Study of Tritium in Groundwater in the Vicinity of the SRB Pembroke Facility

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1.0 INTRODUCTION

This document fully describes an independent study of the influence of a tritium lamp manufacturing facility in Pembroke, Ontario, on local groundwater resources. The Facility is operated by SRB Technologies (Canada) Inc., hereafter referred to simply as “SRB”. The groundwater study was completed by EcoMetrix Incorporated (EcoMetrix) at the request of SRB in order to fulfill specific requirements of the operating license (NSPFOL-13.00/2006) issued by CNSC in December 2005.

1.1 Background

SRB operates a tritium lamp factory (the “facility”) at Pembroke, Ontario. Tritium is imported to the facility for the production of various instruments that rely on tritium in sealed glass for their function. During the routine handling of imported tritium and the manufacture of instruments, best practices are employed to manage the tritium inventory and prevent tritium loss. Some losses are unavoidable, and releases of tritium (HT and HTO) to atmosphere do occur as a result of routine operational procedures. This necessitates efforts to quantify the exposure of members of the public to these radionuclides, and also to quantify the radiation dose received as a result of this exposure. Accordingly, SRB has established an environmental monitoring program (EMP) to annually measure levels of tritium in environmental media (air, plant products, animal products) in the vicinity of the facility. Radiation doses to members of the public are also regularly determined, and derived release limits (DRLs) have been established as required by the Canadian Nuclear Safety Commission (CNSC).

The SRB facility is not designed to collect, treat or discharge any liquid sources of tritium that could contribute to on-site contamination of groundwater, and thus to date the EMP has not focused on groundwater as an environmental media to be assessed. Equally, the DRL that is currently recognized in the facility license (Canatom, 1996) has assumed that public exposure to tritium in groundwater is not significant. At present, there are no known instances of nearby residential wells serving as a primary source of household water, and therefore dose through exposure to water (primarily drinking and bathing) has not been considered to contribute significantly to the total tritium dose. However, a complete site survey has not yet been completed, and there may be residences in the area surrounding SRB that derive some significant portion of the household water supply from an on-site well. Further, the SRB facility is near the current outer extent of development of Pembroke, and adjacent lands (currently undeveloped) could be subject to future residential development. Municipal Official Plans call for a centralized water supply to all new developments, so it is not expected that many new residential wells will be established in these areas. However, it is not completely out of the realm of possibility that residential wells might be established in newly developed areas in relatively close proximity to the SRB facility.

In a recent communication from the CNSC to SRB (CNSC, 2005), concerns were raised regarding the presence of tritium in groundwater near the Facility. Recent tests of groundwater samples taken from nearby residential wells were noted by the CNSC to reveal groundwater concentrations of tritium as high as 2,750 Bq/L. While this maximum local concentration is well below the provincial and federal standard of 7,000 Bq/L, it is indicative of a localized influence of SRB operations on tritium groundwater concentrations. Standing water has also been irregularly sampled on the SRB premises in recent years, and the CNSC noted that tritium concentrations as high as 279,000 Bq/L have been recorded. Also, concentrations of tritium in precipitation as high as 51,120 Bq/L have been reported at SRB. While these measures could be reflective solely of tritium releases to atmosphere, they could also be indicative of point source loadings of tritium in liquid form and subsequent infiltration of loadings to groundwater.

In light of the findings regarding potential tritium sources and the occurrence of acceptable but elevated levels of tritium in local wells, and the potential for the existence of wells not as of yet considered, SRB initiated this assessment of the effects of tritium releases from the facility on local groundwater. The scope and intent of the study is consistent with an Order placed by the CNSC in November, 2005, on the previous operating license NSPFOL-13.00/2005. That order (see Appendix A) was subsequently rescinded and the requirement for a groundwater became a condition of the current operating license NSPFOL-13.00/2006.

1.2 Current Objectives

The objective of this current effort, conducted by EcoMetrix Inc. on behalf of SRB, is to provide an understanding of three key issues:

1. the nature and magnitude of potential sources of release of tritium from SRB that could affect groundwater;
2. the current levels of tritium activity in groundwater, and the spatial variability thereof; and
3. the implications of tritium release and delivery to groundwater in terms of human exposure and dose, and environmental impact.

1.3 Scope of Work

The main tasks completed to meet the stated objectives are as follow:

1. Initial review of documentation and data compiled to date of relevance to the potential influence of the SRB Pembroke Facility on local groundwater resources.
2. Site reconnaissance to identify potential source of tritium release to groundwater
3. Field-level investigation of monitoring wells and residential wells, primarily focussed on sampling and analysis of groundwater for tritium.
4. Test application of the recently revised DRL model (EcoMetrix, 2006) to verify the validity of suitability of the conceptual model for assessing human exposure to tritium in groundwater, and to assess the groundwater-related public exposure to tritium.

2.0 METHODOLOGY

The major components of the groundwater study have been conducted entirely in accordance with the Terms of Reference (TOR) developed in advance of the study (EcoMetrix, 2006). A copy of the final TOR, revised to reflect comments provided by the CNSC following their review of an initial draft of the TOR, is included in Appendix A of this report.

To meet the stated objectives, the following major components were included in the study:

- an initial review of all potential sources and receptors;
- a field-level assessment (groundwater sampling and analysis, investigation of site characteristics); and
- a quantitative assessment of the distribution and impacts of tritium in groundwater.

The specific work tasks to be completed in each of these study components are discussed in the following sections.

2.1 Initial Review

2.1.1 Existing Data and Documents

The first effort at the onset of the study was an initial review of SRB Facility operations (past and current) to identify and characterize all possible releases of tritium that could enter into groundwater. Relevant information from SRB, the CNSC, and other sources was obtained for review purposes. The majority of the data pertaining to measures of tritium in precipitation, surface water, soil and groundwater are provided in Appendix C of this report.

In general, the initial review served to identify and characterize:

- sources of tritium to groundwater;
- locations of potential public exposure to groundwater in the vicinity of the SRB Facility; and
- existing points of access for direct assessment of the current distribution of tritium in groundwater.

In the identification of sources, all facility processes and releases (past and present) were considered, including any unmonitored fugitive emissions and one-time events that might contribute to the total loading of tritium to groundwater.

To identify potential future wells, municipal zoning was consulted to identify locations in close proximity to the Facility that could be developed in the near future.

Regional and local hydrogeological conditions were also delineated in the initial review, primarily through review of regional surveys (e.g. Gillespie at al., 1964 and Golder, 2003). This hydrogeological information was further developed at a local level during the field-level reconnaissance.

Characterization of groundwater in the area of the Facility has also been undertaken in the past at other industrial/commercial properties in the vicinity of SRB. Documentation related to these efforts (e.g. INTERA, 1994, and GeoCor, 1997) was reviewed to assist in the characterization of groundwater.

2.1.2 Site Reconnaissance

An understanding of SRB Facility characteristics and local ambient conditions of relevance to the groundwater study was developed in part through a site reconnaissance, conducted by EcoMetrix staff on 28 December 2005. The reconnaissance included a complete tour of the facility and a detailed examination of all processes involving the use and handling of tritium. A key focus of the reconnaissance was to identify any possible pathways of release of tritium to groundwater at the facility. Atmospheric releases are well-characterized and the focus of the reconnaissance was to identify any potential direct releases of tritium in liquid form to the surrounding environment.

