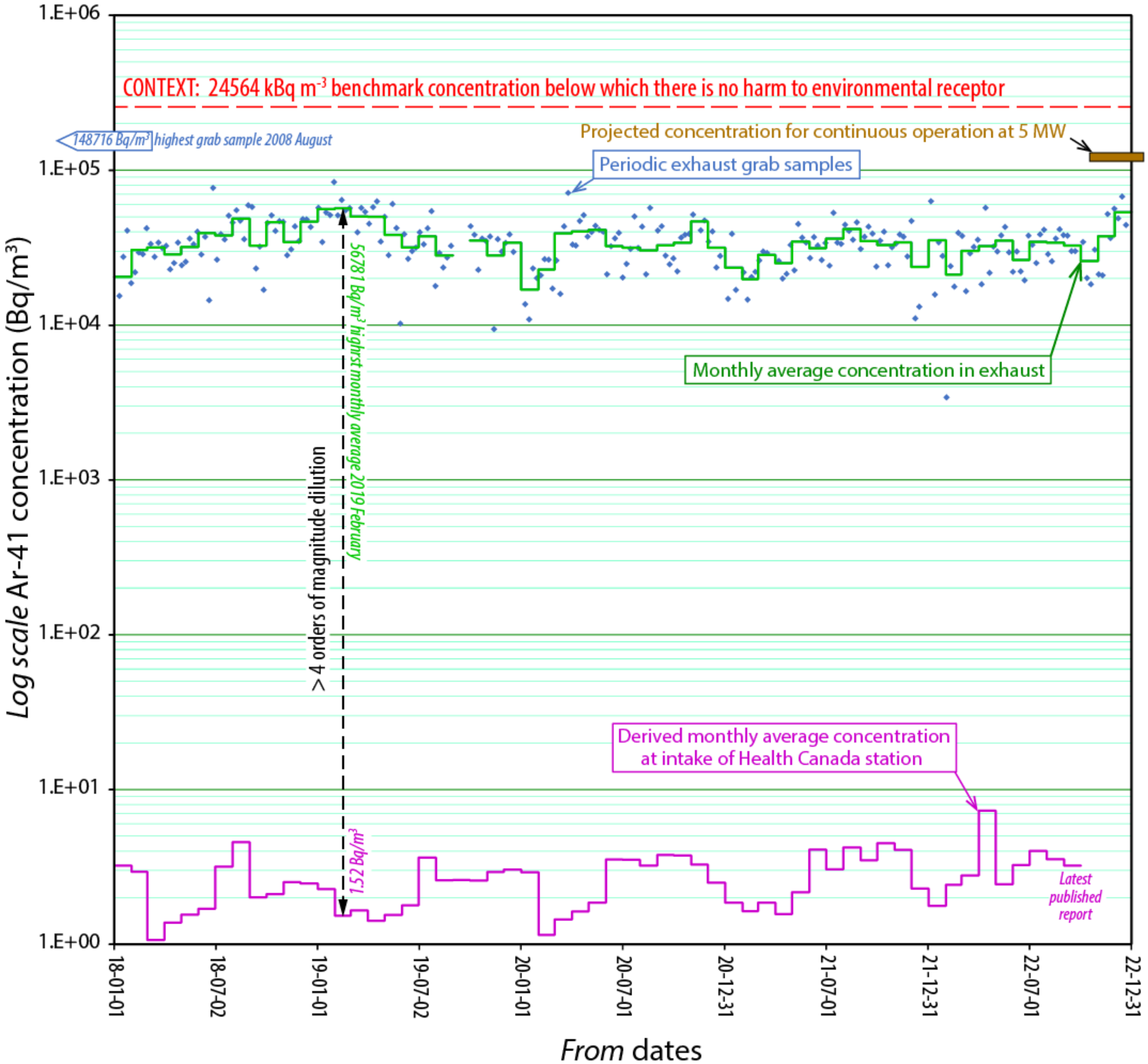


Figure 1: Ar-41 concentrations in MNR exhaust and in outside environment.
Values in this plot are from the internal Health Physics records (exhaust)
and derived from the Health Canada openly available records [3] (environment).
The benchmark concentration is derived in Appendix A for the limiting receptor.
Figure 21 in main report (described and discussed further in Section 4).

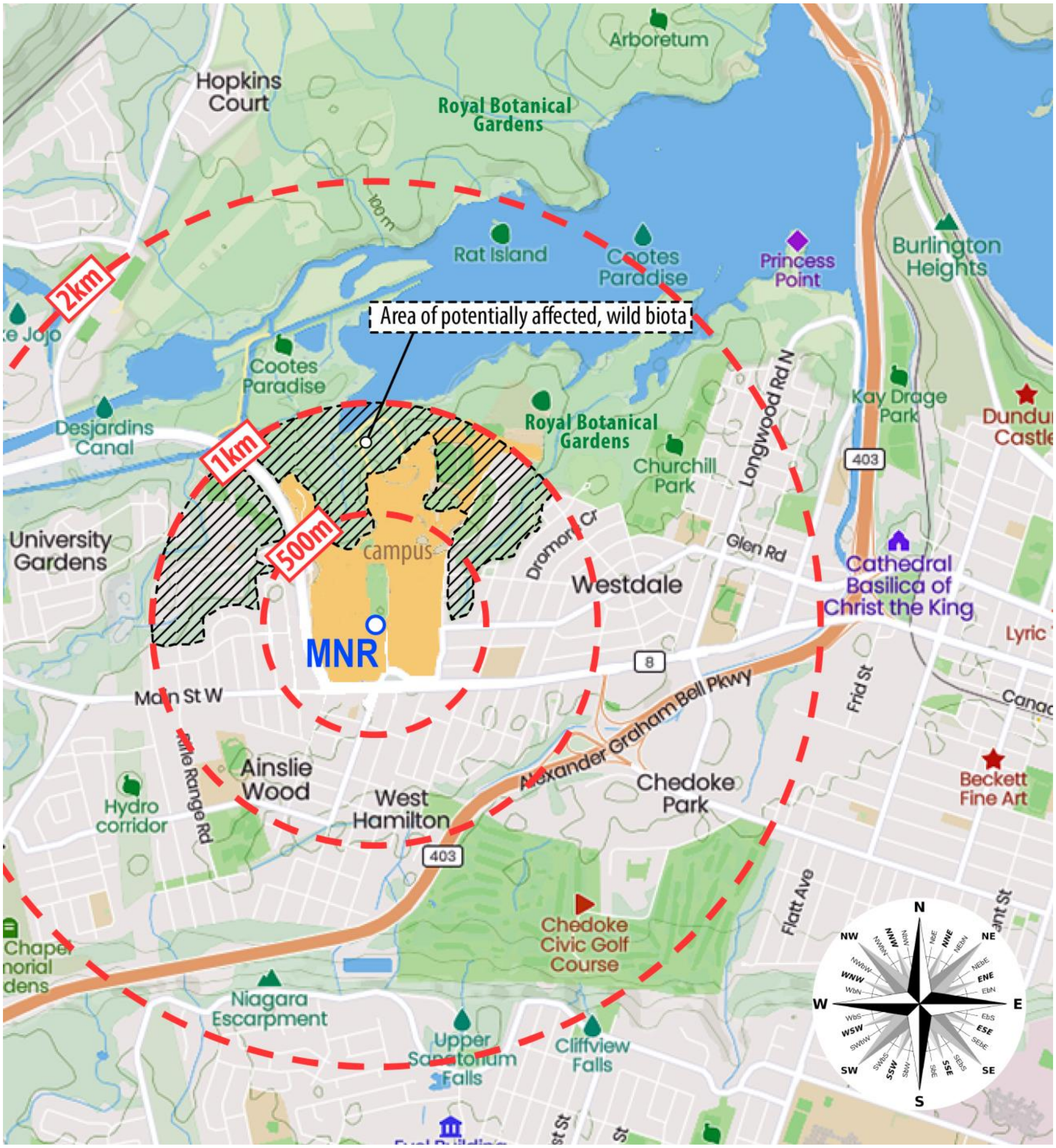


Figure 2: Area of potentially affected wild biota

Figure 2 in Appendix A

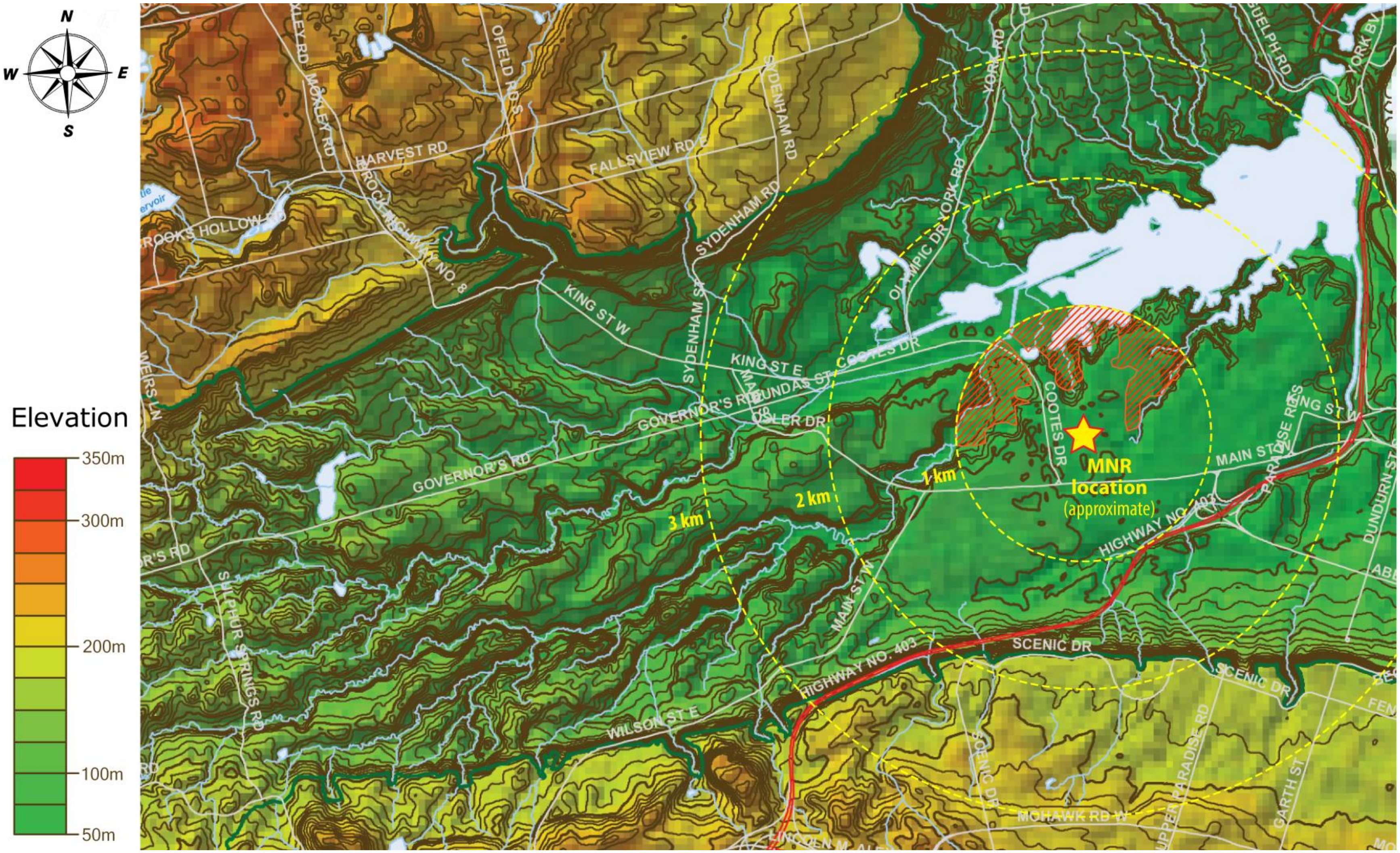


Figure 3: Site topography

Figure 3 in main report

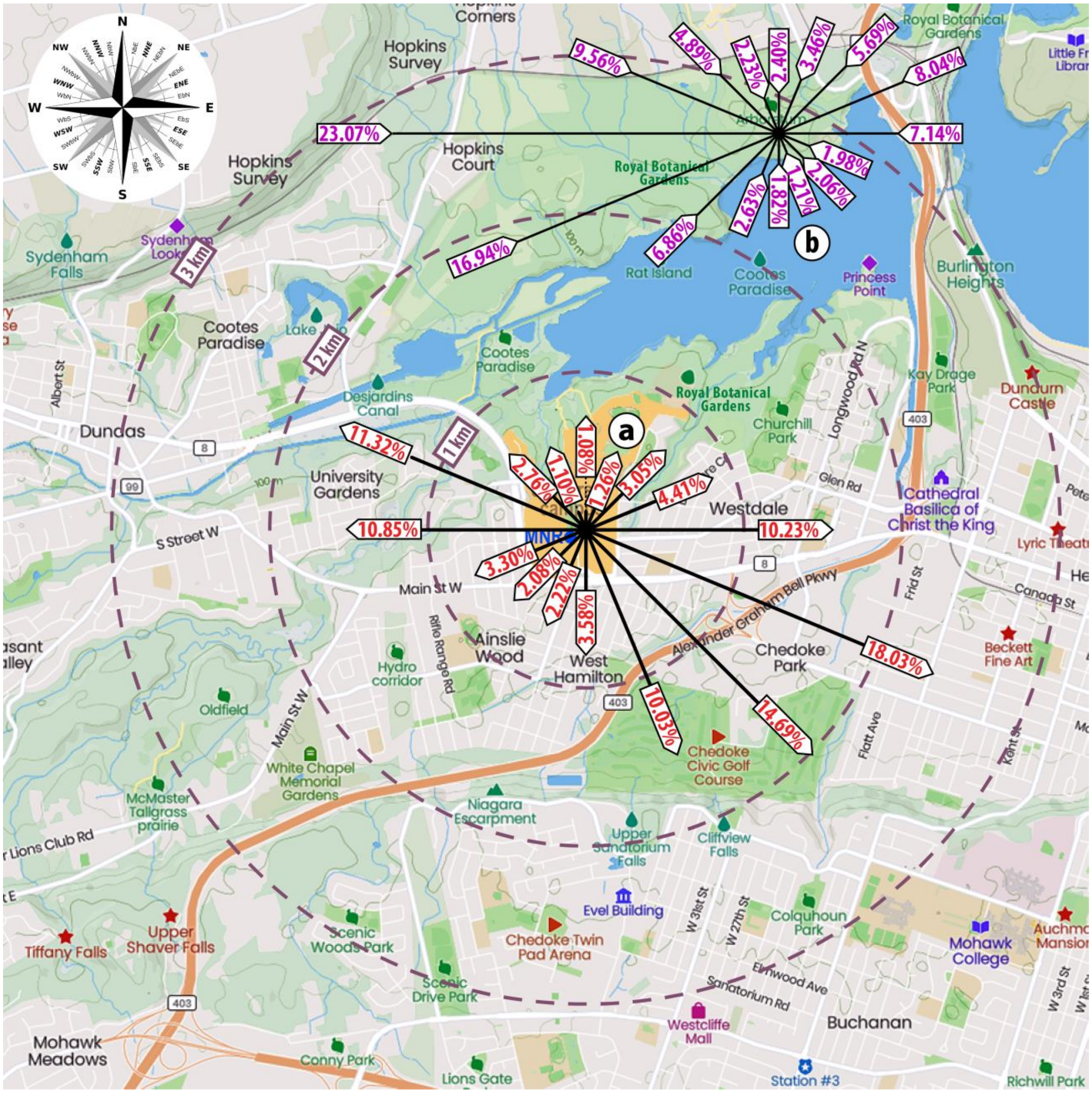


Figure 4: Wind directions around MNR

This is annotated Figure 3 which illustrates the unique effects of site physiography on winds around ***MNR****.*

Prevalence of wind directions at:
(a)[10] *Burke Science Building* ***(directions from MNR)****, and at*
(b)[11] *Royal Botanical Gardens* ***(directions to Arboretum)****.*

Lengths of direction lines are proportional to prevalence percentage.
Human population in grey areas. Green areas are not (or are sparsely) populated by humans
Figure 7 in main report

10 Data for years 2016 to 2021 from McMaster School of Earth, Environment & Society.
11 Data for years 2000 to 2009 from Environment Canada (Appendix C in [2]). This data was used in legacy calculations of atmospheric dispersion of emissions from MNR.

