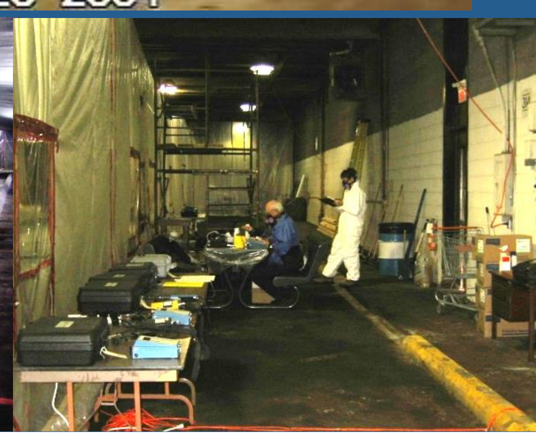
PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol

May, 2016



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PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol

Version 2

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The Protocol may be modified, revised or further developed under the authority of the City of Toronto as additional information or test data becomes available.

While this protocol attempts to provide an extensive level of specific details and guidance, it is impractical to provide every last detail. So as with most standards, it is up to the user to strive to achieve the intent that is written into this protocol. If the user is unsure and needs clarification on any item, those listed as contacts will attempt to provide that information. Any disputes on interpretation of this standard may be referred to the above group of contacts.

ACKNOWLEDGEMENTS

The City of Toronto wishes to acknowledge and thank those who contributed to developing, initiating and undertaking the first Toronto PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Testing in 2007. The work was carried out as a replicable, quantifiable supplement to other subjective and objective evaluation undertaking by both fleet and transportation staff.

The protocol was conceptualized, initiated, developed and implemented by Vesna Stevanovic-Briatico, Transportation Services Division (TSD), and Christopher Morgan.Toronto Environment Office, but they are the first to recognize that implementing the concept successfully required the willing and enthusiastic help from many other City staff.

Matthew Lee (TSD) is owed myriad thanks for all his help in all aspects of implementing the protocol but especially for his computer and video expertise and his willingness to turn his hand to solve every problem that cropped up.

Special appreciation is also owed to Bruce Kentner (TSD) for all his contributions and suggestions that were so critical in making it all happen on Disco Road, Toronto, Ontario and also to his staff, Steve Berneski, Marco Rukavina and Rob Gabrielli who bore the brunt of the physical efforts required to make the project such a great success and did so with grace, helpful ideas and good humour at all times.

Also, many thanks to James Wassermann, Prairie Agricultural Machinery Institute (PAMI), and Steve Guerin and Andrew Houlson (ETV Canada) for their many detailed questions and suggestions that helped to clarify and improve the protocol and make it more universally applicable.

More recently, in 2016, I would like to acknowledge Mark Heilig, from Canada ETV, James Wasserman and Troy Lucyshyn from PAMI, in assisting the City of Toronto in updating and aligning the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Testing Protocol with the current Canadian ETV process.

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1.0 INTRODUCTION

The main objectives of private and public organizations, when providing street sweeping services, are to:

- operate environmentally sustainable technologies that improve human health, air and stormwater quality;
- operate efficiently year round under various sweeping conditions;
- reduce maintenance costs and downtimes;
- evaluate the different types of street sweeper technologies in a manner that produces objective and quantifiable results; and
- require the vendors to have their equipment tested as a requirement of the procurement process.

The Canadian Environment Technology Verification (Canadian ETV) under the licence of Environment Canada and Climate Change provides a mechanism to evaluate and third party verify the environmental and operational performance of various street sweeper technology.

Third-party testing is a method that can be used to evaluate Particulate Matter (PM) removal and entrainment efficiencies (air quality performance) and operational efficiency of various street sweeper technologies using a quantifiable rather than a qualitative method. Canadian ETV can provide a Verification Certificate of operational performance using the Operational On-Street Test Protocol described here.

A Canadian ETV Certificate will indicate the specific make and model of a street sweeper and the efficiency values obtained in respect to each of the established criteria. The user community, through their purchasing process, may compare the efficiency values from multiple street sweepers by using a weighting method to determine the final score for all of the criteria.

A street sweeper can be tested under various operational settings. A change in a street sweeper's operational settings will results in a change in either air quality and/or operational performance. For example, the street sweeper can be tested using either shrouds or no shrouds on the gutter brooms.

Four consecutive tests (weather permitting) must be completed with specific operational settings determined at the start of the testing sequence and a full Test Run must be performed with the same specific operational settings. It is beneficial for the street sweepers to be tested in as many operational settings as are deemed appropriate when taking into consideration the specific operational requirements of the user community.

This document provides the detailed methodology of the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol and all supporting documentation, such as: data log sheets, spreadsheets used to perform calculations and key components of the protocol.

The document is intended to be used in conjunction with the Operational On-Street Test Protocol. In order to ascertain the overall performance of a street sweeper an evaluation of both the air quality and operational performance of the street sweeper should be undertaken.

2.0 BACKGROUND

In 2003, the Clean Roads to Clean Air program (CRCA) was initiated by the City of Toronto and through a number of air quality studies and tests, a standard process, along with efficiency criteria, was developed and used to evaluate various street sweeper technologies. Specifically, the sweeper technologies were evaluated on their efficiency in cleaning streets including: removing "invisible" fine particulate matter (PM_{10} and $PM_{2.5}$)[1] from roads; reducing the concentration levels of fine particulate matter entrained into the air while sweeping; and operating year-round effectively, including during winter periods, under various sweeping conditions typically encountered in Toronto.

In order to meet the above objectives, City of Toronto staff developed two testing protocols: a PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol and an Operational On-Street Test Protocol. The PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol is intended to provide an objective and quantitative method for assessing the ability of the sweeper to capture and remove PM_{10} and $PM_{2.5}$ from typical urban street surfaces and to limit the amount of PM_{10} and $PM_{2.5}$ that is disturbed (entrained) into the air and subsequently deposited during the sweeping process.

It is assumed that the PM_{10} street sweepers tested will be already Southern California Air Resources Board – South Coast Air Quality Management District (SCARB-SCAQMD), California, Rule 1186 compliant, certified or equivalent. "Rule 1186" is a protocol to evaluate a sweeper's ability to entrain PM_{10}. It was designed to evaluate sweepers for use in more temperate climates. Rule 1186 permitted the use of shrouds and unlimited use of water to help suppress dust generated by sweeping.

The PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol was designed to evaluate a sweeper's year round PM entraining capabilities without reliance on any use of water and/or side broom shrouds for dust control and suppression. Reliance on water for dust suppression in the freezing temperatures of Toronto's climate is an unacceptable constraint. The non-use of shrouds as a dust suppression mechanism is an operational and maintenance preference in Toronto.

The City of Toronto developed **testing protocols**, along with **efficiency criteria**, that can be used to evaluate the operational performance and removal and entrainment efficiencies for Particulate Matter (PM) between **various street sweeper technologies**.