The area surrounding the facility was also surveyed to gain a first-hand understanding of the overall scenario in which exposure to tritium emissions from the facility might occur. During this survey, the presence of existing monitoring wells on inactive rail lands to the east of SRB was discovered.

2.2 Field Investigations

Field work was conducted in two phases, following the completion of the initial review. The first phase of field work for the Groundwater Study occurred during the week of 09 to 14 January 2006. The specific efforts undertaken during this period were:

- A field level assessment of monitoring wells previously installed within 300 m of the SRB facility on inactive rail lands to the east side of Boundary Rd. This included an assessment of well integrity, and measures of total well depth, water level, and recovery of each of the 5 wells found on this property.
- Installation of a total of 7 new monitoring wells at 6 locations within 1 km of the SRB facility. During or immediately following installation, major characteristics were recorded, including the composition of overburden, water table depth, and recovery rate.
- Groundwater sample collection from a total of 15 monitoring wells, including 6 of the 7 newly installed monitoring wells and each of the 5 monitoring wells on the property to the east. Well water samples were also collected from 4 of the 6 residential wells that are part of SRBs ongoing environmental monitoring program (EMP). These

samples were collected concurrently to samples that were collected by AECL for independent analysis.

- Collection of depth-integrated snow samples at the locations of the newly installed monitoring wells, and also at the location of the 5 existing monitoring wells on the inactive rail lands on the east side of boundary road.
- Reconnaissance of residential wells in key locations near SRB, as identified in MOE well records obtained for the area.

The second phase of the field investigation occurred during the week of February 20 to 24, 2006. This phase included re-sampling of all wells sampled in the first phase of field work. Samples were also collected from the one new monitoring well (MW4d) and two EMP residential wells not sampled in January. As in January, residential well water samples were collected in tandem with AECL. Sampling of the snow-pack was also re-repeated in the second phase of the field program. Surface water samples were also collected for tritium analysis from the Muskrat and Indian Rivers, under conditions of relatively high contribution of baseflow (low runoff). The second phase of field work also included reconnaissance of potential residential wells for possible sampling, as identified in the Ministry of Environment (MOE) well records.

The following sections describe the specific methods followed in the implementation of the field program. All field activities included in the field program were conducted in accordance with the terms of reference (Appendix A). The primary exception was that blind duplicate samples were not collected for submission to individual labs. This departure from protocol occurred owing to the fact that full parallel sets of samples (monitoring and residential well water, precipitation) were collected and submitted to independent labs (AECL and OPG).

2.2.1 Well Installation

Citing Rationale

The determination of well-sampling requirements was based on a detailed *a priori* understanding of the potential influence of the SRB facility on local groundwater. This understanding was based in part on the site reconnaissance conducted 28 December 2005.

The initial understanding was also based on a review of a number of documents and datasets that provided information on the hydrogeological characteristics of the area and also levels of tritium in various media (rainwater, well water, surface water, and air). The tritium data could provide quantitative estimates of potential loads to groundwater.

The field investigation included the drilling of seven boreholes between January 11 and 13, 2006. The locations of the boreholes are shown in Figure 2.1, and were selected based on several factors, including:

- Location relative to the expected direction of groundwater flow (i.e., towards the N-NE from the SRB facility).
- Location relative to the prevailing wind direction. The highest frequency wind sectors (direction from) are approximately W-NW and ESE-SE, more or less corresponding with the direction of Boundary Road. Low Frequency wind sectors include W-SW and E-NE.
- Distance from the SRB facility.
- Relative positioning of wells in very close proximity to the facility, to allow site-specific determination of hydraulic gradient.
- Position relative to the Muskrat River, which is the main surface water body down-gradient of SRB.
- Association with air monitoring stations, to allow development of a relationship between air quality and groundwater quality.
- The presence and distribution of *existing* wells, in context of all factors above.

An initial review of facility operations and known discharges, including a site reconnaissance conducted in December, 2005, did not reveal any evidence of significant point sources of tritium in liquid form associated with the SRB Facility. Nonetheless, the determination of monitoring well locations considered the possibility of the presence of a lateral groundwater plume, and several wells (new and existing) were situated in locations hydraulically down-gradient of the SRB Facility.

In addition to the seven monitoring wells installed as part of this investigation, five previously installed monitoring wells located down-gradient of the SRB facility were identified, and included in the sampling program. These wells, labeled as CN-1S, CN-1D, CN-2, CN-3S and CN-3D, are located on inactive rail lands currently owned by Ottawa Central Railway on the east side of Boundary Road (Figure 2.1). No information could be obtained regarding the installation or description of these wells. However, the well depth and relative elevation were measured as part of this investigation. At the time of the investigation, the wells did not contain well caps, and due to the amount of snow surrounding the wells, visual examination of the integrity of the interface of the well casing with the ground could not be conducted to identify any potential surface water leakage into the well. The CN wells were fitted with slip caps and dedicated Waterra™ foot valves and LDPE tubing as part of this investigation.

Borehole Drilling and Monitoring Well Installation

Borehole drilling was completed by Geo-Logic Inc. of Pembroke, ON, and their sub-contracted drillers (George Downing Estate Drilling Ltd. of Grenville-Sur-La-Rouge, QC), under the technical supervision of EcoMetrix using a track-mounted CME drill rig and standard hollow stem auger drilling techniques. Boreholes excavations were completed to total depths ranging from 4.6 to 12.2 metres below ground surface (mbgs). Each auger was 1.52 m in length, 10.8 cm inside diameter (ID) and 21 cm outside diameter (OD).

At the completion of drilling, augers and drill rig treads were subject to swipe tests to determine levels of adherent tritium and to prevent possible off-site transport. Swipe tests revealed very low levels of residual tritium; i.e., 0.23 and 0.13 Bq/cm^2 (averaged over 100 cm^2) for the drill rig treads and augers, respectively.

During borehole excavation, soil samples were collected by hammering a split-spoon sampling device (0.61 m long, 3.8 cm ID) into the formation. Samples were collected immediately after split spoon retrieval from the borehole and placed in 250 mL amber glass jars with Teflon lids for potential future analysis. The remainder of the soil in the split spoon was used to evaluate the soil profile of the borehole. Copies of the field borehole logs are provided in Appendix B.

Groundwater monitoring wells were installed within each borehole. Two boreholes were completed at MW06-4 to allow for installation of both shallow (6.1 mbgs) and deep (12.2 mbgs) groundwater monitoring wells at this location. All wells were constructed from schedule 40, polyvinyl chloride (PVC), flush-threaded casing. The inner diameter of the casing was sufficiently large (5.1 cm) to permit the entry of water level measuring and water sampling devices. The appropriate number of risers were coupled with screen sections via threaded joints to construct the well. The well screens consisted of 1.5 m sections of PVC pipe with 0.010-inch factory-generated slots. No PVC cements or other solvents were used in the construction of the wells. The bottoms of the screens were plugged with appropriately sized screw-in end caps. During well installation the tops of the wells were covered with slip-fit caps to prevent the entry of foreign materials. The characteristics of the newly installed monitoring wells and the wells on the CN property are summarized in Table 2.1

A primary filter pack consisting of #3 Silica Sand was placed around the well screen in the boring and extended above the top of the well screen. Hole Plug, a swelling clay that forms an effective barrier to the vertical movement of fluids when installed in a boring, was used as a seal above the filter pack. Hole Plug was also used to create surface seals for all the wells. Each well was fitted with an above-grade 0.3 m diameter lockable protective casing that extends a minimum of 1 m into the ground. The protective casings were secured into the ground with Hole Plug.