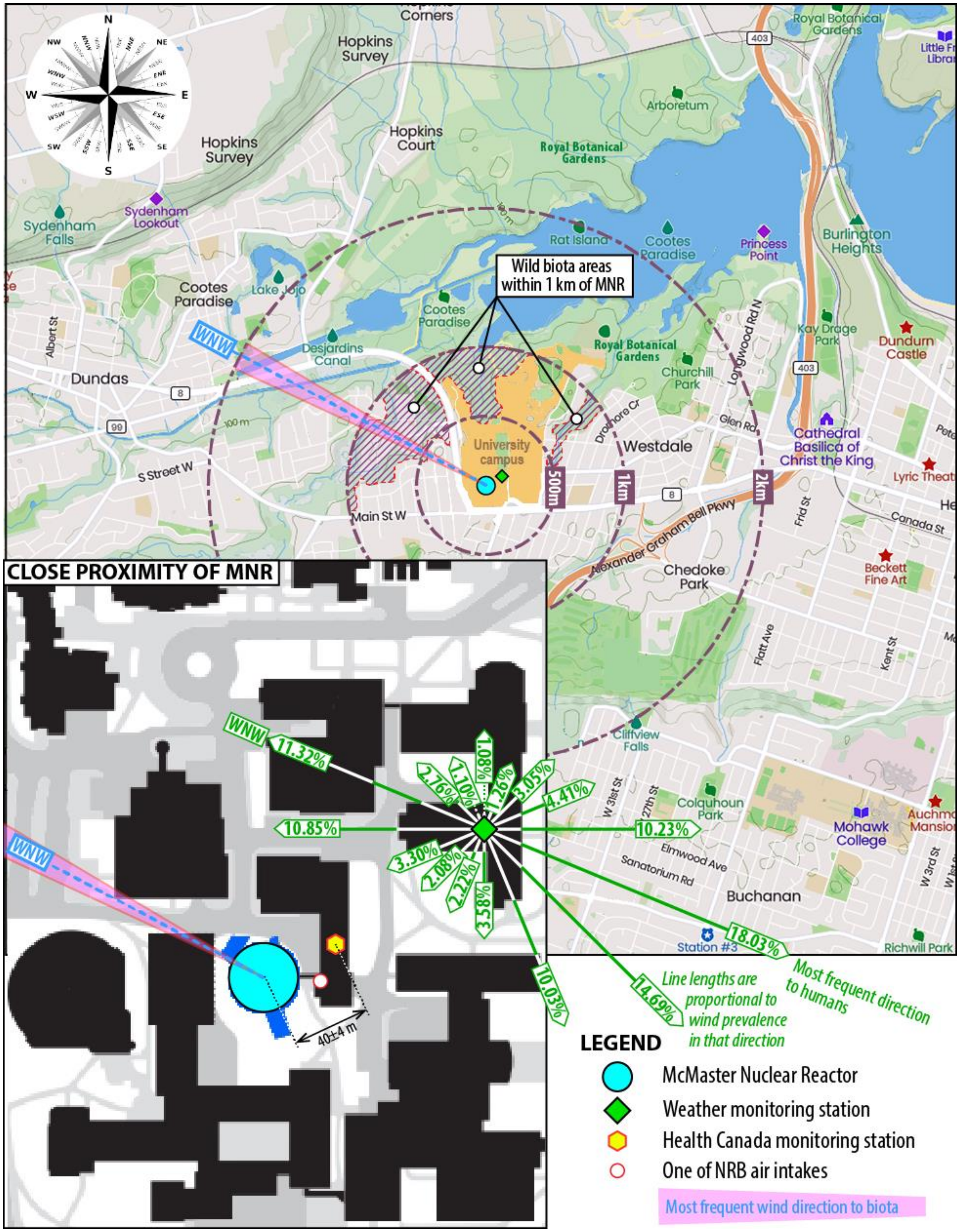


Figure 5: Plume path used in analysis

Figure 28 in main report

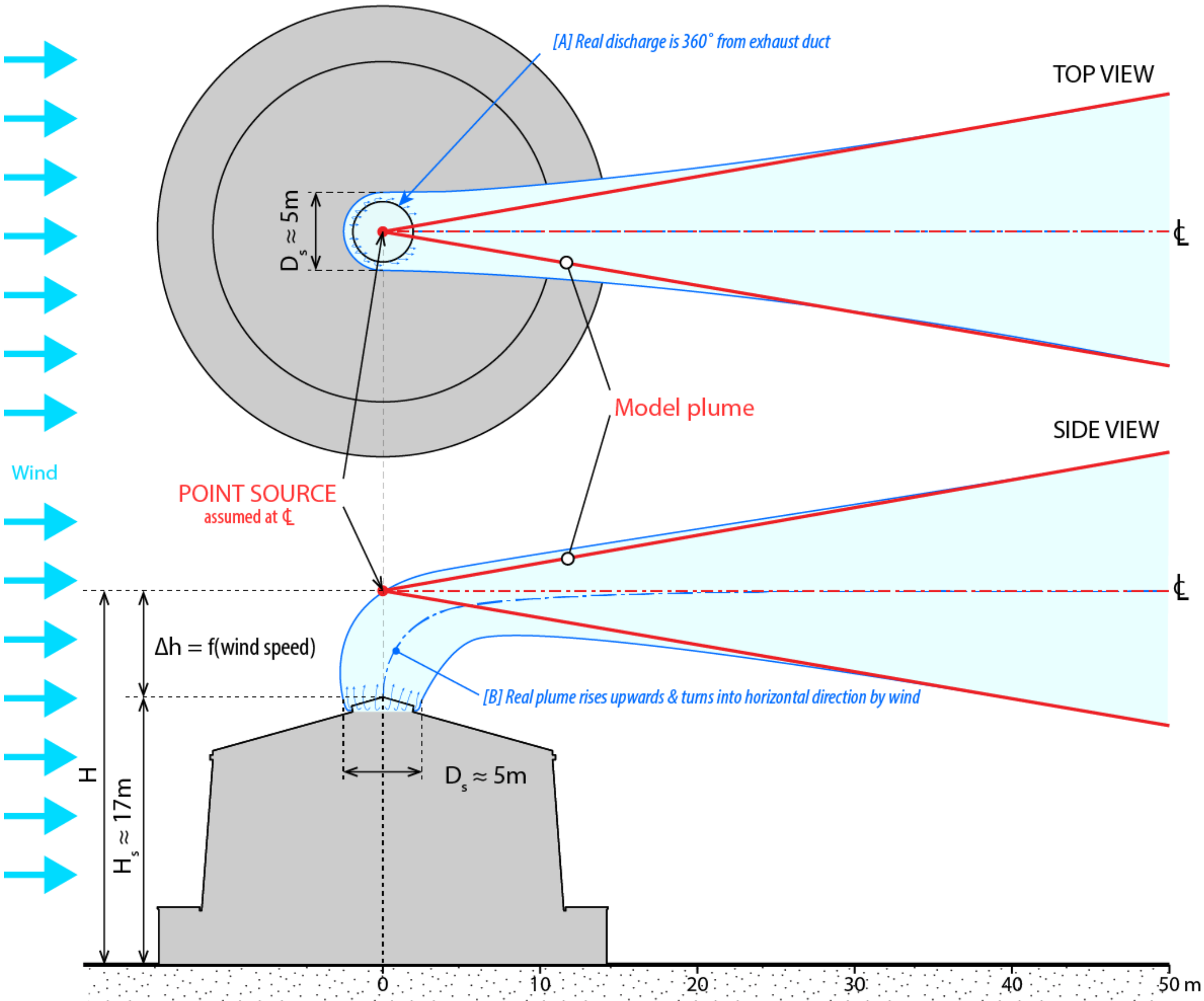


Figure 6: Plume model schematic

The model is documented in the attachment to this appendix

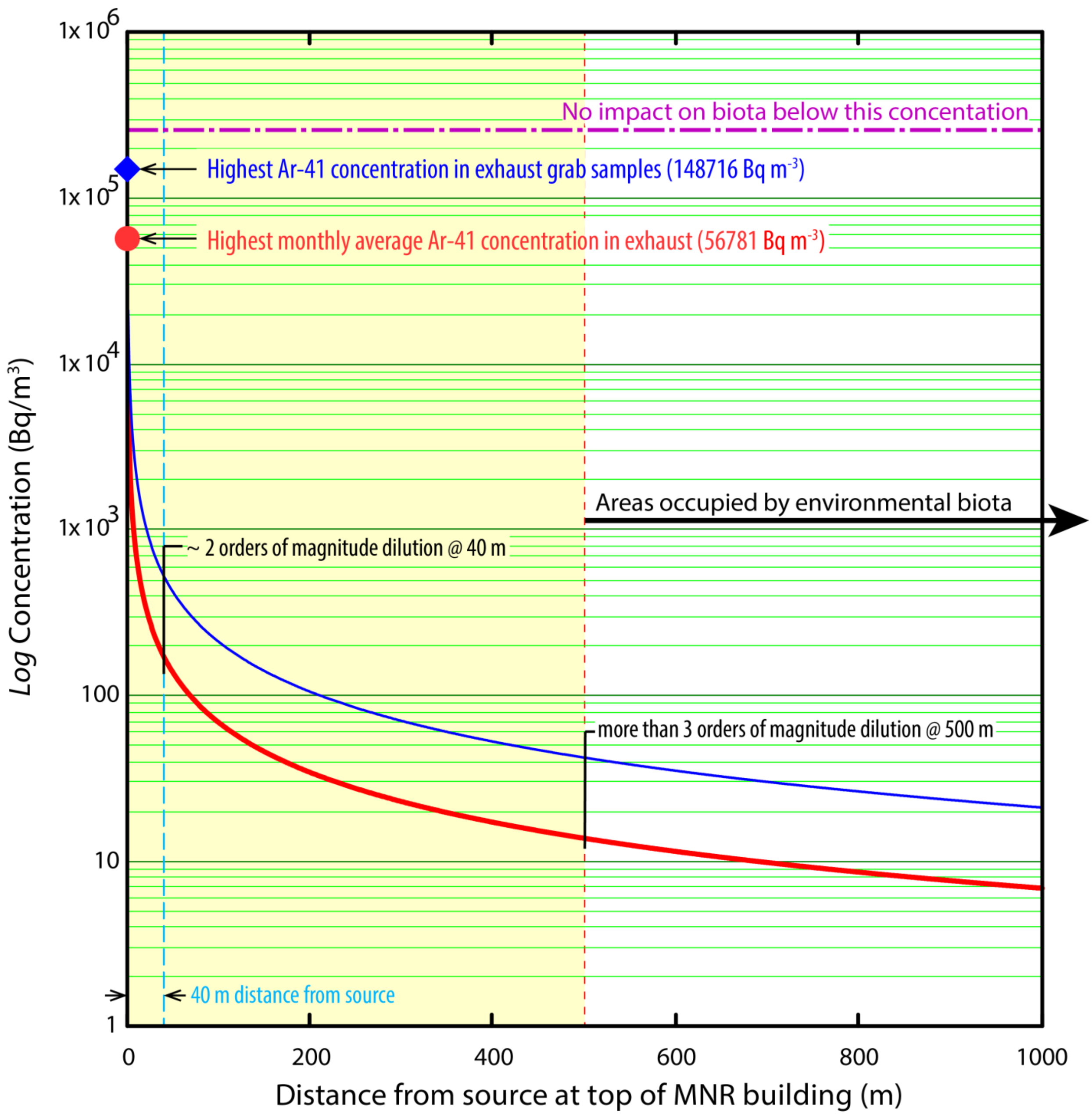


Figure 7: Conservatively calculated dispersion of MNR effluent during transport to wild biota

The calculation is documented in the attachment to this appendix

7. REFERENCES

[1] C. Blahnik, “Defence in Depth of McMaster Nuclear Reactor”, Rev. 0, MNR TR 2011-01, December 2011.

[2] Tucker, D.M., “HP-MNR-13-01 Derived Release Limits for the McMaster Nuclear Reactor”, Revision P0, 2013 November 30.

[3] Government of Canada, ‘Fixed Point Surveillance Network’ in https://www.canada.ca/en/health-canada/services/health-risks-safety/radiation/understanding/measurements.html

[4] ICRP 119, “Compendium of Dose Coefficients based on ICRP Publication 60”, October 2011.

MNR-ERA ATTACHMENT TO APPENDIX B

CALCULATION OF AIRBORNE TRANSPORT AND HAZARD QUOTIENTS FOR SMALL TERRESTRIAL ANIMAL

REVISION: R2 **DATE: 11 September 2023**

Revision History

R0 is the first release. R1 implemets editorial modifications to properly describe the contents of this worksheet. The formulas and numerical values are not altered. R2 corrects typographic errors in Eq. 6 and on page 8, and clarifies definitions of terms in Eq. 15.

ATTACHED WORKSHEETS

Reference:D:\Documents\MCad\Units\UnitsR7.xmcd supplementary units definitions

REFERENCES

[1] Gaussian Plumes
https://www.eng.uwo.ca/people/esavory/gaussian%20plumes.pdf

[2] UNSCEAR 2008,"Sources and Effects of Ionizing Radiation", Volume II, Annex E, "Effects of ionizing radiation on non-human biota", 2011.

[3] ICRP Publication 136, "Dose coefficients for non-nonhuman biota environmentally exposed to radiation", 2017.

[4] BiotaDC database http://biotadc.icrp.org/

HIGHLIHTS

Inputs highlighted in yellow

Definitions of Mathcad 15 functions highlighted in light green

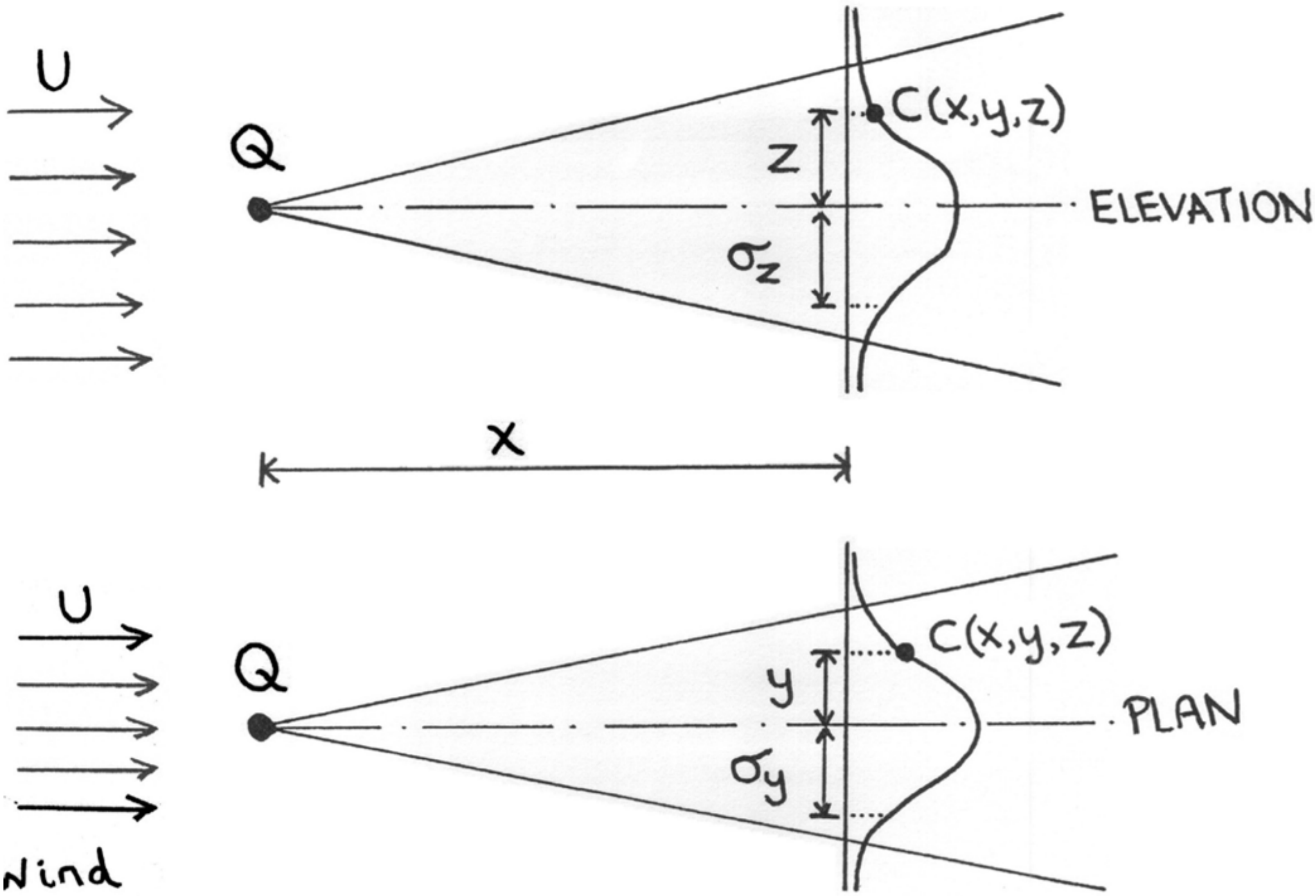
TABLE OF CONTENTS

1. MODEL DESCRIPTION

Based on [1].

Consider a point source somewhere in the air where a pollutant is released at a constant rate Q (kg/s or Bq/s). The wind is blowing continuously in a direction x (measured in metes from the source) with a speed U (m/s). The plume spreads as it moves in the x direction such that the local concentrations C(x,y,z) (kg/m^3 or Bq/m^3) at any point in space form distributions which have shapes that are “Gaussian” or “normal” in planes normal to the x direction.

Sketch 1



In the lateral, or y, direction the profile shape is given by

$$\frac{1}{\sigma_y \cdot \sqrt{2 \cdot \pi}} \cdot e^{\left(\frac{-y^2}{2 \cdot \sigma_y^2}\right)} \qquad \text{[Eq 1]}$$

in the vertical, or z, direction it is given by

$$\frac{1}{\sigma_z \cdot \sqrt{2 \cdot \pi}} \cdot e^{\left(\frac{-z^2}{2 \cdot \sigma_z^2}\right)} \qquad \text{[Eq 2]}$$

The parameters σ_y and σ_z (m) are the standard deviations of these Gaussian distributions, which indicate the spread of the plume in the y and z directions, respectively. They increase with the distance x from the source. The area under the distribution, determined by integration of the functions given above between plus and minus infinity, is equal to unity.

Combining these two-dimensional shape distributions by multiplying the functions together gives us the function for the shape of the distribution in three-dimensions (a kind of "hill" of pollutant).

$$\frac{1}{2\cdot\pi\cdot\sigma_y\cdot\sigma_z}\cdot e^{\left(\frac{-y^2}{2\cdot\sigma_y^2}\right)}\cdot e^{\left(\frac{-z^2}{2\cdot\sigma_z^2}\right)} \qquad \text{[Eq 3]}$$

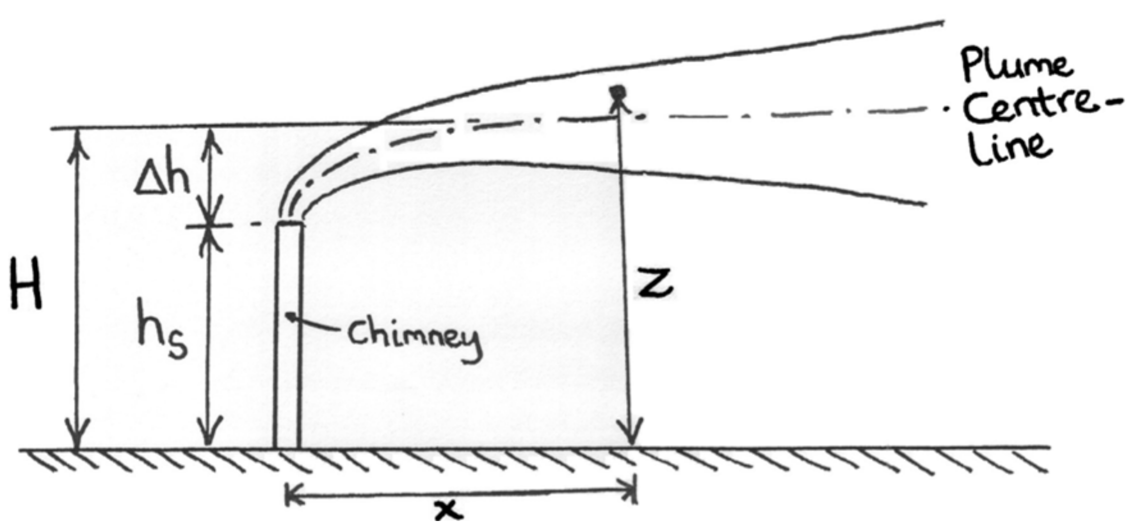
The concentration at any point is given by

$$C(x,y,z) = \frac{Q}{U}\cdot\frac{1}{2\cdot\pi\cdot\sigma_y\cdot\sigma_z}\cdot e^{\left(\frac{-y^2}{2\cdot\sigma_y^2}\right)}\cdot e^{\left(\frac{-z^2}{2\cdot\sigma_z^2}\right)} \qquad \text{[Eq 4]}$$

Hence, the concentration is equal to the rate of emission from the source divided by the wind speed and then multiplied by the shaping function.

This distribution measures y and z normally from the x-axis (the x-axis may also be considered to be the direction of the centre-line of the plume. In practice, the source will usually be raised above the ground (for example the exit of a chimney). Hence we need to modify the z coordinate so that it is measured from the ground.