City of Toronto does not have mandates or resources to test such equipment on a continual basis, and to that end, Canadian ETV and the Prairie Agricultural Machinery Institute (PAMI) were contracted by Toronto to review the Testing Protocols with a view to potentially undertake such testing in the future.

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[1]Fine Particulate matter (PM_{10}) is particulate matter less than 10 microns aerodynamic diameter which includes particulates less that 2.5 microns aerodynamic diameter ($PM_{2.5}$).

Canadian ETV is delivered by GLOBE Performance Solutions under a license agreement with Environment Canada and Climate Change to provide a mechanism for third-party verification of environmental technology performance claims and to facilitate successful technology commercialization. Canadian ETV builds vendor confidence and provides the marketplace with the assurance that environmental performance claims are valid, credible and supported by high quality, independent test data and information. Vendors of equipment **apply to Canadian ETV for verification of their environmental performance claims.**

PAMI is an **independent government testing agency with experience and credentials in street sweeping testing**.

3.0 SCOPE

This protocol establishes a method to gauge the year-round PM_{10} and $PM_{2.5}$ efficiency of street sweepers in an urban environment. The test protocol illustrates a method for assessing the pick-up and entrainment efficiency performance of street sweepers in sweeping simulated fine road dust. The PM efficiency test evaluates the ability of the street sweepers to operate in all seasons as well as meet a high efficiency in the following PM efficiency criteria:

- capture and remove PM_{10} and $PM_{2.5}$ from typical urban street surfaces;
- limit the amount entrained into the air and subsequently deposited into the environment following the sweeping process; and
- limit the amount of PM_{10} and $PM_{2.5}$ that is disturbed and deposited adjacent to the roadway.

The protocol is intended to provide an objective and quantitative method for assessing both the relative maximum PM_{10} and $PM_{2.5}$ "capture-and-remove-by-sweeper" performance as well as the minimum "disturb-and-deposit-elsewhere" performance of street sweepers. Testing is undertaken to establish a comparative assessment rather than to establish a 'pass/fail' approach.

The street sweeper will sweep at 5-10 km/hr, or at a manufacturers recommended speed, throughout each of the Test Runs, applying all required operational settings, including: the main and side brooms, vacuums and filtration system. The street sweeper **must not use any water inside the hopper and on the street sweeper's gutter brooms and main broom while sweeping**. Once the operational settings are determined and documented they must be retained and maintained throughout the Test Sequence for each subsequent test.

Four consecutive tests (weather permitting) must be completed for the specific operational setting. Only the three best overall performance results will be used to establish a sweeper's performance levels for each of the PM efficiency criteria.

4.0 TERMINOLOGY

The following terms are used throughout this document.

PM_{10}:

Particles or particulate matter smaller than 10 microns aerodynamic diameter is referred to as PM_{10}.

$PM_{2.5}$:

Particles or particulate matter smaller than 2.5 microns aerodynamic diameter is referred to as $PM_{2.5}$.

Rule 1186

The California Air Resources Board (CARB), South Coast Air Quality Management District (SCQMD) – [i.e. Los Angeles, California] - adopted the SCQMD Test Protocol, Rule 1186: Certified Street Sweeper Compliance Testing in September 1999. The purpose of Rule 1186 was to describe a test protocol for gauging the "PM_{10} efficiency" of street sweeping equipment and to establish procedures to present test results. "PM_{10} efficiency" in Rule 1186 includes both the equipment's ability to remove typical urban street silt-loadings and to limit the amount of PM_{10} entrained into the air during the sweeping process.

Fine Road Dust:

Fine Road Dust refers to PM material found as road dust. The coarser fraction of PM_{10} (PM_{10}-$PM_{2.5}$) and the finer fraction of $PM_{2.5}$ (less than <$PM_{2.5}$) are both components of Fine Road Dust. The coarser fraction of Fine Road Dust originates largely from the wearing down of roads and vehicle components and is composed of particles of asphalt, tire and brakes. The fine fraction of Fine Road Dust largely emanates from vehicle exhaust. All types and sizes of Fine Road Dust can be reduced further in size, mechanically, by abrasion of passing vehicle tires. The more normally used equivalent term – "fugitive road dust" – is not adopted in this document.

Street Sweeper:

A street sweeper is a self-propelled machine that is primarily designed to remove a wide range of material sizes from road surfaces using mechanical rotating brooms, or mechanical brooms with vacuum assistance or regenerative-air vacuum with gutter brooms.

Test Sweeper:

A Street Sweeper that undertakes a Test Run.

Test Facility:

The enclosed space that contains defined areas for the Track Course, Monitoring and Storage and Weighing Area

Test Course:

Test Course includes the Test Track, Warm-Up Area(s), Track-Out Area(s) and two Sidewalk Areas.

Test Track (see Figure 1):

A defined area of the Test Course over which the subject Test Sweeper is to sweep at normal operating speeds and in keeping with specified operational settings. The Test Track consists of two sections each containing a Test Strip. Curbs (or portable curbs) will be placed on either side of the Test Track and for the full length of the Test Track. The Test Track simulates a two lane curbed roadway and has an aged asphalt surface.

Test Strip(s) (see Figure 1):

Two defined areas located within the Test Track that are located adjacent to the curb and where the Test Material is applied.

Warm-Up Track Area(s) (see Figure 1):

A defined area of the Test Track, where no Test Material is applied, located between the entrance to the Test Course and a section of the Test Track.

Track-Out Area(s) (see Figure 1):

A defined area of the Test Track, where no Test Material is applied, located between the end of a section of the Test Track and the exit of the Test Course.

Sidewalk Area:

An un-swept area of the Test Course, located beside the Test Track and immediately adjacent to the portable curbs running the full length of the Test Track.

Conditioning Road:

A two kilometre section of roadway that the Test Sweeper sweeps at normal operating speeds and with specific operational settings, three times prior to performing the Test Run (i.e. for a total of six kilometres).

Test Sequence:

A combination of four or more consecutive Test Runs.

Test Run:

An individual, replicable, test of a Test Sweeper, whereby the Test Sweeper is tested for its ability to remove the Test Material from the Test Strips and deposits the Test Material into its hopper, and for its ability to minimize airborne contamination caused by the Test Sweeper disturbing but not capturing the Test Material.

Diesel Test (Dry Run)

A Test Run without any Test Material being applied to the Test Strips but during which air concentrations are taken in the Test Facility to provide a background ambient contamination concentration due to diesel exhaust from the Test Sweeper. The Test Sweeper will operate at normal operating speed without sweeping.

Test Material:

A surrogate Fine Road Dust material applied to the Test Strips.

Residue Material:

Residue Material is the Test Material left behind by the Test Sweeper after completing the Test Run.

Operating Speed:

The Test Sweeper will sweep at a constant operating speed between 5 to 10 km per hour (or at manufacturer's recommended sweeping speed).

Operational Settings:

The Test Sweepers are to sweep at the operating speed applying all required operational settings, including but not limited to: the main and side brooms, vacuum, vacuum and filtration systems and should **not** use any water inside and outside the street sweeper as required for dust suppression. The use of shrouds on gutter brooms constitutes a modification to the operational settings and requires the undertaking of a complete new test.