The elevations of the tops of the well casings and the ground surface adjacent to the well were surveyed relative to a geodetic datum by Adam Kasprzak Surveying Ltd. of Pembroke, ON.

Each monitoring well was outfitted with dedicated Waterra™ foot valve attached to a length of 5/8-inch OD, low-density polyethylene (LDPE) tubing. Oscillation of the tubing, together with the action of the foot valve, forces water to the ground surface.

All drill cuttings were placed in 45-gallon drums and are currently under controlled storage at the SRB Facility. These cuttings will be disposed of in accordance with applicable regulatory requirements, pending CNSC approval. The analysis of soil samples collected during well installation provides surrogate characterization of the drill cuttings with respect to tritium content. The results of analysis of the soil (representative of drill cuttings) conducted by OPG are presented in Appendix C, and discussed in Section 3.3.4. In brief, the maximum tritium content of soil samples was ~50,000 Bq/L, so the tritium content of collected drill cuttings is not expected to exceed this level in any drum.

Well Development and Recovery Testing

All monitoring wells were developed prior to collection of groundwater samples. The wells were developed to: (1) remove fine soil particles adjacent to the well screen that may otherwise interfere with water quality analyses; (2) restore the groundwater properties disturbed during the drilling process; and (3) improve the hydraulic communication between the well and the geologic materials.

The volume of water contained in each well casing (the casing volume) was calculated using the diameter and total depth of the well, and the water level measured in the well. Wells were developed by removing a minimum of three times the volume of water contained in the well casing (casing volume) using the dedicated Waterra™ sampling devices. At the time of well development and January sampling, monitoring wells MW06-4D and MW06-5 contained insufficient volumes of water to use the Waterra™ sampling device. These wells were developed using disposable Waterra™ bailers.

After well development, recovery tests were completed on most of the newly installed wells. The results of the recovery tests are presented in Appendix B and provide information regarding the hydraulic conductivity of the soils surrounding the well. The test method consisted of complete initial purging of the well and subsequent monitoring the rise in the water level in the well over time. All water removed from the wells during recovery testing was placed in 45-gallon drums and is currently stored at SRB. Recent analysis of tritium levels in purge water revealed average activity levels ranging from 3,810 Bq/L to 18,465 Bq/L (see Appendix C for details of analysis). The purge water will be disposed of in accordance with applicable regulatory requirements. Purge water may be composed in part of surface water, and may also contain suspended solids, and is not considered to wholly representative of groundwater conditions. The reported levels of tritium serve primarily to guide management and disposal of the wastes generated during the study.

2.2.3 Sample Collection

Monitoring Well Sampling

Prior to collecting groundwater samples for chemical analysis, the depth-to-water (water level) in monitoring wells was measured using a battery-operated signal water level tape. The stagnant water in the well was then evacuated to allow groundwater representative of the aquifer to enter the well. A minimum of three casing volumes of water was removed ("purged") from each well prior to sampling.

The monitoring wells were sampled for tritium on 12 January and 24 February, 2006 and submitted to Ontario Power Generation (OPG) for analysis. Samples were also collected by SRB and Atomic Energy of Canada Limited (AECL) during the February sampling session. Well MW06-4S was also sampled for dissolved metals and tracer parameters (e.g. chloride, nitrates). These samples were submitted to Enviro-Test Laboratories (ETL) in Waterloo, ON. ETL is accredited with the Canadian Association of Environmental Analytical Laboratories (CAEAL).

Groundwater samples were collected by direct transfer of groundwater from the Waterra™ pumping system to appropriate containers after the well had been purged. Due to the lack of water in MW06-5, a bailer was used to collect a groundwater sample from this well during the January sampling event. Insufficient water was present in MW06-4D to allow for a groundwater sample in January from this well. Sufficient water was present both the MW06-4D and MW06-5 during the February sampling, and dedicated Waterra™ sampling devices were used for the February sampling event. Sample bottles were supplied by the laboratory and were not stored at the SRB facility at any time. Care was taken to ensure that no headspace remained in the sample containers used for tritium analysis.

Residential Well Sampling

As part the initial phase of SRB's updated environmental monitoring program (EMP), six residential wells have been sampled and analysed for tritium by AECL. For the specific purposes of this study, samples were collected monthly by AECL. Following this study, the residential well-water sampling component of the EMP will be conducted on an annual basis, as per recommendations of this study (see Section 4.4).

The residential wells that have so far been included in the EMP and this current study, and their general characteristics, are summarized in Table 2.2. Their locations are depicted in Figure 2.2. As part of this investigation, EcoMetrix collected well water samples from 4 of the 6 residential wells on 12 January 2006 for tritium and dissolved metals and 24 February 2006 for tritium only. On both sampling days, occupants of the residences at RW-2 and RW-7 were not at home, and therefore samples could not be collected. Well RW-6, located at 40987 Hwy 41, was added to the list of residential wells for sampling on 24 February, 2006. This well is located only a few hundred meters north of well RW-7.

The samples were collected concurrently to samples that were collected by AECL for independent analysis. Samples were collected from the kitchen taps after allowing the water to run for approximately 1 minute, to ensure that fresh groundwater was collected from the well. Tritium analyses of samples collected by EcoMetrix were completed by Ontario Power Generation (OPG). Samples collected for dissolved metals analyses were field filtered (0.45 micron) and acidified (HNO_3) and submitted to Enviro-Test Laboratories (ETL) in Waterloo, ON. Samples for anion analysis were neither filtered nor preserved.

Precipitation Samples

To evaluate the effects of atmospheric deposition of tritium to groundwater, depth-integrated samples of the snow pack were collected at select locations on 12 January and 24 February 2006 and submitted to OPG for tritium analysis. Depth-integrated snow samples were also collected at the same locations by AECL during the February sampling campaign. Samples were collected at the following locations:

- Midway between MW06-1 and MW06-2
- Adjacent to MW06-3, MW06-4, MW06-5, and MW06-7
- Between CN-1, CN-2 and CN-3 (January only)
- Adjacent to CN-1, CN-2 and CN-3 (February only)
- Adjacent to the SRB emission stacks (February only), and
- Adjacent to the Precipitation Monitor located 500m North of SRB (February only).

Samples were collected in areas that had not been disturbed by drilling or walking/sampling.

Surface Water Sampling

Samples of surface water were collected on 23 February 2006 at selected locations along the Muskrat and Indian Rivers as shown in Figure 2.3. Samples were collected as grab samples (~0.2 m below surface) at the following locations, and submitted to OPG for tritium analysis:

- Muskrat River at Mud Lake Road (labeled as SW Stn B)
- Muskrat River at Bennett Street (labeled as SW Stn C)
- Muskrat River at Pansy Patch Park (labeled as SW Stn D)
- Indian River at Boundary Road (labeled as SW Stn E)

The rationale for these locations was to allow collection of representative surface water samples at the approximate point of discharge of a potential groundwater plume originating from SRB, and also upstream and downstream of that point.

2.2.3 Sample Analysis

All liquid samples were submitted to respective laboratories for analysis of tritium by liquid scintillation counting (LSC). LSC was conducted in replication and with reference matrices, all in accordance with lab-specific protocol. The specifics of methods and QA/QC procedures are identified in the analytical reports presented in Appendix C.

3.0 RESULTS

3.1 General Site Characterization

3.1.1 Facility Characterization

Facility

In 1997, a phase 1 Environmental Site Investigation of 320 Boundary Road was completed, examining the potential environmental liabilities associated with the property. The associated report (GeoCor, 1997) provides a basic understanding of the facility history along with some construction details.