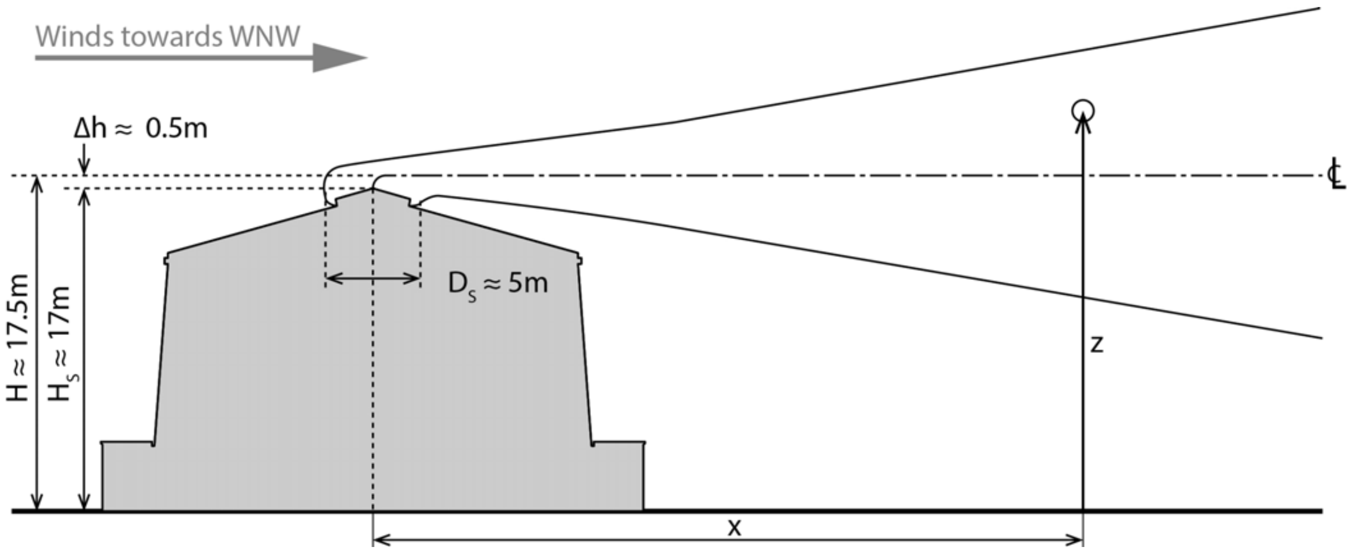
Sketch 2



H = effective height of plume centre-line (m)
h_s = height of source above ground (m)
Δh = initial plume rise (m)
z = coordinate measured vertically from the ground to a point in the plume (m)

The MNR does not have the chimney. However, the above concepts are applicable as illustrated in Sketch 3 on the next page.

Sketch 3 (numerical values explained later in this worksheet)



Relative to the plume axis, the new vertical coordinate is (z-H) giving

$$C(x,y,z) = \frac{Q}{U}\cdot\frac{1}{2\cdot\pi\cdot\sigma_y\cdot\sigma_z}\cdot e^{\left(\frac{-y^2}{2\cdot\sigma_y^2}\right)}\cdot e^{\left[\frac{-(z-H)^2}{2\cdot\sigma_z^2}\right]} \qquad \text{[Eq 5]}$$

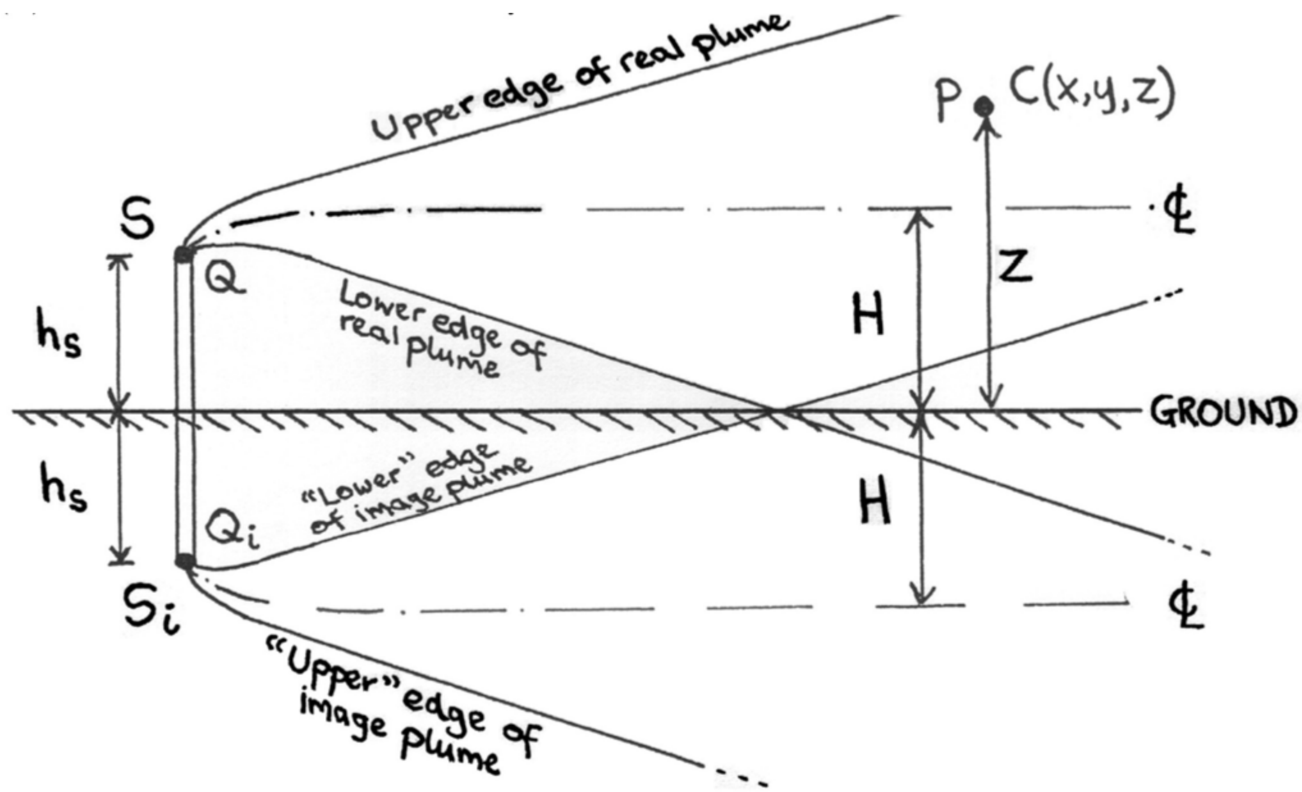
Most plumes are emitted close to the ground, like the MNR case shown in Sketch 3. Hence, as the plume spreads downwards (as well as upwards) as it moves downwind from the source, it will eventually "hit" the ground. Clearly, the plume cannot continue to spread into the ground! Instead, it is "reflected" back into the air above the ground. The effect of the ground boundary is included in the concentration equation mathematically by using a fictitious "mirror-image" source (Si = S) of the same strength (Qi = Q) placed at the same distance from the ground (hs) but on the other side of the boundary (see Sketch 4 on the next page)

Hence, at any point P there is a contribution to the concentration C(x,y,z) from both the real source (S) and the imaginary source (Si). The vertical distance to P from the centre-line of the real plume is (z-H). The vertical distance to P from the centre-line of the imaginary source is (z+H). The lateral distance (y) into the page is the same for both sources.

The total concentration at P is

$$C(x,y,z) = \frac{Q}{U}\cdot\frac{1}{2\cdot\pi\cdot\sigma_y\cdot\sigma_z}\cdot e^{\left(\frac{-y^2}{2\cdot\sigma_y^2}\right)}\cdot\left[e^{\left[\frac{-(z-H)^2}{2\cdot\sigma_z^2}\right]} + e^{\left[\frac{-(z+H)^2}{2\cdot\sigma_z^2}\right]}\right] \qquad \text{[Eq 6]}$$

Sketch 4



If only concentrations at ground level are required then we can simplify the equation by setting z=0. This gives

$$C(x,y,z) = \frac{Q}{U}\cdot\frac{1}{2\cdot\pi\cdot\sigma_y\cdot\sigma_z}\cdot e^{\left(\frac{-y^2}{2\cdot\sigma_y^2}\right)}\cdot e^{\left(\frac{-H^2}{2\cdot\sigma_z^2}\right)} \qquad \text{[Eq 7]}$$

It should be noted that the maximum concentration occurs when

$$\sigma_z = \frac{H}{\sqrt{2}} \qquad \text{[Eq 8]}$$

At large distances from the source, where σz is much larger than H, the concentration varies in proportion to 1/(σy . σz).

If only concentrations at **ground level** on the **centre-line** of the plume (along the x-axis direction) are required then the equation is simplified further since both z=0 and y=0. This gives

$$C(x,0,0) = \frac{Q}{U}\cdot\frac{1}{2\cdot\pi\cdot\sigma_y\cdot\sigma_z}\cdot e^{\left(\frac{-H^2}{2\cdot\sigma_z^2}\right)} \qquad \text{[Eq 9]}$$

Using Eq 6, if we know the rate of emission from the source (Q), the prevailing wind speed (U) and direction (x) and the height of the centre-line of the plume above ground (H), we can determine the concentration (C) at any point (x,y,z). However, to do this we need information about the plume spread by obtaining values for σy and σz.

There are many formulae and semi-empirical expressions available for determining σy and σz under different conditions of atmospheric stability. A reasonable approximation in regions near to the source when the source is elevated above the ground (such as at the top of MNR building) is

$$\sigma_y = I_y \cdot x \quad \text{and} \quad \sigma_z = I_z \cdot x \qquad \text{[Eqs 10 and 11]}$$

where I_y and I_z are the turbulent wind speed fluctuations (turbulence intensities) in the y and z directions, respectively.

Under neutral atmospheric conditions it has been found that, over a range of heights corresponding to the vertical plume spread, centered at approximately h_s, I_y and I_z may be estimated as

$$I_y = \frac{0.88}{\ln\left(\frac{h_s}{z_0}\right)} \quad \text{and} \quad I_z = \frac{0.50}{\ln\left(\frac{h_s}{z_0}\right)} \qquad \text{[Eqs 12 and 13]}$$

where "ln" is the natural log, h_s is the release height and z_0 is the aerodynamic roughness representing different topographic ground conditions.

For general cases of different atmospheric conditions the following typical values apply

Thermal stratification	**Lateral intensity (I_y)**	**Vertical intensity (I_z)**	
Extremely unstable	0.40 - 0.55	0.15 - 0.55	
Moderately unstable	0.25 - 0.40	0.10 - 0.15	
Near neutral	0.10 - 0.25	0.05 - 0.08	< prototypic of limiting wind direction at MNR
Moderately stable	0.08 - 0.25	0.03 - 0.07	
Extremely stable	0.03 - 0.25	0 - 0.03	

It may be seen that the turbulence intensities, especially the vertical wind speed fluctuations, increase as atmospheric conditions become more unstable.

One other factor that needs to be considered in practice is the plume rise (Δh). This is the path or trajectory of the plume centre-line after it leaves the source. Its course depends upon atmospheric conditions and the amount of buoyancy and vertical momentum in the initial plume at the source.

Buoyancy forces causes the plume rise to vary with $x^{2/3}$

Momentum forces cause the plume rise to vary with $x^{1/3}$

Hence, the shape of the trajectory will depend on which forces dominate the plume. If the chimney plume is buoyant the plume rises to a maximum level of Δh = 0.2hs to Δh = 0.6h s above the source, depending on atmospheric conditions. If the initial momentum of the plume dominates then an approximate expression for the final plume rise is:

$$\Delta h = \frac{3 \cdot D_s \cdot VV_{in}}{U} \qquad \text{[Eq 14]}$$

where D_s = diameter of the source (m) - 5 m for MNR (see Sketch 3) $\qquad D_s := 5 \cdot m$

VV_{in} = initial vertical velocity of the plume (m/s)

The MNR effluent is not hot = the initial momentum dominates

MNR effluent discharge rate $v := 4800 \cdot \frac{ft^3}{min}$ $v = 2.265 \frac{m^3}{s}$

Initial vertical velocity of the plume $VV_{in} := \frac{v}{\pi \cdot \left(\frac{D_s}{2}\right)^2}$ $VV_{in} = 0.115 \frac{m}{s}$

The initial vertical velocity is dependant on the prevailing wind speed. So, for the MNR source diameter D_s the plume rise pΔh is a function of wind speed u.

$p\Delta h(u) := \frac{3 \cdot D_s \cdot VV_{in}}{u}$ Mathcad function

Range of wind speeds relevant to MNR effluent discharge towards WNW

PG class Wind speed

$$\begin{pmatrix} F \\ A \\ E \\ B \\ C \\ D \end{pmatrix} \quad u := \begin{pmatrix} 1.34 \\ 2.24 \\ 2.25 \\ 2.84 \\ 3.15 \\ 3.52 \end{pmatrix} \cdot \frac{m}{s}$$

Weather data from the station located at the Burke Sciences Building at McMaster University for the period 2016 to 2021 by the McMaster School of Earth, Environment & Society (SEES) in the department of Science.

<-- D @ 3.52 m/s = most frequent wind towards WNW (54%)

Plume rise for these winds

$i := 0 .. 5$ $\Delta h_i := p\Delta h(u_i)$

$$\begin{pmatrix} F \\ A \\ E \\ B \\ C \\ D \end{pmatrix} \quad u = \begin{pmatrix} 1.34 \\ 2.24 \\ 2.25 \\ 2.84 \\ 3.15 \\ 3.52 \end{pmatrix} \frac{m}{s} \quad \Delta h = \begin{pmatrix} 1.291 \\ 0.773 \\ 0.769 \\ 0.609 \\ 0.549 \\ 0.492 \end{pmatrix} m$$

For the relevant winds to WNW, all values of the plume rise are small relative to the magnitude of the release height and the size of the plume

Hence, the plume centre-line can be considered to be a constant value.

Constant plume centerline elevation

$H_s := 17 \cdot m$ $\Delta H := 0.5 \cdot m$ $H_{CL} := H_s + \Delta H$ $H_{CL} = 17.5 m$

2. BENCHMARK CONCENTRATION FOR SMALL TERRESTRIAL ANIMAL

A small terrestrial animal (mammal or bird) is identified as the relevant receptor in Appendix A. The benchmark dose (i.e., the no adverse effect dose) for small mammals and birds is defined in UNSCEAR 2008 [2] as ≤ 100 μGy/hr. This value is for immersion in radioactive gas (i.e., it is the external dose).

This benchmark dose is the biological effects parameter reported as the absorbed radiation energy per a unit mass of matter over a unit of time. It is not a physically measurable parameter. It is specific to the receptor and it's enumeration involves not only the energy but also other parameters such as the receptor shape, the type of exposure to radiation, the breathing rate, and more. It is a semi-empirical parameter based on observations of the effects to different radiation exposures. ICRP 136 [3] provides a computerized database (program BiotaDC [4]) which facilitates a lookup of available information on various terrestrial ecosystems. The information on the terrestrial fauna (animals) is provided for different exposure conditions (organism mass and shape and source of exposure (type and height) and type of radiation (parent radio nuclide and treatment of decay chain).

The BiotaDC database provides the External DC (Dose Coefficient) for the small bird as (Table 4 in Appendix B):

External exposure to contaminated air
Bird mass = 0.314 kg (tissue-equivalent sphere)
Bird is stationary for 6 month during nesting

Nuclide	Nesting Height	DC (μGy/h per Bq/m³)
Ar-41	10 cm	3.82E-004
	5 m	3.94E-004
I-125	10 cm	5.97E-006
	5 m	7.14E-006

The external DC relates the absorbed dose to activity concentration in the surrounding air.

$DC_{bird\_Ar} := 3.94 \times 10^{-4} \cdot \frac{\mu Gy}{hr} \cdot \frac{m^3}{Bq}$ rounded to $DC_{bird\_Ar} := 3.9 \times 10^{-4} \cdot \frac{\mu Gy}{hr} \cdot \frac{m^3}{Bq}$ < nest at 5 m elevation

The threshold (or benchmark) concentration (ThC) at which the threshold (or benchmark) dose would occur due to bird submersion in Ar-41 contaminated air:

$$ThC_{bird\_Ar} := \frac{100 \cdot \frac{\mu Gy}{hr}}{DC_{bird\_Ar}} \qquad ThC_{bird\_Ar} = 2.564 \times 10^{5} \cdot \frac{Bq}{m^3}$$

The external DC for I-125 is ~2 orders of magnitude lower than that for Ar-41

$$DC_{bird\_I} := 7.14 \times 10^{-6} \cdot \frac{\mu Gy}{hr} \cdot \frac{m^3}{Bq}$$

The threshold (or benchmark) concentration (ThC) at which the threshold (or benchmark) dose would arise in the bird submerged in the I-125 contaminated air:

$$ThC_{bird\_I125} := \frac{100 \cdot \frac{\mu Gy}{hr}}{DC_{bird\_I}} \qquad ThC_{bird\_I125} = 1.401 \times 10^{7} \cdot \frac{Bq}{m^3}$$

It is 2 orders of magnitude higher than that for Ar-41

3 SCREENING CALCULATION OF Ar-41 CONCENTRATIONS IN PLUME

A screening calculation can quickly identify the order of magnitude of the expected concentrations and may even show that more advanced modeling is unnecessary. For simplicity and convenience, a point source is assumed as shown in Sketch 5 on the next page.

The screening calculation is essentially a statement of the conservation of pollutant quantity. Referring to Sketch 6 on the next page, a uniform concentration in the plume passing through the downwind plane HW is assumed.

The formula for estimating worst case mean concentrations downwind of a point source is:

$$C_{wc} = \frac{Q}{U_z \cdot H_{wc} \cdot W_{wc}} \qquad \text{[Eq 15]}$$

Where: Q = source strength or emission rate of gas $\frac{Bq}{s}$ $\quad$ C_{wc} = worst case concentration $\frac{Bq}{m^3}$

U_z = worst case wind speed at height z $\frac{m}{s}$ $\quad$ W_{wc} = worst case plume width m

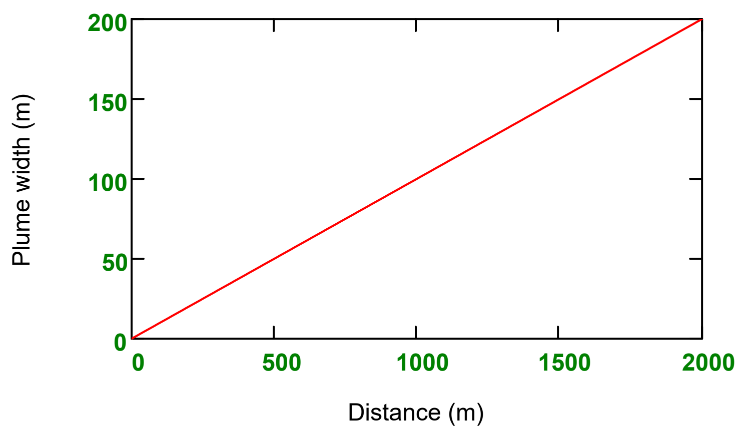
H_{wc} = worst case plume depth m

W_{WC} increases with distance X. It is assumed that W_{WC} = CONST x X where X is distance from the source.