Operational Configuration:

The Test Sweepers are to sweep applying the pick-up head/main broom in a normal operating position. The projection, angle and tilt of gutter brooms can be re-configured within the normal range of operating parameters.

Test Track Surface:

A curbed lane that has a concrete barrier curb with a standard gutter design and asphalt surface. Appendix H shows the Ontario Provincial Standard Drawing OPSD 603.020 of the pre-cast concrete curb design.

5.0 PROTOCOL FEATURES

The Test Sweeper can be tested under various operational settings. A change in a sweeper's operational settings could result in a change in either air quality performance and/or operational performance. For example, the Test Sweeper can be tested using shrouds or no shrouds on the gutter brooms but this must be recorded as such and that information must be included in any subsequent verification certificate. Four consecutive tests (weather permitting) must be completed with specific operational settings determined at the start of the testing sequence and a full Test Sequence performed with the same specific operational settings. Once the operational settings are determined and documented they must be retained and maintained throughout each subsequent Test Run.

Only the three best overall performing days test results will be used to establish the performance levels for each of the PM efficiency criteria. Four days of testing are required such that if there is an operator error and/or a sweeping system failure and the Test Run is deemed null and void there are still three additional opportunities to obtain three valid tests as required to calculate the achieved performance levels. It is deemed beneficial to potential purchasers, such as municipalities, for the manufacturers to test their sweepers in as many operational settings as are deemed appropriate taking into consideration the specific operational requirements by the user community.

The test is to be implemented over several consecutive days (weather permitting), if there are prevailing environmental conditions that prevent four consecutive days of testing, then testing will be postponed and will proceed on the next consecutive day when the environmental conditions are acceptable. Postponement of the testing due to weather is not considered to create a null and void test.

The City of Toronto's specific operational requirements are that sweepers must provide levels of performance without using shrouds/skirts on the sweeper's gutter brooms and/or main brooms.

- The protocol requires an objective test of a sweeper's PM efficiency abilities using a reproducible and quantifiable method at a selected enclosed Test Course with specific characteristics, under specified conditions, using an applied Test Material. A Test Sweeper sweeps using specific operational settings and various operational configurations.

- A sufficient and known amount of Test Material must be applied to permit adequate confidence in the measurements performed - rather than merely applying an amount to represent typical fine road dust loading on a Test Track Surface. The Test Material should consist of a calcium carbonate paint filler-thickener or equivalent, and must represent the Fine Road Dust component of road dust. The PM_{10} and $PM_{2.5}$ surrogate should have a similar particle size distribution as the fine paved road dust of concern. Typically, Fine Road Dust loadings will vary considerably with traffic volumes and sweeping frequency and a standard material is required for testing.

- Prior to each Test Run, a Conditioning Road, which typically exhibits a heavy road dust condition on a daily basis, will be pre-swept three times, and on both sides of the road, by a test agency's in-house street sweeper or by the local municipality's street sweeper. The

Test Sweeper will be "conditioned" by sweeping dry (no use of water permitted inside and outside of the Test Sweeper) one side only of the pre-swept road for six kilometres immediately prior to undertaking the controlled Test Run.

- The Test Track Surface of the Test Course prior to the start of the Test Sequence will be preconditioned by applying the Test Material, sweeping to remove it, and finally by vacuum cleaning the Test Track Surface using test procedures outlined below.

- Prior to the first Test Run, a Dry Run, or Diesel Test, will be arranged to provide each driver with hands-on experience of the Test Course and to assess the particulate matter contribution from the (typically) diesel engine.

- The Test Sweeper will be weighed after completing the Conditioning Run and prior to the controlled Test Run. The Test Sweeper will be re-weighed at the completion of each day's Test Run. The weighing of a Test Sweeper is used only as a quick assessment that illustrates the rough efficiency (or lack of) for any Test Run. If a significant amount of Residue Material is left behind as a result of operator error and/or sweeper malfunction such that the vacuuming procedures should not be initiated, then the Test Run will be aborted and deemed null and void.

- The Test Course will contain one Test Track, (Figure 1). The Test Track will consist of a two lane curbed paved roadway and each lane will be swept as part of one day's Test Run. Following each Test Run, the surface of the Test Track and the Warm-Up/Track-Out Area will be cleaned by using a canister-type vacuum, such as a commercial "Shop-Vac" or equivalent. The Residue Material, captured in HEPA filter and cartridge equipped canisters, will be weighed and identified separately by source area. The Test Course is divided into six source areas comprised of:
    - four equal sections of the travelled portion of the Test Track;
    - two Sidewalk Areas located on the non-travelled portion of the Test Course; and
    - two Warm-Up Track/Track-Out Areas, located on either side of the Test Track.

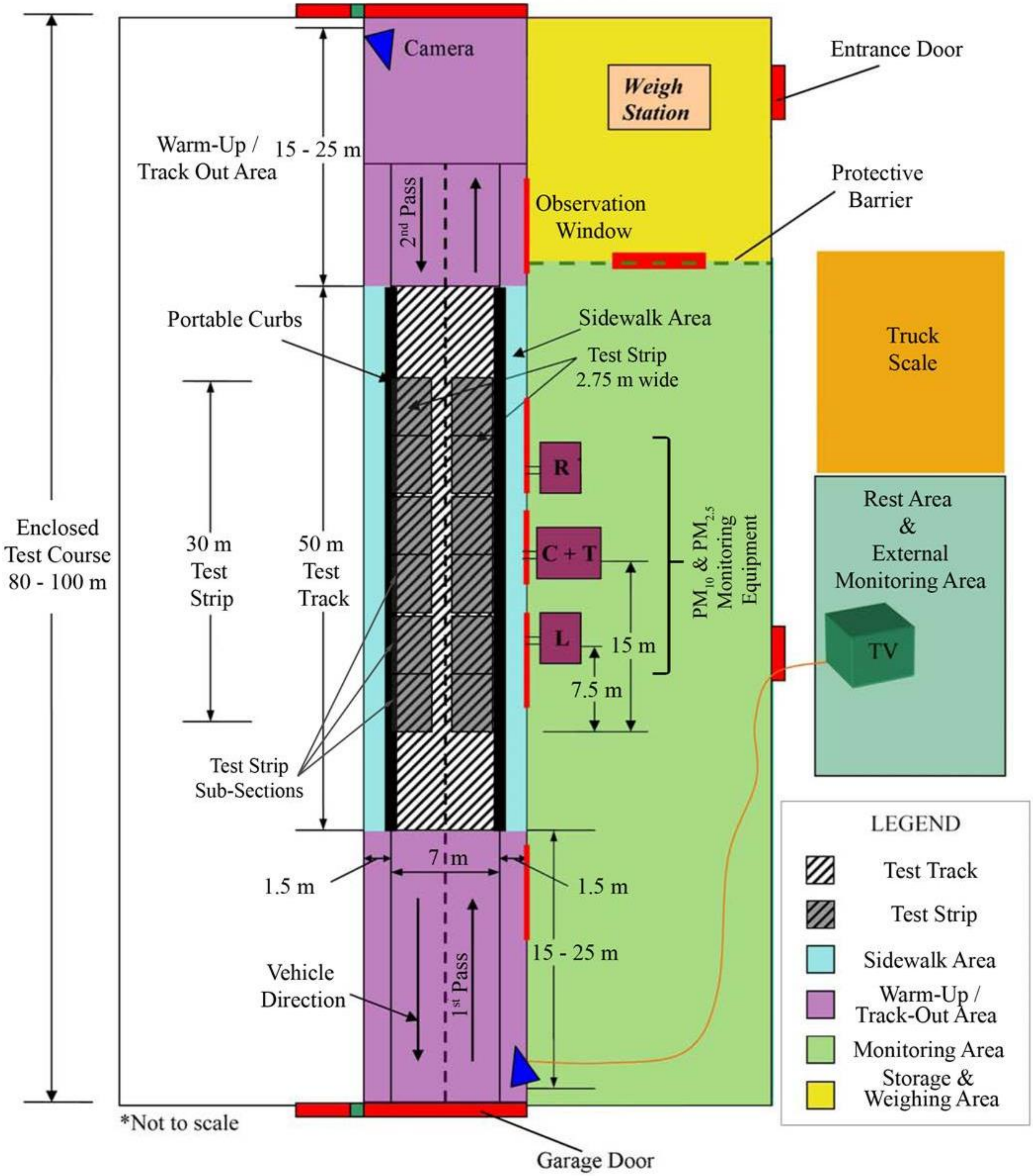
- Following each Test Run, the Test Course should be sealed and left for a minimum of 3 to an ideal of 12 hours to permit the settling of particles. Whatever settling time is selected must be used on all test days. The level of settling can be monitored by use of ambient air monitoring equipment to ensure airborne concentrations settle to a uniform standard. Ambient concentrations of PM_{10} should be less than 3,500 ug/m^3 before personnel are permitted to enter the Test Facility. Venting of the Test Facility can only occur when the concentration levels are a less than 100 µg/m^3 in order to ensure that Test Material that has been disturbed by the Test Sweepers has settled on the surface of the Test Track and there is no release of pollutants from the Test Facility into the surrounding environment.