The building which currently houses SRB's operations is situated on Parts of lots 28 and 29 of Concession 1. It was constructed in 1990 with a slab-on-grade floor, with no floor drains in the controlled Zones 2 or 3 of the facility, where significant levels of tritium could be encountered. A floor plan of the SRB facility is provided in Appendix B. During the site reconnaissance completed in December 2005, this floor was in very good shape, and there were no cracks observed in Zones 2 or 3.

As noted in the Introduction, some environmental releases of tritium do occur as part of normal Facility operations at SRBT. The primary route of release of tritium from the SRB Facility is to atmosphere via two exhaust stacks. The Facility does not generate operational liquid effluents. Minor and intermittent releases to the environment are also associated with facility maintenance. This includes ongoing clean-up of residual tritium in Zones 2 and 3. Clean-up practices involve wipe down and mopping of floors and walls with clean water, and subsequent collection of clean-up water for regulated disposal via the municipal sewer system. Other maintenance-related waste streams (e.g. pump-fluids, broken glass vessels) are handled as controlled wastes and they are appropriately handled and disposed at AECL's Chalk River facility.

The amount of tritium associated with routine facility cleaning and other maintenance-related releases is small relative to the atmospheric release. An inventory of tritium releases compiled by the CNSC (2002) showed that virtually all (>99.9%) of the tritium released from SRB was to atmosphere (see Table C1 in Appendix C).

Surrounding Area

The current zoning of the SRB facility is M3 (Industrial Park Zone), as designated under municipal By-law 88-17. This zoning permits a variety of light industrial uses, but excludes residential use. The closest area under residential zoning is Johnson's Meadows, which was developed in 1970s. At the closest point, this residential area is ~250 m from SRB (measuring from the location of the stacks). The centre of this development is situated more-or-less WNW of SRB, thus lying within a high frequency wind sector. However, this development is fully service by the municipality's central water supply.

A narrow band of land along Boundary Road, approximately SE of SRB, is also zoned as residential. This area is also within a compass sector with a relatively high frequency of winds coming from the direction of SRB (see Table B1 in Appendix B for a summary of sector specific wind frequencies). The closest lot in this strip is >500m from the SRB stacks. To the west of SRB lies the as-of-yet undeveloped lands of the TransCanada Corporate Park, located within an area zoned for Industrial Use.

The main portion of the City of Pembroke lies within the NW to NE compass sectors relative to SRB. For the most part, these are relatively low wind frequency sectors (see Table B1 and Figure 4.1). The closest lot is to the NNE of SRB, just over 600 m from the stacks.

Other than the noted residential zones, the majority of lands adjacent to the SRB Facility within 1 km are zoned Industrial.

3.1.2 General Geology

In advance of field activities, regional and local geological conditions were defined, primarily from existing documentation (e.g. Gillespie at al., 1964, Golder, 2006). This hydrogeological information was further developed at a local scale during the field-level reconnaissance, and ultimately serves in understanding and potential modeling of the groundwater transport of tritium loads from significant sources. Information of relevance includes aquifer characteristics, water table elevations, hydraulic gradients, and various characteristics of the pore-water and groundwater media (overburden and bedrock), such as porosity and hydraulic conductivity.

The study area, including the City of Pembroke and the Township of Laurentian Valley, is located on the oldest part of the Canadian Shield, in the Central Meta-Sedimentary Belt Boundary and the Central Gneiss Belt of (tectonic) Grenville Province. The dominant crust is the “Algonquin Terrane”, and the most common deposit is the Opeongo domain. The Ottawa Valley Clay Plain and the Petawawa Sand Plain are the physiographic regions present.

The City and Township encompass a wide representation of Paleozoic geology, and Precambrian rocks dominate as they are present throughout the township and at the west and southwest perimeter of the city. Other Paleozoic formations also exist. The Rockcliffe Formation runs along the Muskrat River and into the Ottawa River. It is also found in association with the Gull River and Bobcaygeon Formations east of the Muskrat River and on Morrison Island. The Gull River and Bobcaygeon Formations are also found at the east end of Beckett Island and run eastwards north of Cotnam Island. The Oxford Formation is found only just south of Beckett Island (MNDM, 1988). Within the study area, Paleozoic rock formations are Precambrian, undifferentiated metamorphose and igneous rocks. Starting at the north east corner of Boundary Road and Paul Martin Drive and continuing northwards the Oxford Formation is present.

The soils of the area have been well characterized in the Ontario Soil Survey (Gillespie at al., 1964). Figure B1 (Appendix B) depicts the soil survey map for the Pembroke area. The soils in the study area are generally clay silt, silty clay, and clayey silt mixtures. Pockets of sandy to silt, stony subglacial till are present just south of the site. For the most part, the soils are characterized by relatively poor drainage.

A 1982 subsurface investigation for the development of the industrial park immediately west of the SRB facility (Terraspec, 1983) reported overburden stratigraphy as follows:

- Site topsoil is underlain primarily by stratified brown-brown/grey clayey silt, except in the northeast (near SRB) where silty clay is encountered.
- A number of thin seams of fine sand were present in the clayey silt, which was variable in consistency, characterized as soft to hard.
- The silty clay was described as firm to very stiff, and also contained a number of thin sand seams.
- Below the silty clay or clayey silt layers is a layer of grey silty clay identified as Leda clay, common to the Ottawa valley. This layer is about 4-5 m thick, and was characterized as firm to stiff.
- Below the Leda clay is a layer of very dense silty sand till.
- Bedrock was inferred at a depth of 13.7 mbgs. The upper layer of bedrock exhibited an apparent fractured nature.

A site specific investigation of a nearby property was conducted by INTERA (1994). The associated report documents the findings of an environmental investigation conducted subsequent to removal of an underground storage tank and clean-up of soils in the immediate vicinity of the tank. The site in question is located on Boundary Road, immediately adjacent to SRB to the NW. In support of the site investigation, a general site reconnaissance was completed and conditions were recorded during excavation activities. The stratigraphy of overburden was as follows:

- 0 - 0.30 m bgs – gravel fill (not native), underlying asphalt.
- 0.3 to 1.6 m bgs – silty sand and grey, silty, fractured clay.
- 1.6 to 5.5 m bgs – transition to a dense fractured clay.
- >5.5 m bgs – a very dense plastic brown clay.

Overall, the existing documentation suggests that there is a relatively thick overburden layer in the area, dominated primarily by clay and silt with some sand seams. Some fracturing has been reported in clay layers.