$CONST := 0.1$ conservative assumption when no obstacles are present in plume path

$PWD(X) := CONST \cdot X$ Mathcad function $\quad$ $j := 0 .. 200$ distance index

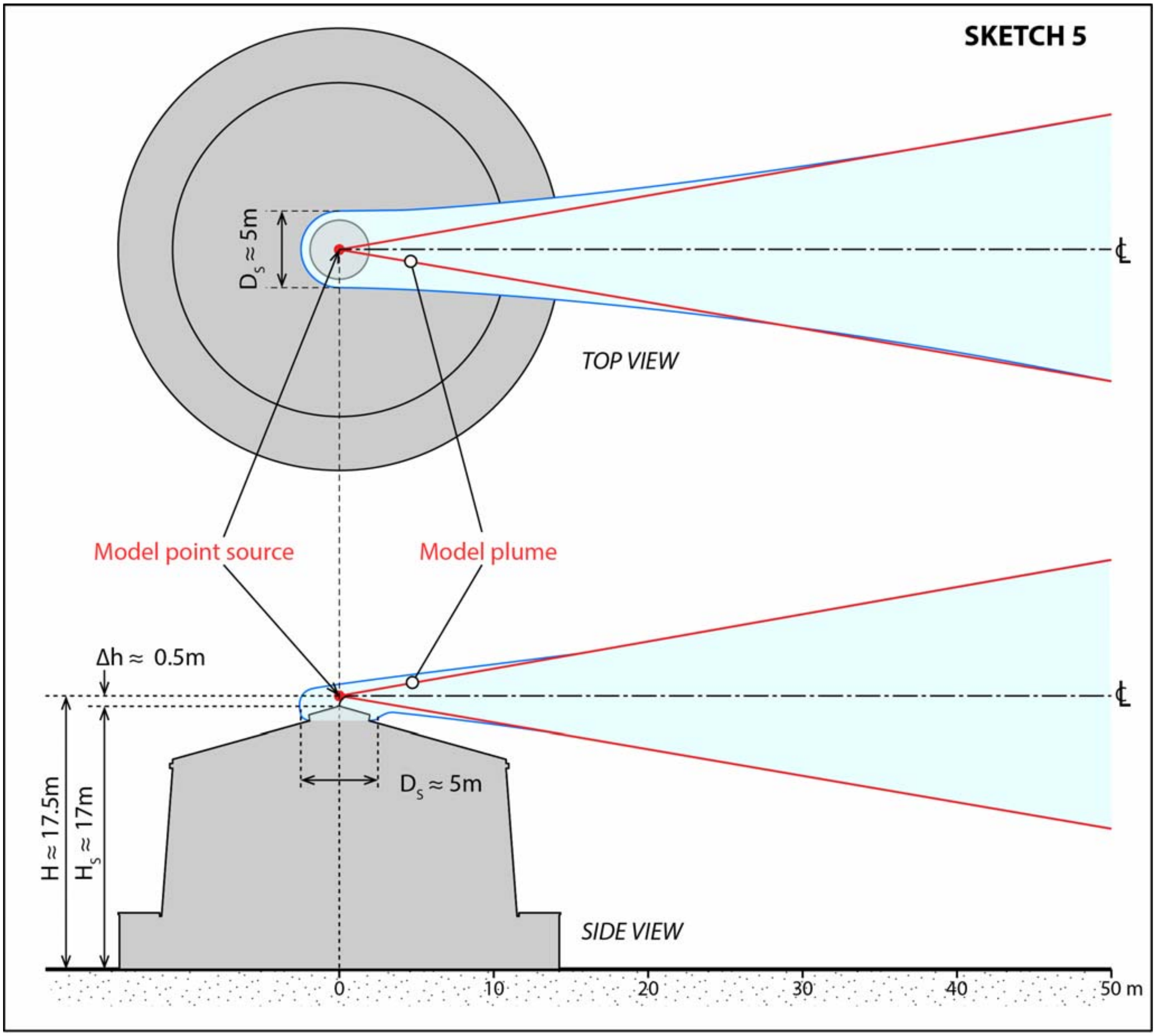
Plume width as the function of distance $\quad$ $Pwidth_j := PWD(j \cdot 10 \cdot m)$

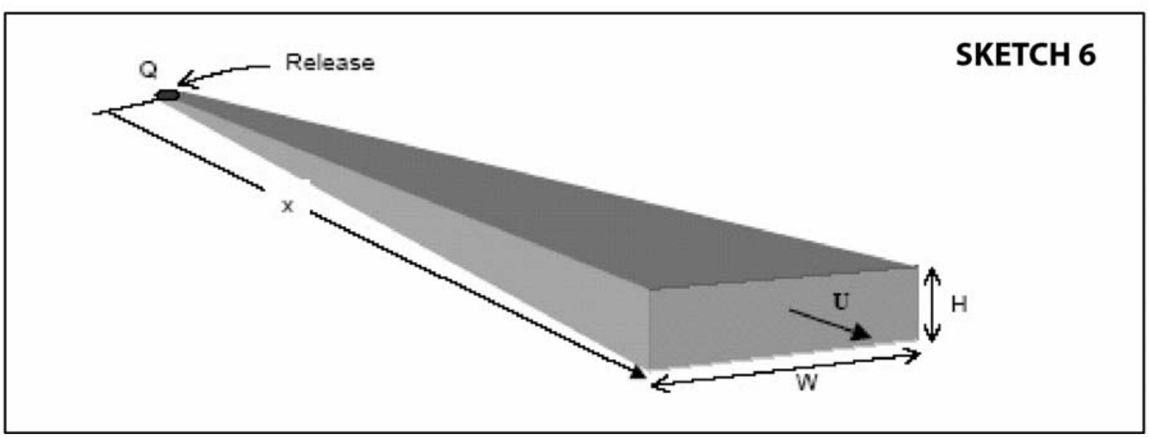


This is a rather narrow plume = conservative

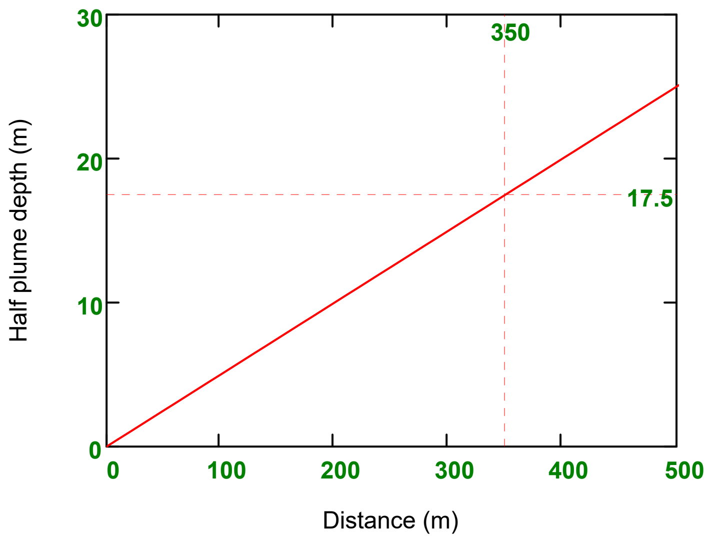
H_{WC} also increases with distance X. The same constant is applied until the hypothetical plume expands such that its bottom touches the ground. This happens when 1/2 H_{WC} is equal to h_{cl} calculated above, which is the function of wind speed

The half depth = 1/2 of plume width calculated above $\quad$ $HPD := \frac{Pwidth}{2}$


SKETCH 5
$D_s \approx 5m$
TOP VIEW
Model point source
Model plume
$\Delta h \approx 0.5m$
$H \approx 17.5m$
$H_s \approx 17m$
$D_s \approx 5m$
SIDE VIEW
0
10
20
30
40
50 m


SKETCH 6
Q
Release
x
U
H
W

The contact with the ground occurs when the half-depth reaches $H_{CL} = 17.5$ m



The contact is at ~ 350 m from the MNR = **before the plume reaches the area occupied by wild biota.**

For the conservative screening calculation, it is assumed that the worst case cloud depth is a constant. This is not realistic but it avoids a complex calculation of the plume expanding only at its top.

Worst case mean concentrations downwind of a point source is given by Eq. 15 in which only the horizontal plume boundaries can expand while the vertical boundaries are constant (see Sketch 6 on the preceding page for the illustration).

$$C_{WC} = \frac{Q}{U \cdot H_{WC} \cdot W_{WC}}$$

Q = source strength or emission rate of activity [Bq/s]

C_{WC} = worst case concentration [Bq/m^3]

U = worst case wind speed at height z = H_{CL} [m/s]

W_{WC} = worst case cloud width [m] (a function of distance from the source)

H_{WC} = worst case cloud depth = depth at 350 m from the source

From Figure 1 in Appendix B (see the next page)

$C1_S := 148716 \cdot \frac{Bq}{m^3}$ Source concentration 1 = highest grab sample since 2008

See Figure 1

$C2_S := 56781 \cdot \frac{Bq}{m^3}$ Source concentration 2 = highest monthly average since 2008

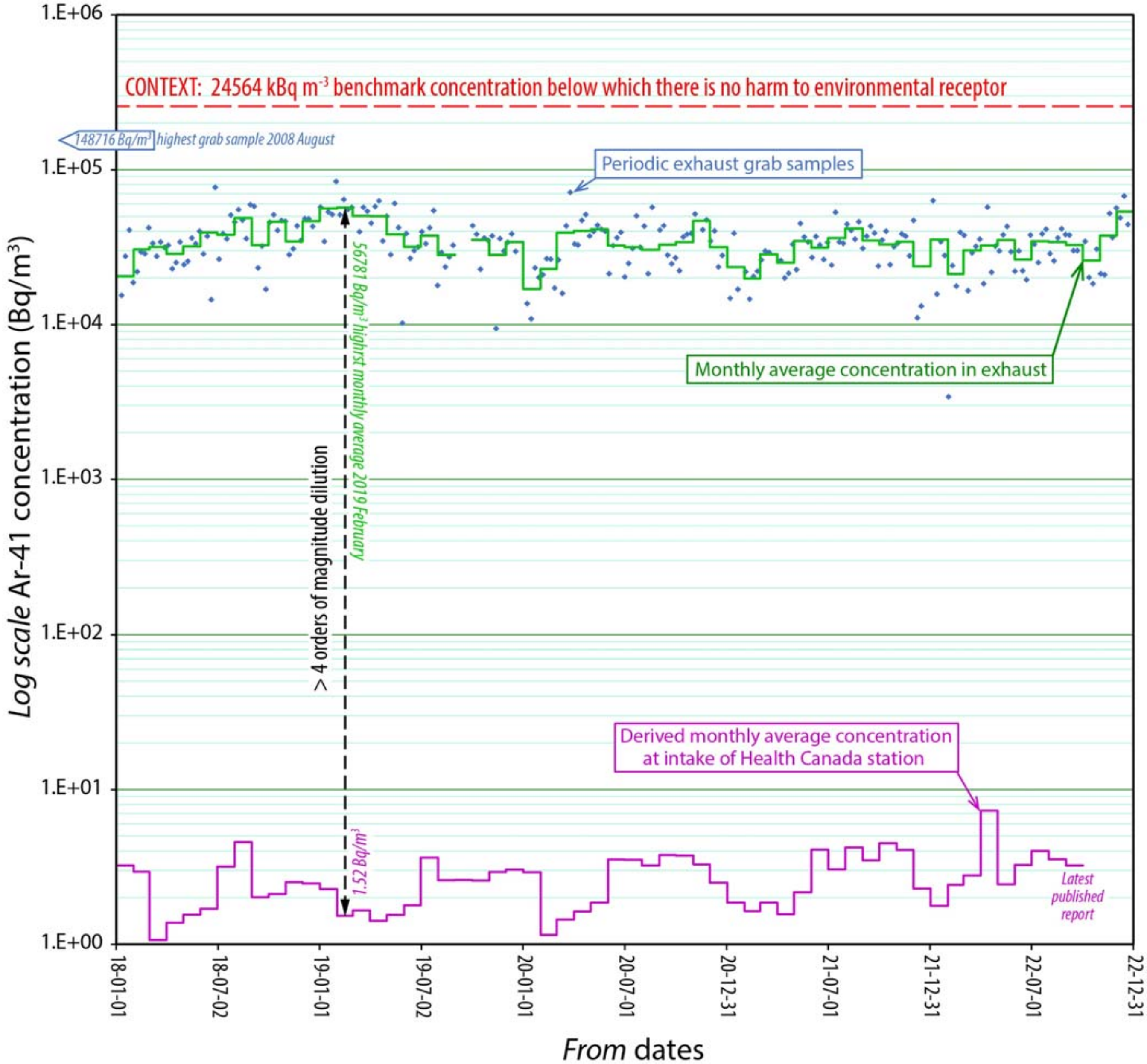
$v = 2.265 \frac{m^3}{s}$ MNR exhaust discharge rate

$Q1 := C1_S \cdot v$ $Q1 = 336.893 \cdot \frac{kBq}{s}$ $Q1 = 3.369 \times 10^5 \cdot \frac{Bq}{s}$ Source Ar-41 for highest grab sample since 2008

$Q2 := C2_S \cdot v$ $Q2 = 128.629 \cdot \frac{kBq}{s}$ $Q2 = 1.286 \times 10^5 \cdot \frac{Bq}{s}$ Source Ar-41 for highest monthly average since 2008

Figure 1: Ar-41 concentrations in MNR exhaust and in outside environment

Figure 1 in Appendix B



$U := u_5$ $\quad U = 3.52 \frac{m}{s}$ $\quad$ wind speed from the range of speeds defined above

$\frac{PWD(350 \cdot m)}{2} = 17.5 m$ $\quad H_{WCmax} := 17.5 \cdot m$ $\quad$ H in Sketch 5 $\quad$ occurs at 350 m distance

Concentrations as function of distance for source concentrations $C1_S$ and $C2_S$ defined above

highest grab sample

$CONC1_0 := C1_S$

$CONC1_0 = 1.487 \times 10^5 \cdot \frac{Bq}{m^3}$

highest monthly average

$CONC2_0 := C2_S$

$CONC2_0 = 5.678 \times 10^4 \cdot \frac{Bq}{m^3}$

$p := 8 .. 350$ $\quad X_p := p \cdot 1 \cdot m$ $\quad$ calculated in 1 m intervals to 350 m $\quad$ start 8 m from point source

$$CONC1_p := \frac{Q1}{U \cdot PWD(X_p)^2} \qquad CONC2_p := \frac{Q2}{U \cdot PWD(X_p)^2}$$

The calculated concentrations at the ~ distance of Health Canada monitor (but in WNW) direction (about 40 m)

$CONC1_{40} = 5982 \cdot \frac{Bq}{m^3}$ $\qquad CONC2_{40} = 2284 \cdot \frac{Bq}{m^3}$

$p := 351 .. 1000$ $\quad X_p := p \cdot 1 \cdot m$ $\quad$ 1 m intervals from 351 m to 1 km

$$CONC1_p := \frac{Q1}{U \cdot PWD(X_p) \cdot PWD(350 \cdot m)} \qquad CONC2_p := \frac{Q2}{U \cdot PWD(X_p) \cdot PWD(350 \cdot m)}$$

The calculated concentrations at 1 km distance

$CONC1_{1000} = 27 \cdot \frac{Bq}{m^3}$ $\qquad CONC2_{1000} = 10 \cdot \frac{Bq}{m^3}$

$p := 0 .. 1000$ $\quad$ Full range

Diluted concentration at 40 m distance as % of source concentration

$$DIL1 := \frac{CONC1_{40}}{C1_S} \qquad DIL2 := \frac{CONC2_{40}}{C2_S}$$

$DIL1 = 4.022 \cdot \%$ $\qquad DIL2 = 4.022 \cdot \%$ $\quad$ almost 2 orders of magnitude dilution

The calculated concentrations at the ~ distance of 500 m = closest biota boundary

$$BDIL1 := \frac{CONC1_{500}}{C1_S} \qquad BDIL2 := \frac{CONC2_{500}}{C2_S}$$

$BDIL1 = 0.037 \cdot \%$ $\qquad BDIL2 = 0.037 \cdot \%$ $\quad$ almost 3 orders of magnitude dilution

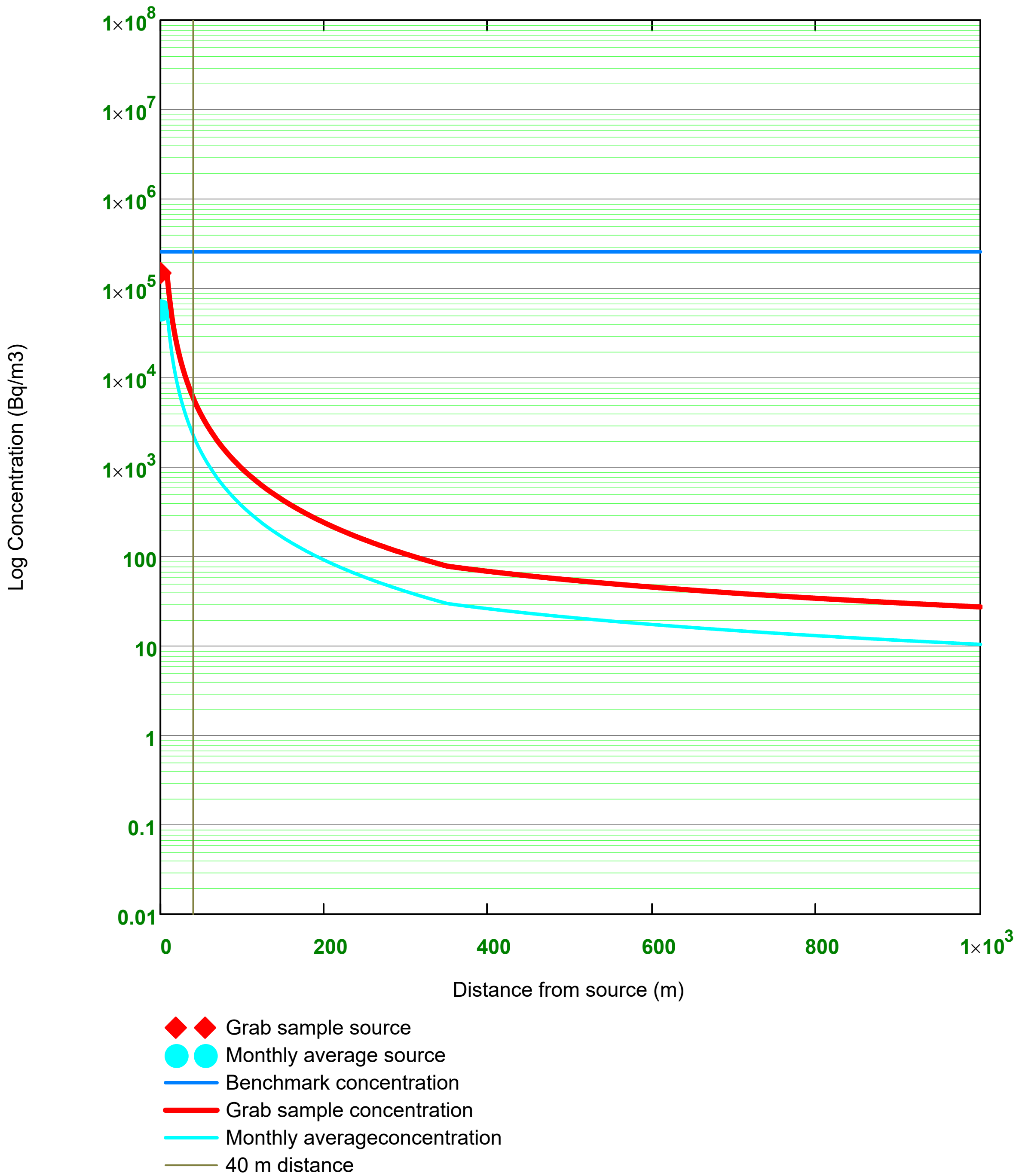
Plot markup definitions are hidden to avoid clutter

$ThC_{bird\_Ar} = 2.56 \times 10^{5} \cdot Bq \cdot m^{-3}$ Benchmark concentration (blue horizontal line)

$C1_S = 1.49 \times 10^{5} \cdot Bq \cdot m^{-3}$ highest grab sample since start of 2008

$C2_S = 5.68 \times 10^{4} \cdot Bq \cdot m^{-3}$ highest monthly average since start of 2008