- During the Test Run, the pre-weighed Test Sweeper will sweep over the two Test Track sections in two passes through the Test Track consecutively. The Test Sweeper, having swept through the first section (1st pass), will stop sweeping once the back of the Test Sweeper passes the end of the Test Track. The Test Sweeper must stop and cease all sweeping systems (i.e. vacuum, gutter brooms, main broom, pick-up head, etc.) before exiting the Track-Out Area. The Test Sweeper will then proceed and travel in a non-sweeping mode through the Track-Out Area and exit the Test Course. The Test Sweeper will turn around outside the Test Course and re-enter the Test Course and initiate all sweeping systems in the Warm-Up Area and must reach optimal operating sweeping speed prior to sweeping the Test Strip.

- Measurements and calculations must be undertaken to clearly determine the amount of Test Material applied, captured and removed by the Test Sweeper as well as the Residual Material left behind by the Test Sweeper for each Test Run in order to permit objective comparison and reporting of the performance levels of the Test Sweeper for each of the PM efficiency criteria.

- The methodology specified in Section 6.15 should be employed to measure all applied and residual materials. Weighing the various Test Materials to be applied on each Test Strip prior to the Test Run and collecting and weighing the amount of material remaining or disturbed to the adjacent Track-Out Area and Sidewalk Area following the completion of the Test Run is central to the methodology. The collection of the Residue Material should be accomplished by using HEPA filter and HEPA cartridge equipped vacuum cleaners. The use of HEPA filter equipped vacuum cleaners permits for an accurate and objective assessment but does require cleaning of large areas of the exposed surfaces of the Test Course.

Figure 1:
Test Facility Schematic



- Six PM efficiency criteria are evaluated to determine the PM efficiency performance levels of the Test Sweeper. The Test Sweeper must use all its operating systems, including gutter brooms, main broom/pick-up head, vacuum and filtration system, with no water to be applied inside or outside the Test Sweeper during the Test Run. The six criteria are as follows:

    - Pick-up Removal Efficiency (%) - Assesses the ability of the Test Sweeper to capture and remove the Test Material from the Test Course during a Test Run;

    - Deposit of Sidewalk Efficiency (%) - Assesses the ability of the Test Sweeper to disturb and deposit the Test Material on the Sidewalk Area during a Test Run;

    - Air Contamination PM_{10} - Maximum Concentration – The Air Contamination of Total PM_{10} Concentration is the maximum PM_{10} reading recorded during the Test Run;

    - Air Contamination PM_{10} - Total Concentration - The Air Contamination of Total PM_{10} Concentration is calculated by summing the 1200 readings taken on 1 second intervals over a 20 minutes period starting at 5 minutes before the maximum PM_{10} reading recorded during the Test Run;

    - Air Contamination $PM_{2.5}$ - Maximum Concentration - The Air Contamination of Total PM_{10} Concentration is the maximum PM_{10} reading recorded during the Test Run; and

    - Air Contamination $PM_{2.5}$ - Total Concentration - The Air Contamination of Total PM_{10} Concentration is calculated by summing the 1200 readings taken on 1 second intervals over a 20 minutes period starting at 5 minutes before the maximum PM_{10} reading recorded during the Test Run.

- A known weight of Test Material is consistently applied on the Test Track Surface with a greater depth of test material close to the curb.

- Test Sweepers will not be permitted to leave and securely housed on the Test Site until all testing is completed.

- The same agency staff should be assigned to the same key tasks throughout the testing process.

- The disposal of Residual Material from a Test Sweeper's hopper must follow all applicable regulations and is to be removed from the Test Sweeper's hopper after the completion of a Test Run.

Figure 2 illustrates the main test events through a photo diary. Section 8 includes a detailed step by step summary of the Test Run procedure. Appendix D contains the key components of the Test Protocol, including site set-up; testing of sweeper, equipment, personal protection and weather requirements; and testing procedures.