3.1.3 General Hydrogeology

In 2003 a groundwater study was completed for the Mississippi Valley Conservation Authority for Renfrew County (Golder, 2003). This study encompasses both the City of Pembroke and adjacent townships. The following general conclusions are drawn from this study:

- Pembroke is entirely within the Ottawa Valley Clay Plain physiographic region.
- Regionally, shallow (<15 mbgs) and deep (>30 mbgs) groundwater flows from the Madawaska Highlands towards the Ottawa River valley (i.e., from the southwest to the northeast).
- Local groundwater flow direction can vary significantly from regional flow direction, reflecting local topography and the presence of bodies of surface water (lakes, rivers).
- In terms of recharge, the area around SRB is indicated as being transitional (i.e. not predominantly discharge nor recharge). Being close to both the Muskrat and Ottawa Rivers, the area in general has a discharge function.
- Typical recharge rates for the region are 150 to 400 mm per annum, but in the area of Pembroke recharge rates are very low (i.e. 0 to 100 mm per annum).
- Overburden in the area is comprised primarily of Champlain Sea deposits (marine offshore clay-silt).
- Typical overburden thickness in the area around Pembroke is 20 to 30 m, with a relatively thin layer of sand and gravel (2 to 4 m thick) generally found immediately above bedrock.
- Hydraulic conductivity is reported as approximately 10^{-5} m/s for basal sand and gravel, and in the range of 10^{-10} to 10^{-6} m/s for clay/till overburden.
- Bedrock elevation in the Pembroke area ranges from 100 to 150 meters above sea levels (masl) which is low for the region.
- The shallow water table is indicated as being in the order of about 125 masl in the Pembroke area, while the deep water table is around 100 masl.
- Significant overburden aquifers are present in the Pembroke area.
- In the Ottawa River valley, depressions in bedrock are typically filled with clay which functions as an aquitard, creating a poor connection between overburden aquifers and groundwater aquifers.
- The Renfrew Groundwater (Golder, 2003) study reports that majority of wells in close proximity to Pembroke are screened into limestone or Precambrian bedrock (granite), as is also indicated by the MOE Well Records for the area within 5 km of SRB.

- Bedrock of sedimentary origin, such as the Rockcliff formation along the Muskrat River, is characterized by both vertical and horizontal fractures.

The site-specific study (INTERA, 1994) at the commercial property immediately adjacent to SRB, generated the following conclusions regarding groundwater:

- There is no known on-site or adjacent off-site groundwater use.
- The site is not connected to an aquifer or sensitive surface water receptor via a natural or man-made conduit.
- The direction of groundwater flow is generally to the east, towards the Muskrat River.
- The highest annual water-table is likely at or above the bottom of basements, with the mean water table depth reported as ~ 4.5 mbgs
- Overburden is composed of primarily of silty-clay to a depth of about 5.5 mbgs, where a layer of dense and plastic brown clay is encountered.
- Hydraulic conductivity of sub-surface materials is likely less than 10^{-6} m/s.

In this 1994 study, liquid phase hydrocarbons were observed in the fracture planes of the silty clay and clay units, indicating the potential for fracture flow to occur in the area.

The 1983 study of the area proposed for development of the Pembroke Industrial Park (Terraspec, 1983), immediately to the west of SRB, included the installation of a piezometer into the fractured bedrock. During the study, the piezometer remained dry, suggesting that this layer of bedrock was hydraulically isolated from overburden, as might be expected given the presence of overlying layers of dense clay.

Overall, the regional and local information that has been reviewed indicates that overburden hydraulic conductivity is relatively low in the area surrounding SRB, and that there is likely a poor connection between the overburden and the bedrock aquifers. Groundwater flow is towards the Muskrat River.

3.2 Characterization through Field Investigation

3.2.1 Local Geology

The local overburden conditions observed at the site during drilling were consistent with conditions ascertained from the existing local and regional documentation. Overburden typically included a thin layer of topsoil at surface underlain by silty sand fill to depths between 0.8 and 2.9 mbgs. The native material typically consisted of grey silty clay that was generally compact above the water table, becoming loose below the water table. The soil conditions at BH-5 (see Appendix B) consisted mainly of a silty-sand till fill with pebbles to approximately 6 mbgs. Sand seams were noted in BH-3, BH-4 and BH-5 at approximate depths of 2.9, 4.4 and 4.6 mbgs, respectively. In BH-4, the sand seams were noted to extend to an approximate depth of 6.7 mbgs. The sand seams can represent an increase in hydraulic conductivity within the silty clay over the particular depth range, creating preferential flow pathways for groundwater. Auger refusal was reached in BH-3 at approximately 5.3 mbgs. It is not known if the refusal was due to bedrock. Although bedrock was not reached in BH-4D which extended to over 12 m in depth, the depth to bedrock is quite variable in the Pembroke area, as evidenced by the presence of outcrops exist short distances away from the SRB site. Copies of the borehole logs for all of the newly installed wells are provided in Appendix B.

3.2.2 Local Hydrology

The groundwater levels were measured in the newly installed monitoring wells as well as the existing wells north of the SRB site on a regular basis between 10 January and 23 February 2006. The water level data is presented as a time series for the individual wells in Figure 3.1. All water level monitoring data are provided in Appendix B (see Table B2 for summary). Figure 3.1 shows that the water levels in most of the newly installed wells appeared to reach equilibrium within a few hours after well installation. However, MW06-4D and MW06-5 both required several days to reach equilibrium. In general, the water levels are constant over the monitoring period, with the exception of MW06-4D, which may still not have reached equilibrium, and the deep and shallow wells at CN-1. The CN wells show an increase in water elevation over the first few days before decreasing over the remaining monitoring time. It is not known why these wells show fluctuation, however the wells may be influenced by surface water intrusion.

A water table map was created for the 23 February water levels and is shown in Figure 3.2. The water table elevations indicate that south of the SRB site, the general groundwater flow is in a northerly direction. Groundwater flow to the west and in the general vicinity of the SRB site is in a more easterly direction towards the Muskrat River. A small anomaly in the groundwater flow is observed near MW06-3, and may be due to the possible shallow bedrock noted during borehole drilling at this location. The anomaly, however, does not change the general flow of groundwater.

The horizontal hydraulic gradient was determined between each of the wells based on the 23 February water levels. The horizontal gradient ranged from 0.001 between MW06-3 and CN-3S to 0.043 between CN-2 and CN-1S, with an average gradient of 0.01. The vertical movement of groundwater is determined through measurement of the vertical hydraulic gradients and indicates whether the groundwater is moving downward (recharge) or upward (discharge). Vertical hydraulic gradients were assessed at MW06-4, CN-1 and CN-3 (Figure 2.1). The vertical hydraulic gradient observed at MW06-4 was downward with an approximate gradient of 0.6. The vertical gradients observed between the shallow and deep wells at CN-1 and CN-3 were 0.9 downward and near unity (gravity flow) downward, respectively. The average vertical gradient for the three sets of wells was 0.9 downward. This suggests that the area surrounding SRB is mainly a groundwater recharge zone, with a predominant downward flow.

Recovery tests were completed on most of the newly installed groundwater monitoring wells. The results of the recovery tests were used to estimate the hydraulic conductivity of the overburden surrounding the wells. The mathematical solution by Hvorslev (1951) was used, and involved matching a straight-line solution to water-level displacement data collected during the recovery test. The time required for the water level in the well to reach 37% of the initial change (T_o) is determined from the plot, and used in the following equation to estimate the hydraulic conductivity (K);

$$K = [r^2 \ln(L/R)] / [2 L T_o]$$

where: r is the radius of the well casing,
R is the radius of the well screen, and
L is the length of the well screen.

In low-permeability aquifers, such as that observed at the wells installed at SRB, Fetter (2001) advises using the length and radius of the sand pack in the well annulus for L and R, respectively.