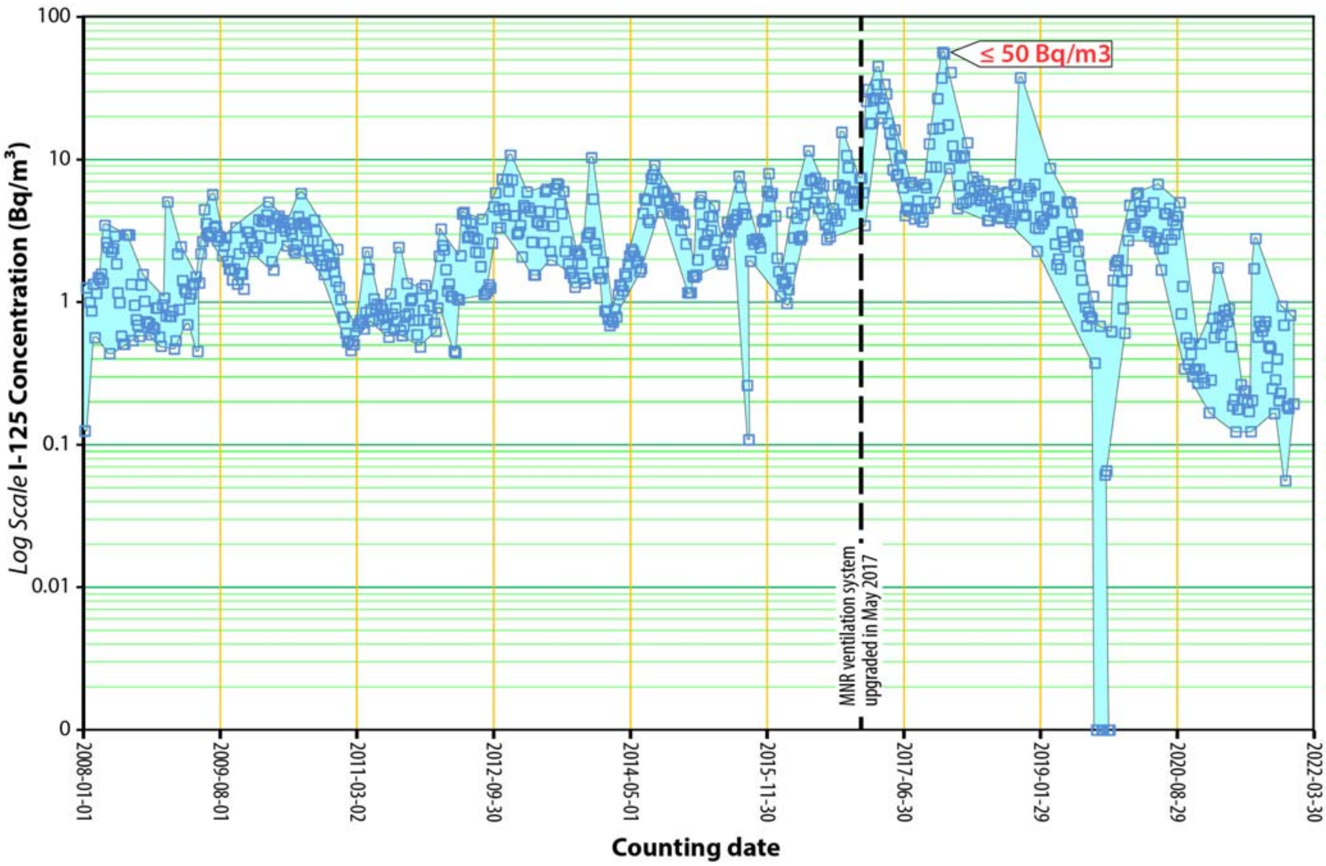
Figure 2: Ar-41 Concentration in plume as function of distance from source



4 SCREENING CALCULATION OF HAZARD QUOTIENTS FOR Ar-41 AND I-125

Figure 3: I-125 concentrations in MNR exhaust

Figure 26 in the main report



$C3_S := 50 \cdot \frac{Bq}{m^3}$ highest I-125 grab sample concentration since 2008, see Figure 3

$Q_{I125} := C3_S \cdot v$ $Q_{I125} = 113.3 \cdot \frac{Bq}{s}$ I-125 Source for highest grab sample since 2008

$p := 8 .. 350$ $X_p := p \cdot 1 \cdot m$ calculated in 1 m intervals to 350 m start 8 m from point source

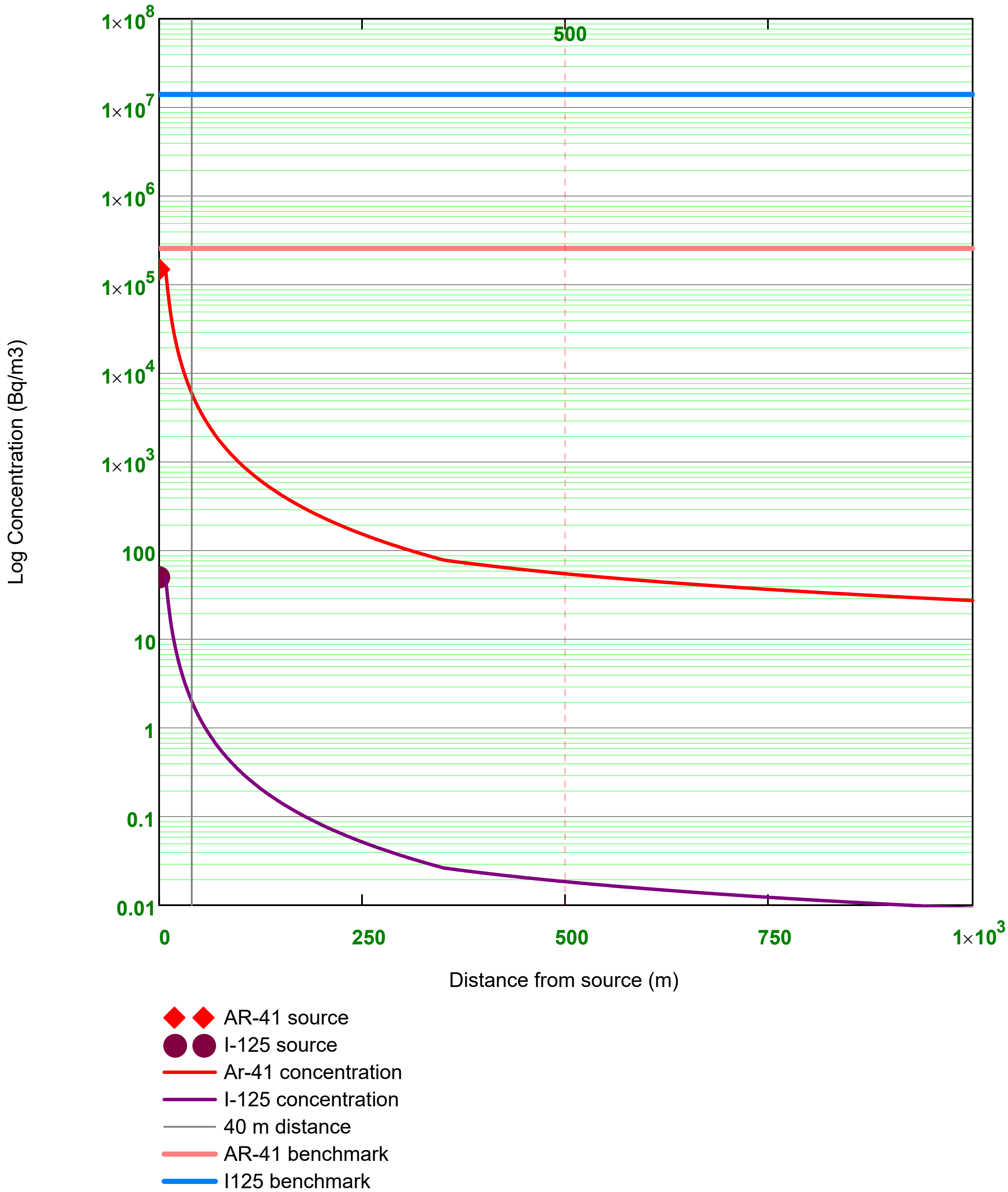
$$CONC3_p := \frac{Q_{I125}}{U \cdot PWD(X_p)^2}$$

$p := 351 .. 1000$ $X_p := p \cdot 1 \cdot m$ 1 m intervals from 351 m to 1 km

$$CONC3_p := \frac{Q_{I125}}{U \cdot PWD(X_p) \cdot PWD(350 \cdot m)}$$

$p := 8 .. 1000$

Figure 4: Ar-41 and I-125 concentrations in plume as function of distance from source



Concentrations

	at 40 m	at 500 m	at 1 km
Ar-41 concentration	$CONC1_{40} = 5982 \cdot \frac{Bq}{m^3}$	$CONC1_{500} = 54.7 \cdot \frac{Bq}{m^3}$	$CONC1_{1000} = 27.3 \cdot \frac{Bq}{m^3}$
I-125 concentration	$CONC3_{40} = 2.011 \cdot \frac{Bq}{m^3}$	$CONC3_{500} = 0.018 \cdot \frac{Bq}{m^3}$	$CONC3_{1000} = 0.009 \cdot \frac{Bq}{m^3}$

Dilution

	at 40 m	at 500 m	at 1 km
Ar-41 dilution	$\frac{C1_S}{CONC1_{40}} = 24.9$	$\frac{C1_S}{CONC1_{500}} = 2.7 \times 10^3$	$\frac{C1_S}{CONC1_{1000}} = 5.4 \times 10^3$
I-125 dilution	$\frac{C3_S}{CONC3_{40}} = 24.9$	$\frac{C3_S}{CONC3_{500}} = 2.7 \times 10^3$	$\frac{C3_S}{CONC3_{1000}} = 5.4 \times 10^3$

Hazard quotients

at 40 m

$$HQ1_{Ar41} := \frac{CONC1_{40}}{ThC_{bird\_Ar}} \qquad HQ1_{Ar41} = 0.02$$

$$HQ1_{I125} := \frac{CONC3_{40}}{ThC_{bird\_I125}} \qquad HQ1_{I125} = 1.44 \times 10^{-7}$$

at 500 m

$$HQ2_{Ar41} := \frac{CONC1_{500}}{ThC_{bird\_Ar}} \qquad HQ2_{Ar41} = 2.13 \times 10^{-4}$$

$$HQ2_{I125} := \frac{CONC3_{500}}{ThC_{bird\_I125}} \qquad HQ2_{I125} = 1.31 \times 10^{-9}$$

at 1 km

$$HQ3_{Ar41} := \frac{CONC1_{1000}}{ThC_{bird\_Ar}} \qquad HQ3_{Ar41} = 1.07 \times 10^{-4}$$

$$HQ3_{I125} := \frac{CONC3_{1000}}{ThC_{bird\_I125}} \qquad HQ3_{I125} = 6.56 \times 10^{-10}$$

ADDENDUM TO MNR ERA

NUMERICAL DATA FOR PAST 5 YEARS IN FIGURE 19
(History of β-emitting particles measured in filters of external stations)

NUMERICAL DATA FOR PAST 5 YEARS IN FIGURE 20
(History of soft γ-emitting I-125 measured in charcoal cartridges of external stations

Prepared by: Chris Malcolmson
Health Physicist, McMaster University

Revision 0
August 2023

Table 1: Numerical data for particles in Figure 19 of main report for past 5 years
Locations A to C

Shaded values are below Minimum Detectable Concentration (MDC)

LOCATION								
[A] IAHS			[B] GSB			[C] NRB		
Date	Bq/m^3		Date	Bq/m^3		Date	Bq/m^3	
	Reading	MDC		Reading	MDC		Reading	MDC
2018-01-02	0.0004735	0.000323	2017-12-05	0.0002232	0.000352	2017-12-18	0.0005167	0.000324
2018-01-08	0.0004978	0.000175	2017-12-11	0.0002555	0.000325	2018-01-02	0.0005260	0.000323
2018-01-15	0.0009766	0.000325	2017-12-18	0.0002665	0.000324	2018-01-08	0.0002238	0.000175
2018-01-22	0.0006206	0.000356	2018-01-02	0.0008477	0.000323	2018-01-15	0.0002615	0.000325
2018-01-29	0.0008160	0.000351	2018-01-08	0.0002571	0.000175	2018-01-22	0.0005686	0.000356
2018-02-05	0.0004992	0.00034	2018-01-15	0.0003083	0.000325	2018-01-29	0.0006320	0.000351
2018-02-12	0.0006882	0.000369	2018-01-22	0.0034527	0.000356	2018-02-05	0.0004992	0.00034
2018-02-19	0.0011765	0.000324	2018-01-29	0.0004818	0.000351	2018-02-12	0.0004643	0.000369
2018-02-26	0.0009919	0.000361	2018-02-05	0.0004303	0.00034	2018-02-19	0.0006314	0.000324
2018-03-05	0.0006233	0.000336	2018-02-12	0.0002927	0.000369	2018-02-26	0.0005833	0.000361
2018-03-12	0.0008005	0.00037	2018-02-19	0.0007323	0.000324	2018-03-05	0.0005367	0.000336
2018-03-19	0.0004303	0.000369	2018-02-26	0.0005989	0.000361	2018-03-12	0.0011938	0.00037
2018-03-26	0.0009469	0.000369	2018-03-05	0.0004675	0.000336	2018-03-19	0.0001028	0.000369
2018-04-02	0.0003246	0.000381	2018-03-12	0.0001018	0.00037	2018-03-26	0.0005680	0.000369
2018-04-09	0.0000502	0.00037	2018-03-19	0.0003101	0.000369	2018-04-02	0.0001878	0.000381
2018-04-16	0.0008121	0.000367	2018-03-26	0.0004303	0.000369	2018-04-09	0.0003536	0.00037
2018-04-23	0.0003924	0.000331	2018-04-02	0.0002735	0.000381	2018-04-16	0.0005468	0.000367
2018-04-30	0.0007950	0.000354	2018-04-09	0.0004377	0.00037	2018-04-23	0.0004770	0.000331
2018-05-07	0.0005828	0.000357	2018-04-16	0.0006173	0.000367	2018-04-30	0.0003975	0.000354
2018-05-14	0.0008242	0.000346	2018-04-23	0.0005969	0.000331	2018-05-07	0.0005150	0.000357
2018-05-22	0.0004261	0.000337	2018-04-30	0.0006058	0.000354	2018-05-14	0.0003778	0.000346
2018-05-30	0.0001723	0.000394	2018-05-07	0.0004977	0.000357	2018-05-22	0.0003580	0.000337
2018-06-06	0.0001716	0.000393	2018-05-14	0.0006176	0.000346	2018-05-30	0.0001382	0.000394
2018-06-11	0.0002570	0.000392	2018-05-22	0.0005452	0.000337	2018-06-06	0	0.000393
2018-06-18	0.0000854	0.000393	2018-05-30	0.0003630	0.000394	2018-06-11	0	0.000392
2018-06-25	0.0002561	0.000338	2018-06-06	0.0001725	0.000393	2018-06-18	0.0002753	0.000393
2018-07-03	0.0000000	0.000739	2018-06-11	0.0005487	0.000392	2018-06-25	0.0003590	0.000338
2018-07-09	0.0002569	0.000396	2018-06-18	0.0001891	0.000393	2018-07-03	0	0.000739
2018-07-16	0.0002502	0.000385	2018-06-25	0.0002223	0.000338	2018-07-09	0.0002907	0.000396
2018-07-23	0.0001587	0.000365	2018-07-03	0	0.000739	2018-07-16	0.0002379	0.000392
2018-07-30	0.0000175	0.000386	2018-07-09	0.0004121	0.000396	2018-07-23	0.0003812	0.000359
2018-08-06	0	0.000377	2018-07-16	0.0005092	0.000392	2018-07-30	0.0001908	0.000386
2018-08-13	0.0000513	0.000401	2018-07-23	0.0004850	0.000359	2018-08-06	0.0000171	0.000377
2018-08-20	0.0002627	0.000345	2018-07-30	0.0002258	0.000386	2018-08-13	0.0002069	0.000401
2018-08-27	0.0002213	0.000417	2018-08-06	0.0005270	0.000377	2018-08-20	0.0001578	0.000345
2018-09-04	0.0003689	0.000353	2018-08-13	0.0003964	0.000401	2018-08-27	0.0000508	0.000417
2018-09-10	0.0000000	0.000633	2018-08-20	0.0005077	0.000345	2018-09-04	0.0004018	0.000353
2018-09-17	0.0003274	0.000425	2018-08-27	0.0003591	0.000417	2018-09-10	0	0.000633
2018-09-24	0.0003936	0.000431	2018-09-04	0.0011901	0.000353	2018-09-17	0.0010642	0.000425

Table 1 continues on next page

Table 1 continued from previous page

LOCATION								
[A] IAHS			**[B] GSB**			**[C] NRB**		
Date	**Bq/m^3**		**Date**	**Bq/m^3**		**Date**	**Bq/m^3**	
	Reading	**MDC**		**Reading**	**MDC**		**Reading**	**MDC**
2018-10-01	0.0001555	0.00043	2018-09-10	0	0.000633	2018-09-24	0.0000983	0.000431
2018-10-09	0.0000000	0.000458	2018-09-17	0.0002456	0.000425	2018-10-01	0	0.00043
2018-10-16	0.0005185	0.000429	2018-09-24	0.0002951	0.000431	2018-10-09	0	0.000457
2018-10-23	0.0002572	0.000432	2018-10-01	0	0.00043	2018-10-16	0.0002556	0.000429
2018-10-29	0.0001084	0.000425	2018-10-09	0	0.000457	2018-10-23	0.0017715	0.000432
2018-11-05	0.0000658	0.00043	2018-10-16	0.0006646	0.000429	2018-10-29	0.0002673	0.000425
2018-11-12	0.0001868	0.000429	2018-10-23	0.0006686	0.000432	2018-11-05	0.0001389	0.00043
2018-11-19	0	0.000429	2018-10-29	0.0003974	0.000425			
2018-11-26	0.0007979	0.000429	2018-11-05	0.0004754	0.00043	2018-11-19	0.0001714	0.00043
2018-12-03	0.0008096	0.000429	2018-11-12	0.0006539	0.000429	2018-11-26	0.0000467	0.000429
2018-12-10	0.0007799	0.00043	2018-11-19	0.0004517	0.00043	2018-12-03	0.0002958	0.000429
2018-12-18	0.0016116	0.000432	2018-11-26	0.0009185	0.000429	2018-12-10	0.0001881	0.000432
2019-01-07	0	0.000428	2018-12-03	0.0011053	0.000429	2018-12-18	0.0002646	0.000429
2019-01-08	0.0007474	0.000212	2018-12-10	0.0010596	0.00043	2019-01-07	0	0.000429
2019-01-14	0.0016198	0.000442	2018-12-18	0.0013463	0.000432	2019-01-08	0.0001093	0.000215
2019-01-21	0.0012073	0.000427	2019-01-07	0	0.000429	2019-01-14	0	0.00043
2019-01-28	0.0012607	0.000429	2019-01-08	0.0008420	0.000215	2019-01-21	0.0003716	0.000427
2019-02-04	0.0013153	0.000429	2019-01-14	0.0013111	0.00043	2019-01-28	0.0003580	0.000429
2019-02-11	0.0010655	0.000376	2019-01-21	0.0006973	0.000427	2019-02-04	0	0.000429
2019-02-19	0.0007697	0.000501	2019-01-28	0.0012459	0.000429	2019-02-11	0.0001657	0.000376
2019-02-25	0.0009970	0.000429	2019-02-04	0.0010565	0.000429	2019-02-19	0.0002720	0.000501
2019-03-04	0.0013790	0.000429	2019-02-11	0.0009751	0.000376	2019-02-25	0.0001893	0.000429
2019-03-11	0.0110780	0.000429	2019-02-19	0.0005980	0.000501	2019-03-04	0.0000868	0.000429
2019-03-18	0.0022156	0.000429	2019-02-25	0.0010995	0.000429	2019-03-11	0.0171214	0.000429
2019-03-25	0.0007228	0.00043	2019-03-04	0.0007614	0.000429	2019-03-18	0.0006741	0.00043
2019-04-01	0	0.00043	2019-03-11	0.0006614	0.000429	2019-03-25	0	0.00043
2019-04-08	0	0.000429	2019-03-18	0.0018634	0.000429	2019-04-01	0	0.000429
2019-04-15	0.0003459	0.00043	2019-03-25	0.0019786	0.00043	2019-04-08	0	0.000429
2019-04-23	0.0014640	0.000426	2019-04-01	0	0.00043	2019-04-15	0.0000943	0.00043
2019-04-29	0	0.000432	2019-04-08	0.0002355	0.000429	2019-04-23	0.0004229	0.000429
2019-05-06	0.0006126	0.000428	2019-04-15	0.0003608	0.00043	2019-04-29	0.0000000	0.000429
2019-05-13	0.0005271	0.000431	2019-04-23	0.0007050	0.000429	2019-05-06	0.0001194	0.000428
2019-05-21	0.0005556	0.000429	2019-04-29	0	0.00043	2019-05-13	0.0006026	0.000431
2019-05-27	0.0001034	0.00043	2019-05-06	0.0005830	0.000428	2019-05-21	0.0002249	0.000429
2019-06-03	0	0.000429	2019-05-13	0.0004673	0.000431	2019-05-27	0.0002249	0.000429
2019-06-10	0	0.000429	2019-05-21	0.0005556	0.000429	2019-06-03	0	0.000429
2019-06-17	0	0.000429	2019-05-27	0.0010351	0.000429	2019-06-10	0	0.000429
2019-06-24	0	0.00043	2019-06-03	0.0000364	0.000429	2019-06-17	0	0.000429
2019-07-03	0	0.000429	2019-06-10	0	0.000429	2019-06-24	0	0.00043
2019-07-08	0	0.000334	2019-06-17	0.0011979	0.000429	2019-07-03	0	0.00043
2019-07-15	0	0.000429	2019-06-24	0.0015467	0.00043	2019-07-08	0	0.000334