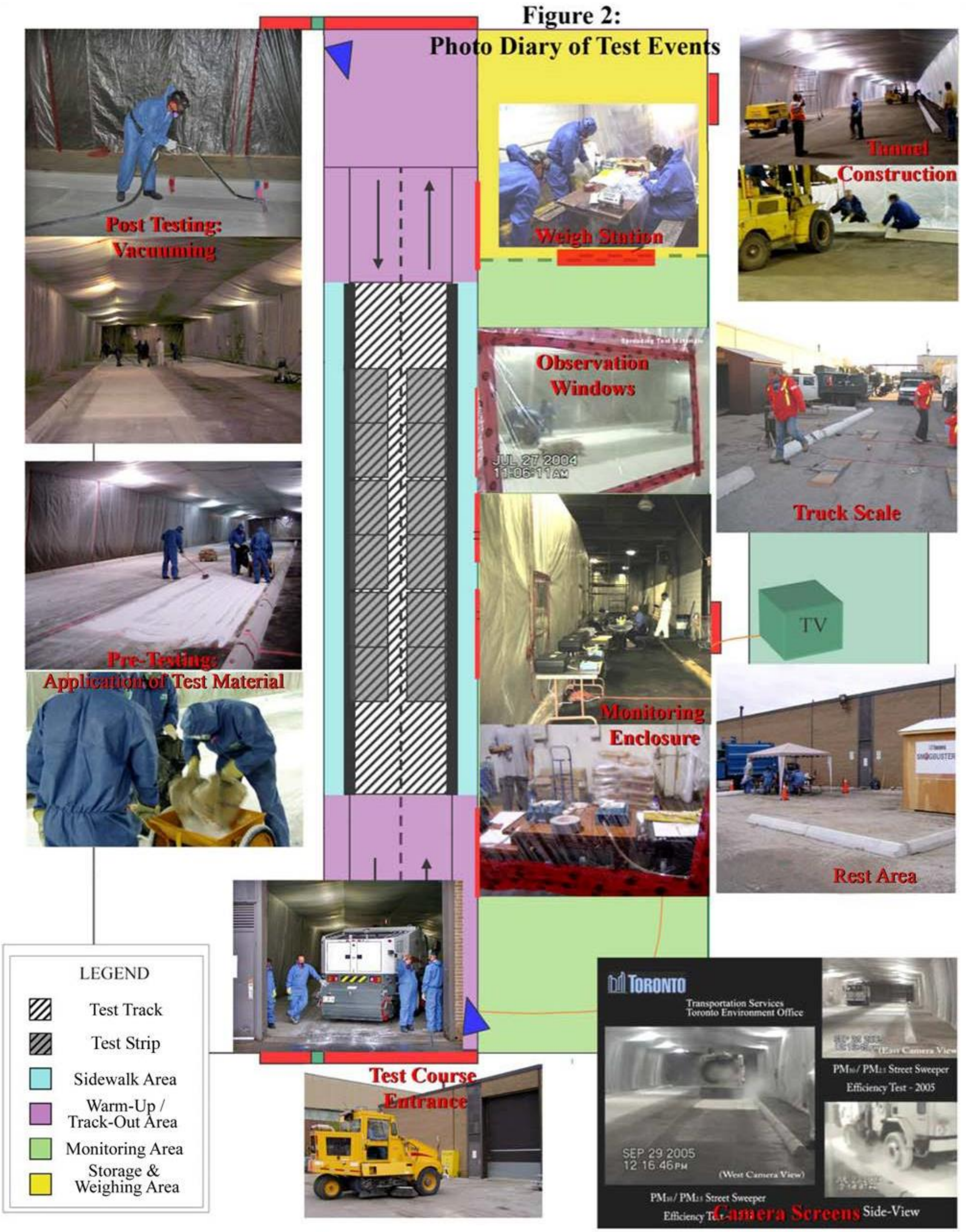


Figure 2:
Photo Diary of Test Events
Post Testing: Vacuuming
Weigh Station
Tunnel Construction
Observation Windows
Truck Scale
TV
Pre-Testing: Application of Test Material
Monitoring Enclosure
Rest Area
LEGEND
Test Track
Test Strip
Sidewalk Area
Warm-Up / Track-Out Area
Monitoring Area
Storage & Weighing Area
Test Course Entrance
TORONTO
Transportation Services
Toronto Environment Office
SEP 29 2005
12 16 46PM
(West Camera View)
(East Camera View)
Camera Screens
Side-View

6.0 PROTOCOL COMPONENT DETAILS

6.1 Submission of Detailed Specifications

Street sweeper manufacturers and/or distributors must provide detailed specifications to the testing agency in advance of the testing. The detailed specifications must include all components/parts that will be present during the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Testing. The detailed specifications will then be included as part of PAMI's "Testing Report" that includes the performance results. The "Testing Report" will be submitted to Canadian ETV for third party verification and ultimately ETV certification.

6.2 Construction of Test Facility

- The Test Facility must be sufficiently enclosed and configured to minimize extraneous disturbance (e.g. as from wind or precipitation) of the applied Test Material during the controlled Test Run as well as have adequate lighting for safe visual operations and to facilitate the use of video recorder and camera for recording and monitoring all aspects of the testing.

- The Test Facility must have sufficient space to allow for the necessary manoeuvring of Test Sweepers inside the Test Course and the installing of all applicable test equipment in the Monitoring and Storing and Weighing Areas.

- The Test Facility area must be available, on a prolonged basis, to permit adequate time for set-up, testing and, ideally, to permit for future replications of testing of same or other sweepers.

- A nearby source of electrical power must be available to operate test equipment (i.e., 110-volt line/receptacle and/or portable generator). (Any portable generator should be located outside the enclosed Test Track Area).

- As shown in Figure 1, the Test Facility must accommodate a Test Course, ideally 80-100 metres in length by 10 metres in width and also include a Monitoring Area and Storage and Weighing Area. The Monitoring Area should be located in an area that is protected from environmental conditions, outside the enclosed Test Course, but adjacent to the Test Track where air quality monitoring equipment are to be located and continual observation throughout the testing can be undertaken by the Testing Agency staff. The Storage and Weighing Area should be a separate area that is protected from environmental conditions, outside the enclosed Test Course, preferably near the Test Course and Monitoring Area, where Test Material and equipment is stored and a weighing station is located.

- The Test Course should be constructed with continuous sealed plastic/coated tarpaulin/tent material or equivalent. The Test Course should be constructed to include two walls (located on the outer edge of the sidewalk section of the Test Course) and ceiling (providing sufficient clearance for the street sweeper) in order to minimize the loss of Test Material (see Figure 3 Example Cross-Section of Test Facility). The surface of the plastic/coated tarpaulin/tent material should have a smooth surface in order to minimize the loss/absorption of the Test Material. The plastic/coated tarpaulin/tent material can be hung over taught cable wire and fastened to the Test Course asphalt by two by four studs using steel rods (or equivalent) in a way that forms a seal and minimizes the loss of Test Material. Portable curbs should be placed for the length of the Test Track in order to simulate a two lane paved curbed roadway. Figure 4 and 5 shows the Test Facility prior to the construction of the plastic/coated tarpaulin/tent and the construction of the portable curbs.