Hydraulic conductivity calculations were completed for MW06-1, MW06-2, MW06-4S and MW06-7. Slow recovery in the other monitoring wells precluded accurate evaluation of conductivity. The calculation results, provided in detail in Appendix B, show that estimated hydraulic conductivity ranges from 1.3×10^{-8} m/s at MW06-2 to 7.1×10^{-8} m/s at MW06-4S, with an average of 4.0×10^{-8} m/s for the SRB vicinity. On the east side of the Muskrat River, near MW06-7, the estimated hydraulic conductivity is slightly higher at 5.1×10^{-7} m/s. These values are within the range of hydraulic conductivity values reported for overburden in the vicinity of SRB (10^{-6} m/s; INTERA, 1994) and for the Renfrew County area (10^{-6} to 10^{-10} m/s; Golder, 1003). The hydraulic conductivity values observed at the SRB site are also consistent with the range of values typical of the types of silty clay overburden observed at the site (10^{-7} to 10^{-10} m/s for marine clay and 10^{-3} to 10^{-7} m/s for silt; Freeze and Cherry, 1979)

Based on the estimated average K for the subsurface in the vicinity of SRB of 4.0×10^{-8} m/s and average vertical and horizontal hydraulic gradients of 0.9 and 0.01, respectively, the groundwater velocity (v) can be estimated by the following equation:

$$V = -K \, (dh/dl) / \eta$$

where: dh/dl is the hydraulic gradient, and
η is the porosity (assign generic value of 0.45).

The estimated lateral groundwater velocity through saturated silty clay overburden is 0.028 m/a. At this velocity, groundwater would travel a distance of 0.344 m in 12.3 years or one half-life of tritium. In other words, in the lateral movement of tritium-bearing groundwater, tritium levels decline by half for every 0.34 m travelled.

In general, it is expected that the low K clay overburden observed at the SRB site creates a predominant downward groundwater flow until a lower K layer is encountered. This lower conductivity unit is likely the fractured bedrock or gravel till layer found above the bedrock. It has been noted that there is some evidence that the hydraulic connection between overburden and bedrock in the study area is significantly limited. Dense clay layers overlying the bedrock may function as an aquitard, and lateral movement of groundwater may be predominantly through the overburden, at least in the areas where the clay is present.

The estimated vertical (downward) groundwater velocity through saturated silty clay overburden is 2.52 m/a, based on the equation provided above. Assuming an annual infiltration rate of 0.1 m/a (Golder, 2003), and a moisture content in the vadose zone of ~30%, the calculated vertical velocity in the vadose zone is 0.33 m/a (i.e., infiltration ÷ moisture content). With an average depth to bedrock of 25 m, and with the water table at 5 mbgs on average, the downward travel would be about 15 years to travel 5 m down to the water-table, and another 9 years from there down to bedrock. The total downward travel time to bedrock would be 24 years, or approximately two tritium half half-lives.

Once groundwater does reach bedrock, the flow becomes predominantly lateral. Based on a hydraulic conductivity of 10^{-3} m/s for the bedrock and a shallow to moderate gradient (Golder, 2003), a lateral velocity is not likely to exceed 1 m/a through this material. It has also been noted that fractures and sand seams are present, but not abundant, in the predominantly clay/loam overburden, and localized fracture flow is possible. Through these seams of fractures through a porous medium, rates of lateral movement of tritium in groundwater may be potentially higher by an order of magnitude or more, but still in the order of <1 m per annum. Overall, the net rate of lateral movement of tritium in groundwater towards the Muskrat River several hundred meters away is expected to be very low.

During both vertical and lateral groundwater transport, tritium will continually undergo radioactive decay and concentrations will decrease. Following release from a point source, the concentration of tritium in groundwater at any down-gradient location will be a function of the total distance travelled (vertical and lateral) and the groundwater velocity. Table 3.1 provides a summary of estimated down-gradient groundwater tritium concentrations based on travel time and decay. This assessment assumes a point source at SRB with tritium present at 279,000 Bq/L. This level was measured in standing surface water at the SRB Facility in 1996 (CNSC, 2005) and is the highest measure of tritium on record for any form of water (precipitation, puddles, river water, or groundwater). It is conservatively used here for discussion purposes only and does not indicate the actual presence of a groundwater plume with tritium at these levels. Even ignoring the time for downward travel (i.e., 35 years or 2.8 tritium half lives), there is substantial decay of the theoretical tritium plume within relatively short distances of SRB. Assuming flow through the more conductive medium at 1 m/a, the initial concentration of 279,000 Bq/L of tritium in groundwater declines to less than 1,000 Bq/L (well below the guideline level of 7,000 Bq/L) within 100 m. The rate of attenuation of tritium in groundwater flow through overburden is much higher, with concentrations declining to less than 1,000 Bq/l within 3 meters of the point source. In either case, the plume undergoes virtually complete attenuation by the time it reaches the Muskrat River, approximately 425 m down-gradient of SRB.

3.3 Tritium in Groundwater and Associated Media

3.3.1 Monitoring Wells

The results of analyses of tritium in groundwater samples collected from monitoring wells and residential wells are presented in Tables 3.2 and 3.3, respectively. Tritium activity levels in monitoring well samples were below the drinking water guideline value of 7,000 Bq/L for all locations except MW06-1, located approximately 25 m east of SRB.

The levels of tritium in MW06-1 are substantially higher than observed in all other monitoring wells, and are suggestive of influences not experienced at the other monitoring locations. There are several phenomena to consider as possible contributors to the elevated levels of tritium in shallow groundwater at this location. It is possible that the well is influenced by lateral transport of highly tritiated groundwater originating immediately at SRB. However, in the initial review of the facility, and in review of data obtained from SRB and the CNSC, there is no evidence of a true plume source of high levels of tritium in liquid form. If a plume was present, the distance of travel to MW06-1 is such that significant decay of tritium could occur en route. Direct washout of atmospheric tritium could also possibly lead to levels of tritium approaching the levels that have been observed at MW06-1. Applications of models that simulate this route of delivery have indicted tritium levels in shallow groundwater at this location in excess of 35,000 Bq/L at times (see Section 3.4 for discussion of modelling).

It is also possible that this well is greatly affected by surface runoff. Very recent sampling by SRB indicates levels of tritium in precipitation or melt-water as high as 40,000 Bq/L (see Table 3.5 - original data is provided in Appendix C). An environmental assessment conducted by SRB in 1999 reported tritium levels in water obtained through downspouts from the Facility roof in the order of 70,000 Bq/L (see Appendix C). The CNSC (2005) also report measures of tritium in rainwater near the site as high as ~50,000 Bq/L. Given that MW06-1 is located at the downstream end of the ditch that receives runoff from the entirely paved Facility grounds, it is possible that site runoff with high levels of tritium may collect and infiltrate at this location. Analysis of soil samples collected at the monitoring well locations indicates that tritium in groundwater is of surface origin (see Section 3.3.4).

3.3.2 Residential Wells

The tritium levels in the series of nearby residential wells were much lower than levels recorded in the monitoring wells. The level of tritium in these residential wells was well below the drinking water guideline value of 7,000 Bq/L. Average tritium activity levels varied with distance and direction, ranging from 3 Bq/L at RW-3 (the furthest well) to a high 1,834 Bq/L at RW-1 (the closest well). For wells that have been sampled in the past, the current tritium levels are similar to those measured previously. Well RW-3 at 183 Mud Lake

Road was sampled by the CNSC in 2003 and found to contain tritium at 400 Bq/L (see Appendix C).