Table 1 continues on next page

Table 1 continued from previous page

LOCATION								
[A] IAHS			**[B] GSB**			**[C] NRB**		
Date	**Bq/m^3**		**Date**	**Bq/m^3**		**Date**	**Bq/m^3**	
	Reading	**MDC**		**Reading**	**MDC**		**Reading**	**MDC**
2019-07-22	0	0.000428	2019-07-03	0	0.00043	2019-07-15	0	0.000429
2019-07-29	0	0.000431	2019-07-08	0	0.000334	2019-07-22	0	0.000427
2019-08-06	0	0.000425	2019-07-15	0	0.000429	2019-07-29	0	0.000432
2019-08-12	0	0.000432	2019-07-22	0	0.000427	2019-08-06	0	0.000425
2019-08-19	0	0.000431	2019-07-29	0	0.000432	2019-08-12	0	0.000431
2019-08-26	0	0.000418	2019-08-06	0	0.000425	2019-08-19	0	0.000431
2019-09-03	0	0.000439	2019-08-12	0.0002642	0.000432	2019-08-26	0	0.000418
2019-09-09	0	0.00042	2019-08-19	0.0002483	0.000431	2019-09-03	0	0.000439
2019-09-16	0	0.000426	2019-08-26	0.0000056	0.000418	2019-09-09	0	0.00042
2019-09-23	0	0.000429	2019-09-03	0.0000000	0.000439	2019-09-16	0	0.000426
2019-09-30	0	0.00043	2019-09-09	0.0000946	0.00042	2019-09-23	0	0.000429
2019-10-07	0	0.000431	2019-09-16	0	0.000426	2019-09-30	0	0.00043
2019-10-15	0	0.000439	2019-09-23	0	0.000429	2019-10-07	0	0.000431
2019-10-21	0	0.000433	2019-09-30	0	0.00043	2019-10-15	0	0.000439
2019-10-28	0	0.000429	2019-10-07	0	0.000431	2019-10-21	0	0.000433
2019-11-04	0	0.000433	2019-10-15	0	0.000439	2019-10-28	0	0.000429
2019-11-11	0	0.000433	2019-10-21	0	0.000433	2019-11-04	0	0.000433
2019-11-18	0	0.000438	2019-10-28	0	0.000429	2019-11-11	0	0.000433
2019-11-25	0	0.000416	2019-11-04	0	0.000433	2019-11-18	0.0001830	0.000438
2019-12-02	0	0.000441	2019-11-11	0	0.000433	2019-11-25	0	0.000416
2019-12-09	0	0.000419	2019-11-18	0	0.000438	2019-12-02	0.0000467	0.000441
2019-12-16	0	0.000435	2019-11-25	0	0.000416	2019-12-09	0	0.000419
2019-12-23	0	0.000376	2019-12-02	0.0000314	0.000441	2019-12-16	0	0.000435
2020-01-06	0	0.000212	2019-12-09	0	0.000419	2019-12-23	0	0.000376
2020-01-13	0	0.00015	2019-12-16	0	0.000435	2020-01-06	0	0.000215
2020-01-20	0	0.000429	2019-12-23	0	0.000376	2020-01-13	0.0003963	0.00015
2020-01-27	0	0.000429	2020-01-06	0	0.000215	2020-01-20	0	0.000429
2020-02-03	0	0.000429	2020-01-13	0	0.00015	2020-01-27	0	0.000429
2020-02-10	0	0.00037	2020-01-20	0	0.000429	2020-02-03	0	0.000429
2020-02-18	0	0.000601	2020-01-27	0	0.000429	2020-02-10	0	0.00037
2020-02-24	0.0004126	0.00044	2020-02-03	0	0.000429	2020-02-18	0	0.000601
2020-03-02	0.0001359	0.000432	2020-02-10	0	0.00037	2020-02-24	0	0.00044
2020-03-09	0.0002938	0.000422	2020-02-18	0	0.000601	2020-03-02	0	0.000432
2020-03-16	0.0000162	0.000435	2020-02-24	0	0.00044	2020-03-09	0	0.000422
2020-03-24	0	0.000431	2020-03-02	0	0.000432	2020-03-16	0.0000464	0.000435
2020-03-30	0.0001499	0.000429	2020-03-09	0	0.000422	2020-03-24	0	0.000431
2020-04-06	0.0001646	0.000429	2020-03-16	0	0.000435	2020-03-30	0	0.000429
2020-04-20	0.0002687	0.000215	2020-03-24	0	0.000431	2020-04-06	0	0.000429
2020-05-04	0.0005036	0.000213	2020-03-30	0	0.000429	2020-04-20	0	0.000215
2020-05-19	0	0.000215	2020-04-06	0	0.000429	2020-05-04	0	0.000213
2020-06-01	0	0.000216	2020-04-20	0	0.000215	2020-05-19	0	0.000215

Table 1 continues on next page

Table 1 continued from previous page

LOCATION								
[A] IAHS			**[B] GSB**			**[C] NRB**		
Date	**Bq/m^3**		**Date**	**Bq/m^3**		**Date**	**Bq/m^3**	
	Reading	**MDC**		**Reading**	**MDC**		**Reading**	**MDC**
2020-06-08	0	0.000429	2020-05-04	0	0.000215	2020-06-01	0	0.000216
2020-06-15	0.0001943	0.000429	2020-05-19	0	0.000213	2020-06-08	0	0.000429
2020-06-22	0	0.000429	2020-06-01	0	0.000215	2020-06-15	0	0.000429
2020-06-29	0	0.00043	2020-06-08	0	0.000216	2020-06-22	0	0.000429
2020-07-06	0	0.000426	2020-06-15	0	0.000429	2020-06-29	0	0.00043
2020-07-13	0	0.000433	2020-06-22	0	0.000429	2020-07-06	0	0.000426
2020-07-20	0	0.000433	2020-06-29	0	0.000429	2020-07-13	0	0.000433
2020-07-27	0	0.000429	2020-07-06	0	0.000429	2020-07-20	0	0.000433
2020-08-04	0	0.000433	2020-07-13	0	0.000433	2020-07-27	0	0.00043
2020-08-10	0	0.000433	2020-07-20	0	0.000433	2020-08-04	0.0003312	0.000433
2020-08-17	0	0.000433	2020-07-27	0	0.000429	2020-08-10	0	0.000433
2020-08-24	0	0.000433	2020-08-04	0	0.000433	2020-08-17	0	0.000433
2020-08-31	0	0.000429	2020-08-10	0	0.000433	2020-08-24	0	0.000433
2020-09-08	0	0.000429	2020-08-17	0	0.000433	2020-08-31	0	0.000428
2020-09-14	0	0.000413	2020-08-24	0	0.000433	2020-09-08	0	0.000428
2020-09-21	0	0.000443	2020-08-31	0	0.000428	2020-09-14	0	0.000418
2020-09-28	0	0.000432	2020-09-08	0	0.000428	2020-09-21	0	0.000438
2020-10-05	0	0.000419	2020-09-14	0	0.000413	2020-09-28	0	0.000433
2020-10-14	0	0.000371	2020-09-21	0	0.000443	2020-10-05	0.0005236	0.000419
2020-10-19	0	0.000446	2020-09-28	0.0003162	0.000433	2020-10-14	0	0.000372
2020-10-26	0	0.000487	2020-10-05	0	0.000419	2020-10-19	0	0.000447
2020-11-02	0	0.000428	2020-10-14	0	0.000372	2020-10-26	0	0.000486
2020-11-09	0	0.00044	2020-10-19	0	0.000447	2020-11-02	0	0.000428
2020-11-16	0	0.000417	2020-10-26	0	0.000486	2020-11-09	0.0000620	0.00044
2020-11-23	0	0.000384	2020-11-02	0	0.000428	2020-11-16	0.0005361	0.000417
2020-11-30	0	0.000507	2020-11-09	0	0.00044	2020-11-23	0	0.000383
2020-12-07	0	0.000428	2020-11-16	0	0.000417	2020-11-30	0	0.00035
2020-12-14	0	0.000288	2020-11-23	0	0.000383	2020-12-07	0	0.000295
2020-12-21	0	0.000297	2020-11-30	0	0.000507	2020-12-14	0	0.000288
2021-01-11	0	0.00031	2020-12-07	0	0.000295	2020-12-21	0	0.000298
2021-01-18	0	0.000616	2020-12-14	0	0.000257	2021-01-11	0.0000846	0.000289
2021-02-01	0	0.000619	2020-12-21	0	0.000339	2021-01-18	0	0.000616
2021-02-08	0	0.000623	2021-01-11	0	0.000289	2021-02-01	0	0.000619
2021-02-17	0	0.000614	2021-01-18	0	0.000616	2021-02-08	0	0.000623
2021-02-22	0	0.000546	2021-02-01	0	0.000619	2021-02-17	0.0001503	0.000614
2021-03-03	0.0002895	0.000361	2021-02-08	0	0.000623	2021-02-22	0	0.000546
2021-03-08	0	0.000308	2021-02-17	0	0.000614	2021-03-03	0.0009038	0.000361
2021-03-15	0.0000524	0.000308	2021-02-22	0	0.000546	2021-03-08	0.0004112	0.000308
2021-03-22	0.0001119	0.000307	2021-03-03	0.0000438	0.000361	2021-03-15	0.0002767	0.000308
2021-03-29	0.0000982	0.000311	2021-03-08	0.0001720	0.000308	2021-03-22	0.0001143	0.000314
2021-04-05	0.0001139	0.000313	2021-03-15	0	0.000308	2021-03-29	0.0003181	0.000304

Table 1 continues on next page

Table 1 continued from previous page

LOCATION								
[A] IAHS			**[B] GSB**			**[C] NRB**		
Date	**Bq/m³**		**Date**	**Bq/m³**		**Date**	**Bq/m³**	
	Reading	**MDC**		**Reading**	**MDC**		**Reading**	**MDC**
2021-04-12	0.0000076	0.000311	2021-03-22	0.0001295	0.000314	2021-04-05	0.0001748	0.000313
2021-04-19	0.0000675	0.000309	2021-03-29	0.0002441	0.000304	2021-04-12	0.0006583	0.000311
2021-04-26	0.0001280	0.00031	2021-04-05	0.0004786	0.000313	2021-04-19	0.0003231	0.000309
2021-05-03	0.0003206	0.000307	2021-04-12	0.0044418	0.000311	2021-04-26	0.0000527	0.00031
2021-05-10	0.0000828	0.00031	2021-04-19	0.0007139	0.000309	2021-05-03	0.0020164	0.000306
2021-05-17	0.0001591	0.000312	2021-04-26	0.0008056	0.00031	2021-05-10	0.0001732	0.00031
2021-05-25	0.0016791	0.00031	2021-05-03	0.0004241	0.000306	2021-05-17	0.0001742	0.000312
2021-05-31	0.0001430	0.00031	2021-05-10	0.0009713	0.00031	2021-05-25	0.0002183	0.00031
2021-06-07	0.0016401	0.000273	2021-05-17	0.0005984	0.000312	2021-05-31	0.0015887	0.00031
2021-06-14	0.0022281	0.000365	2021-05-25	0.0011821	0.00031	2021-06-07	0.0012550	0.000273
2021-06-21	0.0018419	0.000304	2021-05-31	0.0027181	0.00031	2021-06-14	0.0005059	0.000365
2021-06-28	0.0004899	0.000331	2021-06-07	0.0019721	0.000273	2021-06-21	0.0015461	0.000304
2021-07-06	0.0000645	0.000295	2021-06-14	0.0024943	0.000365	2021-06-28	0.0000241	0.000331
2021-07-12	0.0003806	0.000307	2021-06-21	0.0018271	0.000304	2021-07-06	0.0001649	0.000295
2021-07-19	0.0002649	0.000311	2021-06-28	0.0006987	0.000331	2021-07-12	0.0002612	0.000307
2021-07-26	0.0003221	0.000308	2021-07-06	0.0002509	0.000295	2021-07-19	0.0002194	0.000311
2021-08-03	0.0006117	0.000311	2021-07-12	0.0002612	0.000307	2021-07-26	0.0003671	0.000308
2021-08-11	0.0002160	0.000307	2021-07-19	0.0007037	0.000311	2021-08-03	0.0003852	0.000311
2021-08-16	0.0003918	0.000316	2021-07-26	0.0018955	0.000308	2021-08-11	0.0003799	0.000307
2021-08-23	0.0007280	0.000303	2021-08-03	0.0027564	0.000311	2021-08-16	0.0020357	0.000316
2021-08-30	0.0003257	0.000312	2021-08-11	0.0010502	0.000307	2021-08-23	0.0007900	0.000304
2021-09-18	0.0002919	0.000308	2021-08-16	0.0014518	0.000316	2021-08-30	0.0003395	0.000311
2021-09-19	0.0002429	0.00027	2021-08-23	0.0013363	0.000304	2021-09-18	0.0005015	0.000308
2021-09-20	0.0005126	0.000315	2021-08-30	0.0008374	0.000311	2021-09-19	0.0005975	0.00027
2021-09-27	0.0003959	0.000307	2021-09-18	0.0008009	0.000308	2021-09-20	0.0023182	0.000315
2021-10-04	0.0003501	0.000307	2021-09-19	0.0004530	0.00027	2021-09-27	0.0003063	0.000307
2021-10-13	0	0.000402	2021-09-20	0.0011859	0.000315	2021-10-04	0.0004544	0.000307
2021-10-18	0	0.000405	2021-09-27	0.0011579	0.000307	2021-10-13	0.0000819	0.000402
2021-10-25	0	0.000402	2021-10-04	0.0010651	0.000307	2021-10-18	0	0.000405
2021-11-01	0	0.000353	2021-10-13	0.0004615	0.000402	2021-10-25	0	0.000402
2021-11-08	0	0.000464	2021-10-18	0.0004324	0.000405	2021-11-01	0.0001828	0.000353
2021-11-15	0	0.000404	2021-10-25	0.0000000	0.000402	2021-11-08	0	0.000464
2021-11-22	0	0.000403	2021-11-01	0.0002661	0.000353	2021-11-15	0	0.000404
2021-11-29	0	0.000401	2021-11-08	0.0002766	0.000464	2021-11-22	0	0.000403
2021-12-06	0.0003327	0.0004	2021-11-15	0.0004956	0.000404	2021-11-29	0.0000186	0.000401
2021-12-13	0	0.000401	2021-11-22	0.0003040	0.000403	2021-12-06	0.0001285	0.0004
2021-12-20	0	0.000411	2021-11-29	0.0003966	0.000401	2021-12-13	0.0000186	0.000401
2022-01-03	0.0001114	0.000395	2021-12-06	0.0019503	0.0004	2021-12-20	0.0017814	0.000411
2022-01-10	0	4.04E-04	2021-12-13	0.0003966	0.000401	2022-01-03	0.0000183	0.000395
2022-01-18	0	3.49E-04	2021-12-20	0	0.000411	2022-01-10	0	4.04E-04
2022-01-24	0	3.98E-04	2022-01-03	0.0000493	0.000395	2022-01-18	0.0013740	3.49E-04

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Table 1 continued from previous page