Figure 4: Test Facility Prior to Construction

Figure 3:
Example Cross-Section of Test Facility

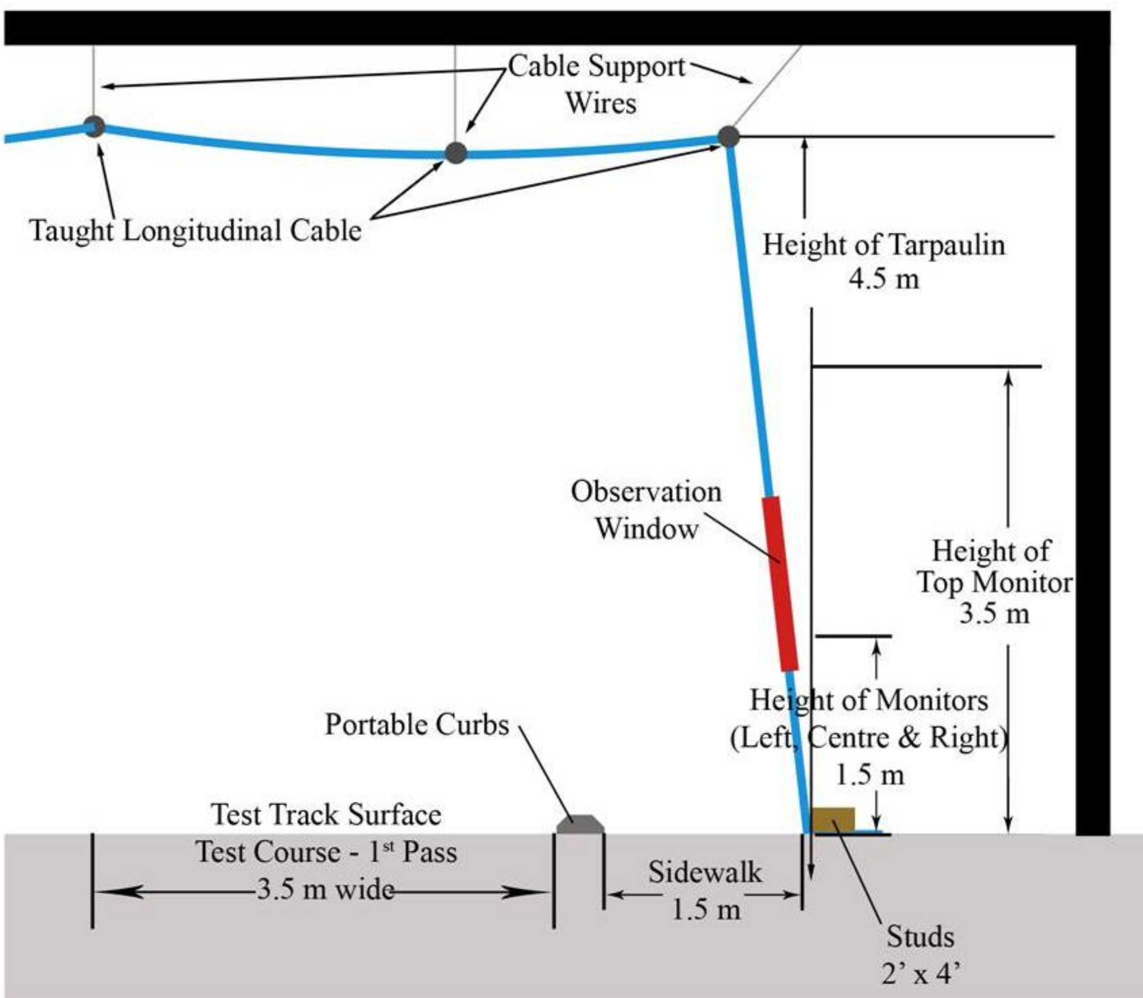
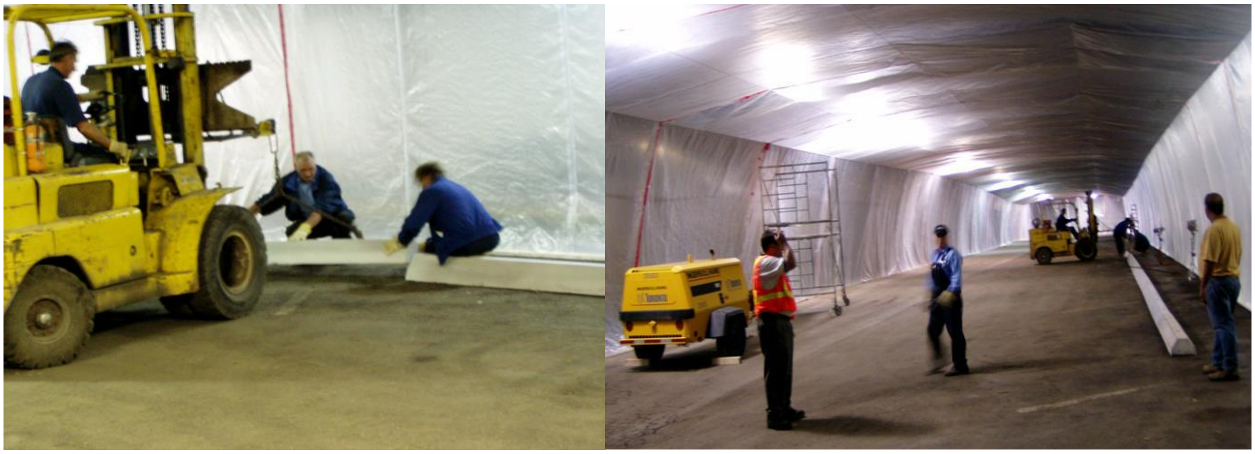


Figure 5: Construction of Enclosure and Installation of Portable Curbs



- The Test Course structure must be large enough to accommodate the Test Sweeper and should have an average roof height of at least 4.5 metres over the length of the Test Course. The asphalt surface of the Test Course must be as level as possible with an elevation difference not exceeding 30 cm over the Test Track.

- There must be **no water** on the surface of the Test Course at any time throughout the Test Sequence.

6.3 Pavement Condition of Test Track

- The pavement condition of the Test Course is determined by two types of distresses: surface defects and cracking. Surface defect distress includes raveling. Cracking distresses include longitudinal and meandering, alligator and transverse cracking.
- The pavement distress requirements only apply to the Test Strip Area (30 m by 7 m) of the Test Track.

- The area of the Test Strip should contain greater than 20% and less than 40% of total raveling and use the following formula to determine the percentage of severe versus moderate raveling:
  Total Raveling = Severe Raveling % x 2 + Moderate Raveling %

  All other raveling must only be slight (no more than loss of fines) or better.

- The area of the Test Strip should contain cracks that are greater than12 mm to less than 30 mm wide and are greater than 10 metres to less than 25 metres in total length. All other cracks must be less than 12 mm wide.

- Other areas of the Test Course should be paved and in reasonable condition such that the Test Sweeper will not loosen pavement particles.

- The following other types of distress must all be at or below the values given, or at a condition better than the descriptions stated:
  - Bleeding – none;
  - Patching - good condition;

- Potholes – none;
- Wheel Track Rutting: less than12 mm;
- Distortion – less than 50 mm deviation;
- Rippling/Shoving - if any, does not create a rough ride; and
- Excess Crown – less than 3% cross fall.

- Any distress that exceeds the allowable range must be corrected with patching or other repair.

- If total raveling and/or cracks is below the allowable range, those conditions need to be created.

- Deviations from the above may only occur if they will not affect results and are approved by the protocol development group.

- Note: As more testing occurs, the allowable range of pavement distress may be modified by the protocol development group if it is determined that a wider acceptable range of conditions does not affect sweeper protocol results.