It should be noted that the residential wells with the relatively high tritium content may be influenced by surface water ingress. The tritium levels in RW-1 (413 Boundary Road) are approximately equivalent to levels that have been recently measured in the snow pack (see Table 3.5). Also, non-radiological parameters measured at RW-1, including high levels of chloride, sodium, iron, and nitrate are indicative of surface water ingress (see Table 3.4). Similar non-radiological tracer indications of surface water ingress were recorded for RW-3 (183 Mud Lake Rd.) where well water levels of tritium (~400 Bq/L) were found to be about a fourth of the levels recently measured in the nearby snow pack (~1,600 Bq/L – see Table 3.5). Other observations of relatively deep wells suggest that concentrations of tritium at depth are an order of magnitude or more below concentrations in shallow groundwater and/or precipitation. This is evident at RW-4 and RW-5, and in the paired monitoring wells at MW06-4.

3.3.3 Surface Water

The sampling and analysis of tritium in surface water, conducted as part of this study during freeze-up conditions, has revealed low levels of tritium in both the Muskrat and Indian Rivers (Table 3.6). The levels measured in this sampling event (7.4 to 11 Bq/L) are low relative to levels in the snow-pack within the watershed, suggesting that they are largely reflective of baseflow. These levels do not suggest that there is any significant influence of discharge of shallow groundwater to the Muskrat River.

3.3.4 Soil

During the installation of monitoring wells, soil samples were collected at continuous depth intervals (see Section 2.2.1). Composite samples were later prepared using sub-samples from each depth increment, so that the composite sample represents the full column of overburden into which each well was installed. The results of analysis of tritium content of these representative samples is provide in Table 3.7, and the detailed OPG report of soil analysis is provided in Appendix C.

The levels of tritium measured in the depth-integrated soil samples correspond very well the levels of tritium measured in associated monitoring wells. For all wells, the level of tritium in groundwater is not significantly different than that in the overlying soil. Even for well MW06-1, where tritium in groundwater samples exceeds 50,000 Bq/L, the level of tritium in the overlying soil is comparable. This trend suggests that the tritium found in groundwater originates through downward migration from the surface.

3.4 Modeling

In the recent calculation of proposed Facility DRLs for SRB (EcoMetrix, 2006), exposure of members of the public to tritium in groundwater was included in the assessment of overall exposure to atmospheric tritium releases. For this purpose, relevant fate and transport models from modern DRL Guidance (COG, 2005) were applied to the SRB site. The overall site DRL model included sub-models for atmospheric dispersion and also transfer from atmosphere to groundwater. These sub-models have been applied as part of this groundwater study to affirm their suitability for quantifying public exposure to tritium in groundwater. Following that affirmation, the models have been applied predictively to understand the general distribution of tritium in groundwater in the area surrounding the SRB Facility.

Appendix D provides a detailed description of the sub-models and site-specific inputs used in this study. The following sections present and discuss model results in context of the two noted purposes.

3.4.1 Model Validation

For validation of the groundwater models, concentrations of tritium in groundwater were estimated for each of the monitoring and residential wells that were directly examined in this study. The model is an equilibrium model and thus cannot retroactively account for the presence of tritium from past releases. However, the model can be applied to understand what levels of tritium would have occurred in the past under equilibrium assumptions.

Table 3.8 summarizes the results of this model application. These results illustrate several major points. First, estimated levels of tritium in groundwater at current time are lower than estimated for years prior. Second, when considering an average of results for the last 5 years to account for legacy effects, the model predictions are higher than actual measures for all wells except MW06-1, which has been discussed in Section 3.3. For those wells which do not show evidence of surface water ingress (RW-4 and RW-5), the model estimates are higher than measures by more than an order of magnitude. Overall, the groundwater models associated with the Facility DRLs are conservative in representing possible exposure of the public to tritium in well water.

3.4.2 Predictive Application

The groundwater models have been applied to provide a quantitative indication of tritium levels in groundwater throughout the area closely surrounding SRB. For this purpose, 2000-to-2005 average facility emission rates of HT and HTO were used as model input. In the initial model validation (see Section 3.4.1), averaged yearly estimates of tritium in groundwater over this period (2000 to 2005) provided a conservative approximation of present day conditions.

The results of this predictive model application are summarized in Table 3.9. It is important to note that these are conservative estimates of the levels of tritium that would be found in shallow groundwater. Levels in properly installed and maintained residential wells would be considerably lower, perhaps by a factor of 10 or more.

The modelled distribution of groundwater tritium levels within 2 km of SRB illustrates several key points. First, as expected, tritium levels vary with distance and orientation. Highest levels are found in closer proximity in compass directions associated with a high frequency of wind blowing from the direction of SRB (e.g., the NW sector). Second, the conservative estimates of tritium in shallow groundwater, expected to be much lower in an actual drinking water supply well that may exist at a given location, are all less than the drinking water guideline of 7,000 Bq/L. Beyond 1 km distance from SRB, the upper level estimate of tritium in shallow groundwater is ~2,500 Bq/L.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The various efforts comprising this study have provided detailed and reliable information that serves to understand the impacts of SRB operations on local groundwater resources. This information is now interpreted in an integrated and weight-of-evidence manner.

4.1 Sources and Distribution of Tritium in Groundwater

In review of SRB Facility operations and all available monitoring data, there was no direct or consistent evidence of a true plume of tritiated groundwater emanating from the SRB Facility. No significant liquid sources of tritium were identified, and the data from direct measures of tritium in groundwater are suggestive of an atmospheric influence. Even the relatively higher levels of tritium in one monitoring well (MW06-1) in very close proximity to the Facility are consistent with conditions that would occur in the presence of only surface influences.

If there was a tritiated groundwater plume originating at SRB, lateral transport would be in the direction of the Muskrat River through inactive industrial lands, and such a plume would thus not affect residential drinking water supply wells. The current understanding of hydrogeological conditions in the study area suggest that travel times for lateral transport would lead to substantial attenuation of tritium in groundwater as a result of radiological decay (see Table 3.1). The levels of tritium measured in the wells on that industrial land (i.e., the CN wells) and in surface water samples from the Muskrat River (~400 m down-gradient of SRB,) indicate that any lateral transport that might be occurring is not extensive in its influence.

Figure 4.1 shows the location of the series of wells examined in this study relative to the two potentially influencing variables: direction of groundwater flow and wind direction/frequency. The levels of tritium measured in groundwater samples (see Tables 3.2 and 3.3) are primarily reflective of distance and direction, consistent with an atmospheric influence. The application of the model to simulate the Facility influence on groundwater via atmospheric releases also generates good agreement with measures (see Table 3.8).

Overall, the information developed and considered in this study suggests that atmospheric dispersion of tritium emitted from SRB stacks is the only significant influence on local groundwater resources.

4.2 Ecological Implications

In terms of potential ecological effects, exposure of biological organisms to shallow groundwater may occur at any location, although exposure would be highly limited by the presence of built-up or paved surfaces. Ecological exposure is not constrained by the existence of wells.

Based on the groundwater data presented in this study, is possible that organisms residing at locations in immediate down-gradient proximity of SRB could be exposed to concentrations of tritium in shallow groundwater as high as 50,000 to 60,000 Bq/L. In a recent assessment of ecological effects of tritium in groundwater at the Pickering Nuclear Generating Station (CH2Mhill, 2002), an upper limit for tritium in groundwater was developed for ecological exposure considerations. The limit was acknowledged as being conservative, and was based on limiting the radiological dose to earthworms within acceptable levels (i.e., no more than 1 mGy/d). This upper limit considers the relative biological effectiveness (RBE) of tritium, assigning an RBE factor of 3, and also the implications of transformation of tritium to organically bound tritium (OBT) in animal tissues, assigning a further multiplier of 1.5. The resulting criterion value is 3 million Bq/L of tritium in groundwater. This is similar to the generic screening criterion (GSC) of 4 million Bq/L of tritium in groundwater that was developed by JWEL (2000) for ecological exposure at nuclear power generating facilities. This GSC was also developed based on highly-exposed earthworms (the most sensitive organism) using similar considerations. The GSC and the Pickering site-specific limit are both very conservative screening levels, representing levels below which there is absolutely no expectation of ecological effect. Maximum exposure levels observed in the immediate vicinity of SRB are nearly 100 times lower than these limits. Based on this comparison, there is no expectation of any ecological effects of tritium in groundwater near SRB.