LOCATION								
[A] IAHS			[B] GSB			[C] NRB		
Date	Bq/m³		Date	Bq/m³		Date	Bq/m³	
	Reading	MDC		Reading	MDC		Reading	MDC
2022-01-31	0.0039990	4.69E-04	2022-01-10	0	4.03E-04	2022-01-24	0.0000341	3.98E-04
2022-02-07	0	3.54E-04	2022-01-18	0.0015865	3.51E-04	2022-01-31	Not available	
2022-02-14	0.0012050	3.97E-04	2022-01-24	0.0022398	3.98E-04	2022-02-07	0.0000000	2.02E-04
2022-02-22	0	4.04E-04	2022-01-31	0.0011818	4.69E-04	2022-02-14	0.0017670	3.97E-04
2022-02-28	0	4.00E-04	2022-02-07	0.0019372	3.54E-04	2022-02-22	0.0000028	4.04E-04
2022-03-07	0.0000187	4.04E-04	2022-02-14	0.0016421	3.97E-04	2022-02-28	0.0003018	4.00E-04
2022-03-14	0.0013128	4.02E-04	2022-02-22	0.0030325	4.04E-04	2022-03-07	0	4.04E-04
2022-03-21	0	4.00E-04	2022-02-28	0.0019542	4.00E-04	2022-03-14	0.0002554	4.02E-04
2022-03-28	0.0015654	4.02E-04	2022-03-07	0.0021781	4.04E-04	2022-03-21	0.0000499	4.00E-04
2022-04-04	0	4.02E-04	2022-03-14	0.0016127	4.02E-04	2022-03-28	0.0012813	4.02E-04
2022-04-11	0.0014520	4.01E-04	2022-03-21	0.0014006	4.00E-04	2022-04-04	0	4.02E-04
2022-04-19	0	4.00E-04	2022-03-28	0.0026386	4.02E-04	2022-04-11	0.0015638	4.01E-04
2022-04-25	0.0015180	4.02E-04	2022-04-04	0.0007604	4.02E-04	2022-04-19	0	3.99E-04
2022-05-02	0	4.04E-04	2022-04-11	0.0023656	4.01E-04	2022-04-25	0.0016285	4.02E-04
2022-05-09	0	4.01E-04	2022-04-19	0.0007095	4.00E-04	2022-05-02	0	4.04E-04
2022-05-16	0	4.02E-04	2022-04-25	0.0021493	4.02E-04	2022-05-09	0.0014534	4.01E-04
2022-05-24	0	3.99E-04	2022-05-02	0.0009555	4.04E-04	2022-05-16	0.0000028	4.02E-04
2022-05-30	0	3.99E-04	2022-05-09	0.0027306	4.01E-04	2022-05-24	0.0014775	3.99E-04
2022-06-06	0	4.14E-04	2022-05-16	0.0012036	4.02E-04	2022-05-30	0	3.99E-04
2022-06-13	0	4.02E-04	2022-05-24	0.0006774	3.99E-04	2022-06-06	0.0000354	4.14E-04
2022-06-20	0	4.01E-04	2022-05-30	0.0005519	3.99E-04	2022-06-13	0	4.02E-04
2022-07-04	0	4.02E-04	2022-06-06	0.0024430	4.14E-04	2022-06-20	0	4.01E-04
2022-07-11	0	4.02E-04	2022-06-13	0.0005710	4.02E-04	2022-07-04	0.0000818	4.02E-04
2022-07-18	0.0000818	4.02E-04	2022-06-20	0.0006339	4.01E-04	2022-07-11	0	4.02E-04
2022-07-25	0	4.02E-04	2022-07-04	0.0007446	4.02E-04	2022-07-18	0.0016916	4.02E-04
2022-08-01	0	4.02E-04	2022-07-11	0.0009814	4.02E-04	2022-07-25	0.0000186	4.02E-04
2022-08-15	0.0000028	4.02E-04	2022-07-18	0.0008078	4.02E-04	2022-08-01	0	4.02E-04
2022-08-22	0.0000028	4.02E-04	2022-07-25	0.0006342	4.02E-04	2022-08-15	0	4.02E-04
2022-08-29	0	4.02E-04	2022-08-01	0.0007446	4.02E-04	2022-08-22	0	4.02E-04
2022-09-06	0.0030372	4.71E-04	2022-08-15	0.0009498	4.02E-04	2022-08-29	0.0000028	4.02E-04
2022-09-12	0	4.02E-04	2022-08-22	0.0012340	4.02E-04	2022-09-06	0.0000000	4.71E-04
2022-09-19	0	4.02E-04	2022-08-29	0.0011550	4.02E-04	2022-09-12	0.0001135	4.02E-04
2022-09-26	0	0.000402	2022-09-06	0.0020013	4.71E-04	2022-09-19	0.0019126	4.02E-04
2022-10-03	0	0.000402	2022-09-12	0.0004132	4.02E-04	2022-09-26	0	0.000402
2022-10-11	0	0.000402	2022-09-19	0.0009340	4.02E-04	2022-10-03	0	0.000402
2022-10-17	0.0000028	0.000402	2022-09-26	0.0017706	0.000402	2022-10-11	0.0001606	0.000402
2022-10-25	0	0.000402	2022-10-03	0.0007920	0.000402	2022-10-17	0.0000000	0.000402
2022-10-31	0	0.000201	2022-10-11	0.0004448	0.000402	2022-10-25	0.0014391	0.000402
2022-11-07	0	0.000402	2022-10-17	0.0013918	0.000402	2022-10-31	0	0.000201

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Table 1 continued from previous page

LOCATION								
[A] IAHS			**[B] GSB**			**[C] NRB**		
Date	**Bq/m^3**		**Date**	**Bq/m^3**		**Date**	**Bq/m^3**	
	Reading	**MDC**		**Reading**	**MDC**		**Reading**	**MDC**
2022-11-14	0.0007306	0.000403	2022-10-25	0.0012340	0.000402	2022-11-07	0	0.000402
2022-11-21	0.0000697	0.000558	2022-10-31	0.0006715	0.000201	2022-11-14	0.0000660	0.000402
2022-11-28	0.0008078	0.000402	2022-11-07	0.0009182	0.000402	2022-11-21	0.0000970	0.000399
2022-12-05	0	0.000402	2022-11-14	0.0012655	0.000402	2022-11-28	0.0000502	0.000402
2022-12-12	0.0032036	0.000399	2022-11-21	0.0007245	0.000399	2022-12-05	0	0.000402
2022-12-19	0.0029412	0.000352	2022-11-28	0.0025597	0.000402	2022-12-12	0.0023720	0.000399
			2022-12-05	0.0007446	0.000402	2022-12-19	0.0047786	0.000352
			2022-12-12	0.0036271	0.000399			
			2022-12-19	0.0042274	0.000352			

End **of** Table 1

Average and maximum values in Table 1 Bq/m^3)

LOCATION					
[A] IAHS		**[B] GSB**		**[C] NRB**	
Average:	**0.0003603**	Average:	**0.0005988**	Average:	**0.0003354**
Maximum:	**0.0110780**	Maximum:	**0.0044418**	Maximum:	**0.0171214**

These average values include the measured values which are below Minimum Detectable Concentration.

Table 2: Numerical data for particles in Figure 19 of main report for past 5 years)
Locations D to F

Shaded values are below Minimum Detectable Concentration (MDC)

LOCATION								
[D] Mills Library			[E] NFAS - Station 10			[F] ABB		
Date counted	Bq/m^3		Date counted	Bq/m^3		Date counted	Bq/m^3	
	Reading	MDC		Reading	MDC		Reading	MDC
2018-01-15	0.0004399	0.000325	2018-01-15	0.0002284	0.000325	Station not in service		
2018-01-22	0.0003444	0.000356	2018-01-22	0.0000699	0.000356			
2018-01-29	0.0004827	0.000351	2018-01-29	0.0002822	0.000351			
2018-02-05	0.0004129	0.00034	2018-02-05	0.0003267	0.00034			
2018-02-12	0.0003267	0.000369	2018-02-12	0.0002579	0.000369			
2018-02-19	0.0003588	0.000324	2018-02-19	0.0001708	0.000324			
2018-02-26	0.0004787	0.000361	2018-02-26	0.0002389	0.000361			
2018-03-05	0.0006058	0.000336	2018-03-05	0.0001383	0.000336			
2018-03-12	0.0004089	0.00037	2018-03-12	0.0001026	0.00037			
2018-03-19	0.0003964	0.000369	2018-03-19	0.0002413	0.000369			
2018-03-26	0.0001028	0.000369	2018-03-26	0.0001891	0.000369			
2018-04-02	0.0001022	0.000381	2018-04-02	0.0002562	0.000381			
2018-04-09	0.0007395	0.00037	2018-04-09	0	0.00037			
2018-04-16	0.0003886	0.000367	2018-04-16	0.0001412	0.000367			
2018-04-23	0.0003752	0.000331	2018-04-23	0.0002044	0.000331			
2018-04-30	0.0000517	0.000354	2018-04-30	0.0001900	0.000354			
2018-05-07	0.0005316	0.000357	2018-05-07	0.0002059	0.000357			
2018-05-14	0.0003423	0.000346	2018-05-14	0.0002050	0.000346			
2018-05-22	0.0005287	0.000337	2018-05-22	0.0001026	0.000337			
2018-05-30	0.0002248	0.000394	2018-05-30	0	0.000394			
2018-06-06	0	0.000393	2018-06-06	0	0.000393			
2018-06-11	0.0004801	0.000392	2018-06-11	0.0001372	0.000392			
2018-06-18	0.0001028	0.000393	2018-06-18	0.0000000	0.000393			
2018-06-25	0.0005468	0.000338	2018-06-25	0.0001713	0.000338			
2018-07-03	0	0.000739	2018-07-03	0	0.000739			
2018-07-09	0.0001371	0.000396	2018-07-09	0	0.000396			
2018-07-16	0.0002550	0.000392	2018-07-16	0.0000169	0.000385			
2018-07-23	0.0002250	0.000359	2018-07-23	0.0001932	0.000365			
2018-07-30	0.0001343	0.000374	2018-07-30	0.0000350	0.000386			
2018-08-06	0.0002793	0.000388	2018-08-06	0.0000507	0.000372			
2018-08-13	0.0006554	0.000401	2018-08-13	0	0.000406			
2018-08-20	0.0002795	0.000345	2018-08-20	0.0000873	0.000345			
2018-08-27	0.0007690	0.000417	2018-08-27	0.0000672	0.000411			
2018-09-04	0.0012906	0.000353	2018-09-04	0.0013070	0.000357			
2018-09-10	0	0.000633	2018-09-10	0	0.000633			
2018-09-17	0.0001637	0.000425	2018-09-17	0.0003274	0.000425			
2018-09-24	0.0007869	0.000431	2018-09-24	0.0002954	0.000431			
2018-10-01	0	0.00043	2018-10-01	0.0000000	0.00043			

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Table 2 continued from previous page

LOCATION								
[D] Mills Library			[E] NFAS – Station 10			[F] ABB		
Date counted	Bq/m^3		Date counted	Bq/m^3		Date counted	Bq/m^3	
	Reading	MDC		Reading	MDC		Reading	MDC
2018-10-09	0.0003317	0.000458	2018-10-09	0.0001663	0.000459	Station not in service		
2018-10-16	0.0004163	0.000429	2018-10-16	0.0003286	0.000429			
2018-10-23	0.0001836	0.000432	2018-10-23	0.0003745	0.000432			
2018-10-29	0.0003107	0.000425	2018-10-29	-0.0000506	0.000425			
2018-11-05	0.0000366	0.00043	2018-11-05	0.0001389	0.00043			
2018-11-12	0	0.000429	2018-11-12	0.0001868	0.000429			
2018-11-19	0.0002492	0.00043	2018-11-19	0.0000932	0.000428			
2018-11-26	0.0002803	0.000429	2018-11-26	0.0001868	0.000429			
2018-12-03	0.0002803	0.000429	2018-12-03	0.0004826	0.000429			
2018-12-10	0.0001249	0.00043	2018-12-10	0.0006559	0.000431			
2018-12-18	0.0001253	0.000432	2018-12-18	0.0013456	0.000432			
2019-01-07	0	0.000429	2019-01-07	0	0.000428			
2019-01-08	0.0001093	0.000215	2019-01-08	0.0009323	0.000212			
2019-01-14	0.0002345	0.00043	2019-01-14	0.0014912	0.000442			
2019-01-21	0.0001702	0.000427	2019-01-21	0.0005884	0.000427			
2019-01-28	0.0000885	0.000429	2019-01-28	0.0008565	0.000429			
2019-02-04	0	0.000429	2019-02-04	0.0011376	0.000429			
2019-02-11	0.0002944	0.000376	2019-02-11	0.0007827	0.000376			
2019-02-19	0.0001186	0.000501	2019-02-19	0.0004784	0.000501			
2019-02-25	0.0001306	0.000429	2019-02-25	0.0009383	0.000429			
2019-03-04	0.0003365	0.000429	2019-03-04	0.0008499	0.000429			
2019-03-11	0.0003307	0.000429	2019-03-11	0.0099983	0.000429			
2019-03-18	0.0022735	0.000429	2019-03-18	0.0016733	0.00043			
2019-03-25	0.0020101	0.00043	2019-03-25	0	0.00043			
2019-04-01	0.0015864	0.00043	2019-04-01	0	0.00043			
2019-04-08	0.0029617	0.000429	2019-04-08	0.0006586	0.000429			
2019-04-15	0.0025281	0.00043	2019-04-15	0.0013977	0.00043			
2019-04-23	0.0026473	0.000426	2019-04-23	0.0011516	0.000426			
2019-04-29	0	0.000432	2019-04-29	0	0.000432			
2019-05-06	0.0027050	0.000428	2019-05-06	0.0002693	0.000428			
2019-05-13	0.0024552	0.000431	2019-05-13	0.0002563	0.000431			
2019-05-21	0.0019056	0.000429	2019-05-21	0.0005101	0.000429			
2019-05-27	0.0022068	0.00043	2019-05-27	0.0012016	0.00043			
2019-06-03	0.0026144	0.000429	2019-06-03	0	0.000429			
2019-06-10	0.0018154	0.000429	2019-06-10	0	0.000429			
2019-06-17	0.0005484	0.000429	2019-06-17	0	0.000429			
2019-06-24	0	0.00043	2019-06-24	0	0.00043			
2019-07-03	0	0.000429	2019-07-03	0	0.000429			
2019-07-08	0.0022451	0.000334	2019-07-08	0	0.000334			
2019-07-15	0.0021635	0.000429	2019-07-15	0	0.000429			
2019-07-22	0.0019006	0.000428	2019-07-22	0	0.000428			

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LOCATION								
[D] Mills Library			[E] NFAS – Station 10			[F] ABB		
Date counted	Bq/m³		Date counted	Bq/m³		Date counted	Bq/m³	
	Reading	MDC		Reading	MDC		Reading	MDC
2019-07-29	0.0011860	0.00043	2019-07-29	0	0.000432	Station not in service		
2019-08-06	0.0024423	0.000425	2019-08-06	0	0.000424			
2019-08-12	0.0000000	0.000432	2019-08-12	0	0.000432			
2019-08-19	0.0016725	0.000431	2019-08-19	0	0.000431			
2019-08-26	0.0024597	0.000418	2019-08-26	0	0.000418			
2019-09-03	0.0017343	0.000439	2019-09-03	0	0.000439			
2019-09-09	0.0017176	0.00042	2019-09-09	0	0.00042			
2019-09-16	0.0025414	0.000426	2019-09-16	0	0.000426			
2019-09-23	0.0015600	0.000429	2019-09-23	0	0.000429			
2019-09-30	0	0.00043	2019-09-30	0	0.00043			
2019-10-07	0.0023539	0.000431	2019-10-07	0	0.000431			
2019-10-15	0.0023528	0.000439	2019-10-15	0	0.000439			
2019-10-21	0.0021917	0.000433	2019-10-21	0	0.000433			
2019-10-28	0.0009229	0.000429	2019-10-28	0	0.000429			
2019-11-04	0.0016517	0.000433	2019-11-04	0	0.000433			
2019-11-11	0.0015017	0.000433	2019-11-11	0	0.000433			
2019-11-18	0.0018387	0.000438	2019-11-18	0	0.000438			
2019-11-25	0.0017875	0.000416	2019-11-25	0	0.000416			
2019-12-02	0.0020364	0.000441	2019-12-02	0	0.000441			
2019-12-09	0.0009750	0.000419	2019-12-09	0	0.000419			
2019-12-16	0.0015701	0.000435	2019-12-16	0	0.000435			
2019-12-23	0	0.000376	2019-12-23	0	0.000376			
2020-01-06	0.0005223	0.000215	2020-01-06	0	0.000212			
2020-01-13	0.0008600	0.00015	2020-01-13	0	0.00015			
2020-01-20	0.0009686	0.000429	2020-01-20	0	0.000429			
2020-01-27	0.0007155	0.000429	2020-01-27	0	0.000429			
2020-02-03	0.0004476	0.000429	2020-02-03	0	0.000429			
2020-02-10	0.0015263	0.00037	2020-02-10	0	0.00037			
2020-02-18	0.0015633	0.000601	2020-02-18	0	0.000601			
2020-02-24	0.0011288	0.00044	2020-02-24	0	0.00044			
2020-03-02	0.0008404	0.000432	2020-03-02	0	0.000432			
2020-03-09	0.0002498	0.000422	2020-03-09	0	0.000422			
2020-03-16	0.0002728	0.000435	2020-03-16	0	0.000435			
2020-03-24	0.0010466	0.000431	2020-03-24	0	0.000431			
2020-03-30	0.0007602	0.000429	2020-03-30	0	0.000429			
2020-04-06	0.0007000	0.000429	2020-04-06	0	0.000429			
2020-04-20	0.0003656	0.000215	2020-04-20	0	0.000215			
2020-05-04	0.0004888	0.000213	2020-05-04	0	0.000213			
2020-05-19	0.0004334	0.000215	2020-05-19	0	0.000215			
2020-06-01	0.0003682	0.000216	2020-06-01	0	0.000216			
2020-06-08	0.0002091	0.000429	2020-06-08	0	0.000429			

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LOCATION								
[D] Mills Library			**[E] NFAS – Station 10**			**[F] ABB**		
Date counted	**Bq/m^3**		**Date counted**	**Bq/m^3**		**Date counted**	**Bq/m^3**	
	Reading	**MDC**		**Reading**	**MDC**		**Reading**	**MDC**
2020-06-15	0	0.000429	2020-06-15	0	0.000429	Station not in service		
2020-06-22	0.0001052	0.000429	2020-06-22	0	0.000429			
2020-06-29	0	0.00043	2020-06-29	0	0.00043			
2020-07-06	0	0.000426	2020-07-06	0	0.000426			
2020-07-13	0.0005262	0.000433	2020-07-13	0	0.000433			
2020-07-20	0	0.000433	2020-07-20	0	0.000433			
2020-07-27	0	0.000429	2020-07-27	0	0.000429			
2020-08-04	0	0.000433	2020-08-04	0	0.000433			
2020-08-10	0	0.000433	2020-08-10	0	0.000433			
2020-08-17	0	0.000433	2020-08-17	0	0.000433			
2020-08-24	0	0.000433	2020-08-24	0	0.000433			
2020-08-31	0	0.000377	2020-08-31	0	0.000429			
2020-09-08	0	0.000377	2020-09-08	0	0.000429	2020-08-31	0	0.000642
2020-09-14	0	0.000477	2020-09-14	0	0.000413	2020-09-14	Not available	
2020-09-21	0	0.000443	2020-09-21	0	0.000443	2020-09-21	0	0.000742
2020-09-28	0	0.000432	2020-09-28	0	0.000432	2020-09-28	0.0000910	0.000624
2020-10-05	0	0.000419	2020-10-05	0.0001754	0.000419	2020-09-28	0.0000910	0.000624
2020-10-14	0	0.000371	2020-10-14	0	0.000371	2020-10-05	0.0010328	0.000605
2020-10-19	0	0.000446	2020-10-19	0	0.000446	2020-10-14	Not available	
2020-10-26	0	0.000487	2020-10-26	0	0.000487	2020-10-19	0.0003148	0.000725
2020-11-02	0	0.000428	2020-11-02	0	0.000428	2020-10-26	0	0.000702
2020-11-09	0	0.00044	2020-11-09	0	0.00044	2020-11-02	0	0.000619
2020-11-16	0	0.000417	2020-11-16	0.0004493	0.000417	2020-11-11	0.0017071	0.000635
2020-11-23	0	0.000384	2020-11-23	0	0.000384	2020-11-16	0.0025740	0.000602
2020-11-30	0	0.000506	2020-11-30	0	0.000344	2020-11-30	0.0012744	0.00031
2020-12-07	0	0.000295	2020-12-07	0	0.000299	2020-12-07	0.0013294	0.000616
2020-12-14	0	0.000287	2020-12-14	0	0.000288	2020-12-14	0.0012719	0.000603
2020-12-21	0	0.000298	2020-12-21	0.0001633	0.000267	2020-12-21	0.0007220	0.00062
2021-01-11	0	0.000289	2021-01-11	0	0.00031	2021-01-11	0.0002379	0.000288
2021-01-18	0	0.000616	2021-01-18	0	0.000617	2021-01-18	0.0000763	0.000617
2021-02-01	0	0.000619	2021-02-01	0	0.000619	2021-02-01	0.0000000	0.000619
2021-02-08	0	0.000623	2021-02-08	0	0.000623	2021-02-08	0	0.000623
2021-02-17	0	0.000614	2021-02-17	0	0.000614	2021-02-17	0	0.000614
2021-02-22	0	0.000546	2021-02-22	0	0.000546	2021-02-22	0	0.000546
2021-03-03	0.0004124	0.000361	2021-03-03	0.0011494	0.000361	2021-03-03	0.0013249	0.000361
2021-03-08	0	0.000308	2021-03-08	0.0006649	0.000307	2021-03-08	Not available	
2021-03-15	0.0001720	0.000308	2021-03-15	0.0008158	0.000308	2021-03-15	0.0003026	0.000356
2021-03-22	0.0000228	0.000314	2021-03-22	0.0013322	0.000313	2021-03-22	0.0003578	0.000313
2021-03-29	0.0004364	0.000304	2021-03-29	0.0006293	0.000305	2021-03-29	0.0003628	0.000305
2021-04-05	0.0002659	0.000313	2021-04-05	0.0005546	0.000313	2021-04-05	0.0005698	0.000313
2021-04-12	0.0000076	0.000311	2021-04-12	0.0007037	0.000311	2021-04-12	0.0003405	0.000311