- Appendix F, Description of Key Flexible Pavement Distresses provides detailed description of the key pavement distresses that are being used to determine the pavement condition of the Test Track. Also, included is the City of Toronto's, Pavement Distress Manifestations Summary Table for Composite and Flexible Pavements summarizing the pavement distress types, the severity and extent criteria.

6.4 Pre-Cleaning of Test Track Surface

- Prior to testing, the Test Course will require a very thorough cleaning of all appropriate surfaces and the paved asphalt surface must be conditioned with the Test Material prior to initiating any official testing of street sweepers. All catch basins, inspection covers, or road gratings within the Test Track must be covered and sealed with a suitable temporary cover.

- The surface of the Test Course must be completely dry and kept dry throughout the testing. All oils and paints or any other materials that would interact with the Test Material must be removed or appropriate cleaning undertaken to ensure the surface is interaction-free.

- Once an "interaction free" state is established on the Test Course surfaces, further cleaning prior to application of the Test Material and following each Test Run shall be undertaken with HEPA vacuum equipment.

6.5 Test Course

The Test Course must have the following features and must be available and used for all comparative testing:

- The Test Course consists of a Test Track, Warm-Up/Track-Out Areas and two Sidewalk Areas;

- The Test Facility must contain a Test Course of sufficient length (ideally 80-100 metres) and 10 metres wide. A Test Course contains a two lane Test Track (ideally 7 metres wide) to accommodate a Test Sweeper sweeping at a constant operating speed (5 to 10 km per hour) and in keeping with specified operating conditions;

- Any catch basins or inspection covers must be temporarily covered and sealed for the duration of the Test Sequence;

- The Test Course must have curbs extending the full length of the Test Track;

- A Warm-Up Track/Track-Out Areas (ideally 15 metres or greater), located between the entrance to the Test Course and Test Track, must be of adequate size to allow a Test Sweeper to attain all operational setting and optimal operating speed prior to sweeping the Test Track;

- The Test Sweeper can be stored and all necessary operational configurations can be performed in preparation of each Test Run;

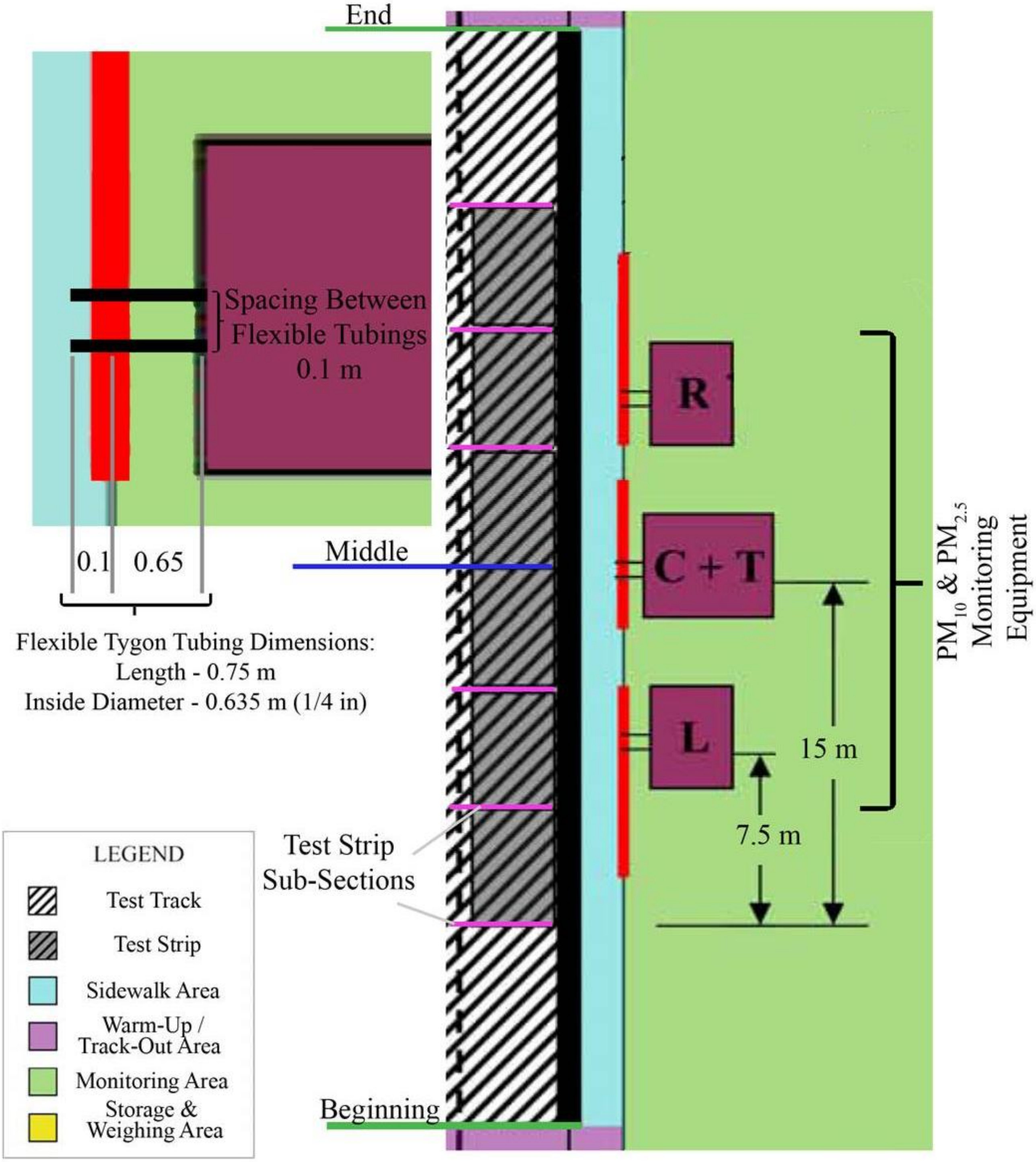
- A Test Strip area (30 metres by 2.75 metres) is located in the centre of each of the 50 metre Test Track, where a known amount of Test Material is applied;

- Test Strip(s) are divided into six 5 metre sections along the length of the Test Strip(s);

- Sidewalk Area – areas located within the Test Course adjacent to the curb running the full length of the Test Track; and

- Figure 6 illustrates the Test Track detailed markings for each of the areas: the mid point (solid blue line) of the Test Track, and the beginning and end of each Test Strip (solid pink line), the Test Strip sections defined (dashed pink line) and the beginning and end of the Test Track (solid green line);

Figure 6:
Detailed Markings of Test Track



6.6 Test Material

An appropriate and Standard Test Material must be used for all Test Runs. An example of a Test Material that can be used is a paint filler product called “Camel Wite” (as manufactured by Debro Chemical & Pharmaceuticals) or equivalent which has a mean diameter of 3 microns. This Test Material was chosen because it consists of a material of known weight and has a constant particle size distribution and simulates Fine Road Dust found on typical paved road surfaces. At least 80% of the mass of the Test Material must have an aerodynamic diameter less than 10 microns. Appendix G contains MSDS sheets for Camel Wite.