4.3 Residential Water Use Implications

The predicted levels of tritium in shallow groundwater (Section 3.4.2) arising from atmospheric transport have been used to develop tritium-in-groundwater contours around the facility. These contours, based on the conservative model predictions that were presented in Table 3.9, are depicted in Figure 4.2. This provides an understanding of what would arguably be maximum levels in drinking water wells around the site. The data herein suggest that actual levels in drinking water supply wells would be a fraction of those indicated by the contours.

The theoretical distribution of tritium can be considered in context of the distribution and nature of wells in the area that has been developed from Ministry of the Environment (MOE) well records. Tables 4.1 and 4.2 provide a summary of wells in the area surrounding SRB, as indicated by the MOE records. It should be noted that the MOE records may include wells that are no longer active or in existence, as landowners rarely submit records of well decommissioning. Many of the wells in the area were installed more than 30 years ago, and subsequent urbanization has probably led to the abandonment of many wells that are still listed in the MOE database. The field reconnaissance completed for this study found that several wells indicated as being immediately west of SRB were no longer active or in existence. Notwithstanding such limitations of the records, the do provide a general understanding of well-water use in the area.

The records indicate that there have been 847 wells installed within a five km radius of SRB Technologies. The majority of the wells (89%) are located two or more km away from the site, with the greatest concentration of wells occurring between two and three km from SRB (36.5%). The largest number of wells is located east of the SRB property (26%), which is a high frequency wind sector. However, the majority of wells in this direction are located two to three km from the site.

The large majority of the wells (95%) are recorded as being installed into bedrock, and of these wells only 8% are found in the overburden. Overburden wells typically supply domestic water (livestock or residential). Wells that are located in the overburden are mostly two or more km away from the study site. For all wells within five kilometres of SRB average well depths are in the order of 30+ m, with the shallowest well being ~5 m deep (observation well, commercial) and the deepest at ~200 m deep (public water supply, Laurentian Valley).

Overall, most wells are deep, installed into bedrock, and are more than 2 km from SRB. The concentrations of tritium in shallow groundwater are conservatively estimated to be ~1,000 Bq/L or less, and it is expected that associated levels in deep well-water would likely not exceed 100 Bq/L in absence of surface water ingress. For the few wells on record that are in closer proximity to the site (1 km or less) only 1 is installed in overburden, to a depth of ~ 7 m. It is possible that this well might be reflective of shallow groundwater containing tritium at concentrations conservatively estimated to approach levels as high as 6,000 Bq/L.

There are two means for assessing the implications of observed and predicted levels of tritium in groundwater to the public use of that groundwater. First, all value can be compared to the federal and provincial drinking water guideline of 7,000 Bq/L. That guideline has been derived so as to limit human dose through drinking water ingestion to 0.1 mSv/a, assuming that 100% of the drinking water supply originates from the tritiated source. Based on conservative projections (Table 3.9) wells at a distance of 500 m or more from SRB, regardless of direction, would not contain levels of tritium that would exceed this protective level. Actual measures of tritium in residential wells in close proximity to SRB (see Table 3.3) are well below the 7,000 Bq/L guideline.

The other approach to assessing the implications of tritium in groundwater is to directly calculate the associated dose. This has been done for the predicted (see Table 3.9) and observed (Tables 3.2 and 3.3) levels of tritium in the study area. The doses presented and discussed herein consider exposure via drinking water ingestion and immersion, and are calculated in the same manner as were doses for these exposure pathways in the recently revised DRLs (EcoMetrix, 2006). This report considers the dose for the nursing infant, assuming that the mother also obtains 100% of her drinking water supply from the tritiated groundwater source. The details of dose calculation equations are provided in Appendix D.

It is not at all reasonable to assume that any of the monitoring wells would serve as a sole source of residential drinking water. However, the dose implications associated with the monitoring well have been calculated for discussion purposes. The doses associated with all monitoring wells (see Table 3.2) range from <1 to ~940 µSv/a. Even for MW06-1, where concentrations of tritium exceed 50,000 Bq/L, the dose remains below the public dose limit of 1 mSv/a. Other than MW06-1, all associated doses are less than 100 µSv/a. The conservative model predictions of tritium in shallow groundwater at distance intervals throughout the study area (Table 3.9) also translate to public doses that are almost entirely less than 100 µsV/a. The maximum groundwater-related dose is 102 µSv/a at 500 m to the NW dose. In wind sectors other than those that are "high frequency", associated doses are mostly less than 50 µSv/a at 500 m. The conservatively estimated doses at 1 km are consistently less than 50 µSv/a, regardless of direction. At 2 km, the maximum estimated public dose associated with groundwater exposure is 20 µSv/a, and in moderate and low frequency wind sectors is <10µSv/a.

The most meaningful doses are those associated with tritium levels that have been directly measured in existing residential wells in close proximity to SRB (see Table 3.3). The highest public dose, conservatively estimated assuming that there is a nursing infant at this residence and that 100% of the drinking water supply is taken from the well, is ~30µSv/a. This dose is associated with an average tritium concentration of 1,853 Bq/L. For the other 6 wells that were examined in this study, the associated dose ranges from 0.05 to 6.6 µSv/a. This is consistent with a dose assessment of tritium in water in the study area, recently completed by the CNSC in 2001. In that assessment, the maximum combined immersion and ingestion dose arising due to the presence of tritium in residential water supplies was reported as 4 µSv/a. The CNSC assessment is summarized in Appendix C.

Overall, a conservative examination of doses associated with tritium in groundwater in the SRB study area indicates that such doses will not exceed the public dose limit. The weight-of-evidence suggests that doses in the area will remain well below 100 µSv/L, and in most cases where exposure to groundwater may actually occur at present (i.e., at residences with active wells) doses are very low (<10 µSv/a).

4.4 Recommendations

In summary, atmospheric releases of HT and HTO are the only significant influence on tritium levels in groundwater in the vicinity of SRB. All available information suggests that this influence, which has been diminishing steadily in time, has not led to levels of tritium in groundwater that are of concern with respect to either human or ecological exposure. With decreasing rates of atmospheric emission and continual radiological decay of legacy tritium in groundwater, the levels of tritium in groundwater observed at present should exhibit a declining trend in coming years.

To confirm this trend, and to provide assurance that tritium levels in groundwater remain acceptable, it is recommended that SRB continue to maintain an effective EMP that includes the sampling and analysis of groundwater on an annual basis. The program should include select monitoring wells (at a minimum, MW06-1, -2, and -3), and several of residential wells that were examined in this study. Residential wells RW-4, RW-5 and RW-7 could be omitted or monitored at reduced frequency since they are either duplicate locations to wells which have exhibited higher tritium levels, or have such low levels that they are of no concern under present conditions.

For purposes of estimating potential public exposure to tritium in groundwater, the models derived from the DRL procedure are considered to conservative and suitable for use at SRB.

5.0 REFERENCES

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