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LOCATION								
[D] Mills Library			**[E] NFAS – Station 10**			**[F] ABB**		
Date counted	**Bq/m³**		**Date counted**	**Bq/m³**		**Date counted**	**Bq/m³**	
	Reading	**MDC**		**Reading**	**MDC**		**Reading**	**MDC**
2021-04-19	0.0001126	0.000309	2021-04-19	0.0005020	0.000308	2021-04-19	0.0003529	0.000309
2021-04-26	0.0002786	0.00031	2021-04-26	0.0003539	0.00031	2021-04-26	0.0003237	0.00031
2021-05-03	0.0020482	0.000307	2021-05-03	0.0004403	0.000307	2021-05-03	0.0002309	0.000307
2021-05-10	0.0001430	0.00031	2021-05-10	0.0005195	0.00031	2021-05-10	0.0004894	0.00031
2021-05-17	0.0002499	0.000312	2021-05-17	0.0003712	0.000312	2021-05-17	0.0015982	0.000312
2021-05-25	0.0001129	0.00031	2021-05-25	0.0019350	0.00031	2021-05-25	0.0017242	0.00031
2021-05-31	0.0016941	0.00031	2021-05-31	0.0006550	0.00031	2021-05-31	0.0017845	0.00031
2021-06-07	0.0016002	0.000273	2021-06-07	0.0002590	0.000273	2021-06-07	0.0002590	0.000273
2021-06-14	0.0024943	0.000365	2021-06-14	0.0025654	0.000365	2021-06-14	0.0002219	0.000365
2021-06-21	0.0000370	0.000304	2021-06-21	0.0003181	0.000304	2021-06-21	0.0000962	0.000304
2021-06-28	0.0003936	0.000331	2021-06-28	0.0001526	0.000331	2021-06-28	0.0000884	0.000331
2021-07-06	0.0005948	0.000295	2021-07-06	0.0002221	0.000295	2021-07-06	0.0001218	0.000295
2021-07-12	0.0002313	0.000307	2021-07-12	0.0000821	0.000307	2021-07-12	0.0000970	0.000307
2021-07-19	0.0006886	0.000311	2021-07-19	0.0004919	0.000311	2021-07-19	0.0003708	0.000311
2021-07-26	0.0003522	0.000308	2021-07-26	0.0006518	0.000308	2021-07-26	0.0004420	0.000308
2021-08-03	0.0022278	0.000311	2021-08-03	0.0026054	0.000311	2021-08-03	0.0002492	0.000311
2021-08-11	0.0005735	0.000307	2021-08-11	0.0008118	0.000307	2021-08-11	0.0004245	0.000307
2021-08-16	0.0006069	0.000316	2021-08-16	0.0034184	0.000316	2021-08-16	0.0003456	0.000316
2021-08-23	0.0007014	0.000304	2021-08-23	0.0011105	0.000303	2021-08-23	0.0007280	0.000303
2021-08-30	0.0006563	0.000311	2021-08-30	0.0006135	0.000312	2021-08-30	0.0002196	0.000312
2021-09-18	0.0005164	0.000308	2021-09-18	0.0002620	0.000308	2021-09-18	0.0003668	0.000308
2021-09-19	0.0005187	0.00027	2021-09-19	0.0004136	0.00027	2021-09-19	0.0004005	0.00027
2021-09-20	0.0007421	0.000315	2021-09-20	0.0008943	0.000315	2021-09-20	0.0004825	0.000315
2021-09-27	0.0019347	0.000307	2021-09-27	0.0002617	0.000308	2021-09-27	Not available	
2021-10-04	0.0006927	0.000307	2021-10-04	0.0005586	0.000307	2021-10-04	0.0001528	0.000153
2021-10-13	0	0.000402	2021-10-13	0.0005089	0.000402	2021-10-13	0.0005722	0.000402
2021-10-18	0	0.000405	2021-10-18	0.0009256	0.000405	2021-10-18	0.0004802	0.000405
2021-10-25	0	0.000402	2021-10-25	0.0004140	0.000402	2021-10-25	0	0.000402
2021-11-01	0.0000857	0.000353	2021-11-01	0.0004186	0.000353	2021-11-01	0.0000857	0.000353
2021-11-08	0.0000000	0.000464	2021-11-08	0.0006411	0.000464	2021-11-08	0.0002219	0.000464
2021-11-15	0.0001618	0.000404	2021-11-15	0.0010995	0.000404	2021-11-15	0.0001936	0.000404
2021-11-22	0.0018568	0.000403	2021-11-22	0.0021579	0.000403	2021-11-22	0.0000000	0.000403
2021-11-29	0.0002706	0.000401	2021-11-29	0.0009479	0.000401	2021-11-29	0.0000186	0.000401
2021-12-06	0	0.0004	2021-12-06	0.0006310	0.000400	2021-12-06	0.0003327	0.0004
2021-12-13	0	0.000401	2021-12-13	0.0006802	0.000401	2021-12-13	0.0002233	0.000401
2021-12-20	0.0016844	0.000411	2021-12-20	0.0009406	0.000411	2021-12-20	0.0002454	0.000411
2022-01-03	0.0000000	0.000395	2022-01-03	0.0007936	0.000395	2022-01-03	0.0000455	0.000161
2022-01-10	0.0001616	4.04E-04	2022-01-10	0.0022098	4.04E-04	2022-01-10	0.0000346	4.04E-04
2022-01-18	0.0012768	3.49E-04	2022-01-18	0.0012631	3.49E-04	2022-01-18	0.0001532	3.49E-04
2022-01-24	0.0002375	3.98E-04	2022-01-24	0.0015515	3.98E-04	2022-01-24	0	3.98E-04
2022-01-31	0.0000000	4.69E-04	2022-01-31	0.0028759	4.69E-04	2022-01-31	Not available	
2022-02-07	0.0000000	3.54E-04	2022-02-07	0.0010604	3.54E-04	2022-02-07	0.0000411	2.02E-04

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LOCATION								
[D] Mills Library			[E] NFAS – Station 10			[F] ABB		
Date counted	Bq/m^3		Date counted	Bq/m^3		Date counted	Bq/m^3	
	Reading	MDC		Reading	MDC		Reading	MDC
2022-02-14	0.0000000	3.97E-04	2022-02-14	0.0025633	3.97E-04	2022-02-14	0.0001745	3.97E-04
2022-02-22	0.0000980	4.04E-04	2022-02-22	0.0005263	4.04E-04	2022-02-22	0	4.04E-04
2022-02-28	0.0016551	4.00E-04	2022-02-28	0.0019698	4.00E-04	2022-02-28	0.0000343	4.00E-04
2022-03-07	0.0000000	4.04E-04	2022-03-07	0.0007173	4.04E-04	2022-03-07	0.0000505	4.04E-04
2022-03-14	0.0000000	4.02E-04	2022-03-14	0.0023230	4.02E-04	2022-03-14	0.0000000	4.02E-04
2022-03-21	0.0000000	4.00E-04	2022-03-21	0.0006153	4.00E-04	2022-03-21	0.0000000	4.00E-04
2022-03-28	0.0012970	4.02E-04	2022-03-28	0.0018810	4.02E-04	2022-03-28	0.0000000	4.02E-04
2022-04-04	0.0000000	4.02E-04	2022-04-04	0.0004606	4.02E-04	2022-04-04	0.0001764	4.02E-04
2022-04-11	0.0016252	4.01E-04	2022-04-11	0.0003809	4.01E-04	2022-04-11	0.0000000	4.01E-04
2022-04-19	0.0000000	4.00E-04	2022-04-19	0.0004740	4.00E-04	2022-04-19	0.0001285	4.00E-04
2022-04-25	0.0000000	4.02E-04	2022-04-25	0.0002396	4.02E-04	2022-04-25	0.0000502	4.02E-04
2022-05-02	0.0000000	4.04E-04	2022-05-02	0.0005903	4.04E-04	2022-05-02	0.0001299	4.04E-04
2022-05-09	0.0015638	4.01E-04	2022-05-09	0.0002236	4.01E-04	2022-05-09	0.0000186	4.01E-04
2022-05-16	0.0000000	4.02E-04	2022-05-16	0.0009191	4.02E-04	2022-05-16	0.0002398	4.02E-04
2022-05-24	0.0000813	3.99E-04	2022-05-24	0.0004892	3.99E-04	2022-05-24	0	3.99E-04
2022-05-30	0.0000000	3.99E-04	2022-05-30	0.0002068	3.99E-04	2022-05-30	0	3.99E-04
2022-06-06	0.0001331	4.14E-04	2022-06-06	0.0002469	4.14E-04	2022-06-06	0.0000517	4.14E-04
2022-06-13	0.0000000	4.02E-04	2022-06-13	0.0000028	4.02E-04	2022-06-13	0.0000000	4.02E-04
2022-06-20	0.0000000	4.01E-04	2022-06-20	0.0003814	4.01E-04	2022-06-20	0.0000817	4.01E-04
2022-07-04	0.0002554	4.02E-04	2022-07-04	0.0003343	4.02E-04	2022-07-04	0.0000000	4.02E-04
2022-07-11	0.0000344	4.02E-04	2022-07-11	0.0005236	4.02E-04	2022-07-11	0.0000976	4.02E-04
2022-07-18	0.0000000	4.02E-04	2022-07-18	0.0003816	4.02E-04	2022-07-18	0.0000000	4.02E-04
2022-07-25	0.0012182	4.02E-04	2022-07-25	0.0003500	4.02E-04	2022-07-25	0.0000000	4.02E-04
2022-08-01	0.0008394	4.02E-04	2022-08-01	0.0020546	4.02E-04	2022-08-01	0.0000000	4.02E-04
2022-08-15	0.0007920	4.02E-04	2022-08-15	0.0006184	4.02E-04	2022-08-15	0.0000000	4.02E-04
2022-08-22	0.0003027	4.02E-04	2022-08-22	0.0003658	4.02E-04	2022-08-22	0.0000186	4.02E-04
2022-08-29	0.0007446	4.02E-04	2022-08-29	0.0006658	4.02E-04	2022-08-29	0.0000000	4.02E-04
2022-09-06	0.0004103	4.71E-04	2022-09-06	0.0004823	4.69E-04	2022-09-06	0.0000213	4.60E-04
2022-09-12	0.0003027	4.02E-04	2022-09-12	0.0006367	4.03E-04	2022-09-12	0	4.09E-04
2022-09-19	0.0006658	4.02E-04	2022-09-19	0.0003198	4.03E-04	2022-09-19	0	4.10E-04
2022-09-26	0.0016916	0.000402	2022-09-26	0.0006208	0.000403	2022-09-26	0	0.00041
2022-10-03	0.0009182	0.000402	2022-10-03	0.0004132	0.000402	2022-10-03	0	0.000402
2022-10-11	0.0007446	0.000402	2022-10-11	0.0002554	0.000402	2022-10-11	0.0000660	0.000402
2022-10-17	0.0010761	0.000402	2022-10-17	0.0004448	0.000402	2022-10-17	0	0.000402
2022-10-25	0.0005868	0.000402	2022-10-25	0.0005552	0.000402	2022-10-25	0	0.000402
2022-10-31	0.0003089	0.000201	2022-10-31	0.0003875	0.000201	2022-10-31	0.0000881	0.000201
2022-11-07	0.0002396	0.000402	2022-11-07	0.0006026	0.000402	2022-11-07	0	0.000402
2022-11-14	0.0012024	0.000402	2022-11-14	0.0006658	0.000402	2022-11-14	0	0.000803
2022-11-21	0.0003480	0.000399	2022-11-21	0.0003794	0.000399	2022-11-21	0	0.000798

Table 2 continues on next page

Table 2 continued from previous page

LOCATION								
[D] Mills Library			**[E] NFAS – Station 10**			**[F] ABB**		
Date counted	**Bq/m³**		**Date counted**	**Bq/m³**		**Date counted**	**Bq/m³**	
2022-11-28	0.0021651	0.000402	2022-11-28	0.0011708	0.000402	2022-11-28	0	0.000803
2022-12-05	0.0006658	0.000402	2022-12-05	0.0005710	0.000402	2022-12-05	0.0000688	0.000803
2022-12-12	0.0031408	0.000399	2022-12-12	0.0028270	0.000399	2022-12-12	0.0051833	0.000798
2022-12-19	0.0034770	0.000352	2022-12-19	0.0031709	0.000352	2022-12-19	0.0050657	0.000357

End **of** Table 2

Average and maximum values in Table 2 (Bq/m³)

[D] Mills Library		**[E] NFAS – Station 10**		**[F] ABB**	
Average:	**0.0006378**	Average:	**0.0004697**	Average:	**0.0003665**
Maximum:	**0.0034770**	Maximum:	**0.0099983**	Maximum:	**0.0051833**

These average values include the measured values which are below Minimum Detectable Concentration.

Table 3: Numerical data for I-125 in Figure 20 of main report for past 5 years)

	LOCATION					
	[A] IAHS	[B] GSB	[C] NRB	[D] Mills Libr	[E] NFAS	[F] ABB
Count Date	Concentration (Bq/m^3)					
2018-01-22	0.0000000	0.002136417	0.011082393	0.000630918	0.000900689	Station not in service
2018-02-20	0.0000000	0.000735424	0.007168173	0	0.000434166	
2018-03-20	0.0000000	0	0.02120696	0.004754585	0	
2018-04-23	0.0001650	0.000451624	0.006392218	0.001215911	0	
2018-05-22	0.0000000	0.001780441	0.007002345	0.003409738	0.00169359	
2018-06-18	0.0002891	0.001161953	0.002591211	0	0.000212752	
2018-07-23	0.0007245	0.001496694	0.004993319	0.000386104	0.000984781	
2018-08-23	0.0007628	0.003835676	0.006124006	0.001972322	0.002538956	
2018-09-24	0.0000000	0.000217127	0.001771756	0	0	
2018-10-25	0.0000000	0.001590934	0.000893649	0	0.000664705	
2018-11-19	0.0000000	0	0	0	0	
2018-12-17	0.0000000	0.000588428	0	0	0	
2019-01-21	0.0001479	0.000200153	0.000165344	0	0.000382902	
2019-02-19	0.0000000	0	0	0	0	
2019-03-18	0.0000000	0	0.000446769	0	0	
2019-04-23	0.0008824	0	0	0	0	
2019-05-21	0.0000000	0	0	0	0	
2019-06-17	0.0014457	0	0.001293506	0	0	
2019-07-22	0.0022082	0	0	0.000712882	0.002147341	
2019-08-19	0.0019808	0.001806626	0.007618301	0.003308519	0	
2019-09-23	0.0000043	0.000116671	0.000116671	0	0	
2019-10-21	0.0000000	0.000684451	0.00506617	0	0	
2019-11-18	0.0000000	0	0	0	0	
2019-12-16	0.0000000	0	0	0.000964384	0	
2020-01-20	0.0000000	0	0.000635269	0	0	
2020-02-18	0.0006748	0	0	0.000467981	0	
2020-03-23	0.0121795	0.011606351	0.013791498	0.013084012	0	
2020-04-20	0.0000000	0.00036459	0	0	0	
2020-05-19	0.0000000	0	0.000336547	0.000314834	0	
2020-06-22	0.0014009	0.000554246	0.001819848	0.001784935	0	
2020-07-20	0.0000000	0	0.000675179	0	0	
2020-08-18	0.0005061	0	0.001997083	0.001311436	0	
2020-09-15	0.0000000	0.000779727	0.004212263	0	0	
2020-10-19	0.0026938	0	0.002782174	0.001841338	0	
2020-11-23	0.0030269	0	0.001199627	0.000330301	0	
2020-11-30	0.0000000	0	0	0	0	
2020-12-14	0.0000000	0	0	0	0	
2020-12-21	0.0001083	0	0	0.000638943	0	
2021-01-18	0.0008068	0.000427767	0	0	0	

Table 3 continues on next page

Table 3 continued from previous page

	LOCATION					
	[A] IAHS	[B] GSB	[C] NRB	[D] Mills Libr	[E] NFAS	[F] ABB
Count Date	Concentration (Bq/m^3)					
2021-02-22	0.0102543	0.002877472	0.001028914	0.00180496	0	
2021-03-22	0.0000000	0	0	0.000556567	0	
2021-04-26	0.0000000	0.001978743	0	0	0.007383302	0.008172333
2021-05-25	0.0006034	0	0.001338444	0.003843763	0	0.000867576
2021-06-21	0.0053064	0.006865547	0.008260539	0.002475426	0.004034535	0.006003934
2021-07-19	0.0009935	0	0.006666791	0.003213489	0	0.007242341
2021-08-03	0.0068402	0.002040618	0.006203478	0.006513652	0.005321931	0.002122242
2021-08-16	0.0000000	0	0.005404584	0	0	0.005390884
2021-10-25	0.0048012	0.005581562	0	0.002968916	0	0.013826879
2021-11-22	0.0011036	0	0.001685842	0.000616111	0.002444132	0
2021-12-20	0.0000000	0	0	0	0	0
2022-01-26	0.0012113	0	0.002085227	0.000735637	3.87177E-05	0.001233437
2022-02-28	0.0027349	0.001196983	0	0.001791847	0.005172416	0.003576439
2022-03-28	0.0000000	0	0.001325917	0	0.000340536	0.000253591
2022-04-25	0.0000000	0	0.000824959	0.000318405	0	0.000274986
2022-05-24	0.0002247	0	0.000314633	0	0	0
2022-06-20	0.0004576	0	0.002665023	0.002745781	0	0.003432227
2022-07-18	0.0000000	0	0	0	0	0
2022-08-15	0.0000000	0.003313503	0.003580721	0.004475902	0.001830443	0.001149037
2022-09-19	0.0000000	0	0	0	0	0
2022-09-19	0.0000000	0	0	0	0	0
2022-11-07	0.0000000	0	0.001645642	0	0	0
2022-11-21	0.0000000	0	0	0	0.000337717	0
2022-12-19	0.0024430	0.000236854	0.002158754	0	0.001170735	0

End of Table 3