The following steps should be taken for the preparation, measurement and documentation of the Test Material:

- select and store 12 bags of pre-packaged Test Material required for each Test Run;
- each Test Material bag contains approximately 22.6 kg (+/- 1kg)
- one bag of Test Material is required for each Test Strip sub-section (see Figure 1); and
- weigh and label each of the bags of Test Material and fill out all appropriate documentation.

6.7 Test Material Application

A mass of approximately 272 kg (+/- 5 kg) of Test Material must be applied within clearly marked Test Strip(s) using a fertilizer spreader or equivalent. For each Test Run, a known weight of the Test Material must be consistently applied on the Test Strips over the full length of 30 metres to a width of 2.75 metres from the curb. A known weight of Test Material is consistently applied on the Test Track Surface with a greater depth of test material close to the curb. The width of the Test Strip shall be less than maximum sweeping path.

The amount of Test Material is chosen in order to ensure sufficient material would be captured to be detectable when the sweeper is weighed post sweeping. A mass of approximately 272 kg is selected as it represented the average mass of 12 bags of pre-packaged Camel Wite. For each Test Run, the exact weight of test material that is applied must be measured and recorded.

Figure 7 illustrates the application of the Test Material. Test agency staff must be trained to consistently apply the Test Material. Ideally, the staff should be consistently assigned to the same tasks throughout the testing process. The 12 bags of Test Material should be brought to an area of the Test Track, located between the two Test Strips. Each bag of Test Material is emptied into a fertilizer spreader, with the empty bag being placed into a garbage bag. The operator of the fertilizer spreader than begins to push the fertilizer spreader at a constant speed down one of the six sub-sections of the Test Strip. The operator of the fertilizer spreader will move down the sub-section spreading the Test

Figure7: Application of Test Material

Material and once reaching the end of the sub-section turn around and continue to spread without stopping until the sub-section is covered with Test Material. Once the sub-section of the Test Strip is completely covered with Test Material, a second pass is made by the operator of the fertilizer spreader spreading additional Test Material next to the curb.

A professional grade, manually operated and powered, large fertilizer spreader should be used to deposit the Test Material uniformly in the Test Strips, plus it is necessary to also make delicate use of a broom as administered by a designated operator to redistribute a small amount of the Test Material closer to the curb. Figure 8 shows the fertilizer spreader and broom used for spreading the Test Material.

Figure 8: Fertilizer Spreader and Broom

6.8 Diesel Test

The Diesel Test requires the Test Sweeper to enter the Test Course and operate in a non-sweeping mode at constant operating speed through both sections of the Test Track. Emissions readings are taken every second to determine the concentration levels of both PM_{10} and $PM_{2.5}$ emitted from the sweeper's engines.

The Diesel Test also allows the Test Sweeper operator to effectively experience a dry run through the Test Course and become familiar with Test Run conditions and the required Test Sweeper operational settings for the Test Course prior to an actual Test Run.

6.9 Test Run

During a Test Run, the pre-weighed Test Sweeper will sweep through the Test Course making two passes through the Test Track, consecutively. The Test Sweeper will enter the Warm-Up Track Area. The Test Sweeper stops traveling while all the necessary operational settings are made prior to the initiation of the Test Run. Also the Test Sweeper can be temporarily stored in the Warm-Up Track Area in the event of inclement weather (e.g. rain). Once all sweeper operational settings and configurations have been adjusted, the Test Sweeper must activate all sweeping systems and when ready initiate travel and sweep into the Test Track. The Test Sweeper must reach optimal operating speed prior to entering the Test Strip portion of the Test Track.

The Test Sweeper, having swept through the first section (1st pass) of the Test Track, will stop sweeping once the back of the Test Sweeper passes the end of the Test Track. The Test Sweeper must stop and cease all sweeping systems (i.e. vacuum, gutter brooms, main broom, raise pick-up head, etc.) before exiting the Track-Out Area. The Test Sweeper will then proceed and travel in a non-sweeping mode through the Track-Out Area and exit the Test Course. The Test Sweeper may turn around outside the Test Course (weather permitting or manoeuvre the Test Sweeper inside the Warm-Up/Track-Out Area of the Test Course for the 2nd pass) and re-enter the Test Course and initiate all sweeping systems in the Warm-Up Area and must reach optimal operating sweeping speed prior to sweeping the 2nd pass of the Test Track.

The test agency staff must document all the changes made to the Test Sweeper's settings as implemented by the manufacturer's representatives.

All Test Sweepers must operate with steel-bristled gutter brooms. Main brooms may be either poly-bristled or steel-bristled. Test Sweepers will use standard gutter broom operating procedures regarding their proximity to a curb, their rotation speed and angle of attack, when deploying their gutter brooms.

No water may be used either inside or outside of any Test Sweeper during the test.

All Test Sweepers must be operated in accordance with manufacturer/supplier recommended maintenance schedules, safety checks, and daily operational checks.

All Test Sweepers' operating parameters must be recorded and confirmed to be in compliance for each Test Run by a "sweeper experienced" testing agency representative riding in the cab with the Test Sweeper operator. Sweepings (Test Material) from the Test Run must be removed from the Test Sweeper's hopper after the completion of each Test Run following all applicable regulations and procedures for street sweeping disposal. Figure 9 shows the enclosed pit as the recommended storage facility to store the swept Test Material once emptied from the Test Sweeper's hopper in that it minimizes the release of PM_{10} and $PM_{2.5}$ during the disposal and/or subsequent disturbance of Test Material by wind into the air. Figure 10 illustrates the method the test agency staff should use when emptying the Test Sweeper's hopper, by wetting the sweepings prior to dumping and subsequent washing of the Test Sweeper.

Figure 9: Enclosed Street Sweeping Pit

Figure 10: Dumping of Residue Material

6.10 Number of Test Runs

Four consecutive tests (weather permitting) must be completed with specific operational settings as determined prior to the start of the Test Sequence and a full Test Sequence performed with the same specific operational settings. Once the operational settings are determined and documented they must be maintained throughout each of the subsequent Test Runs.

Only the three best overall performing days as determined by the testing agency will be used to determine the average values and to establish the performance levels achieved for each of the PM efficiency criteria. Four days of testing are required such that if there is an operator error and/or a sweeping system failure and the Test Run is deemed null and void and there are still three other opportunities to obtain three valid tests as required to calculate the achieved performance levels.

6.11 Equipment Used to Vacuum the Residue Material

A canister type HEPA (High Efficiency Particulate Air) vacuum must be used to clean the Test Track following each of the Test Runs in order to remove the Residue Material left behind. It is advisable to use at least four Shop Vac (e.g. Contractors Model) vacuums throughout the testing. The Shop Vac vacuum must be equipped with a combination of High-Performance HEPA Cartridge Filters and High-Efficiency Disposable HEPA Filter Bags. The vacuums must be fitted with stainless steel accessories and metal brushes. Any equivalent commercially available unit of equivalent performance and accessories or better can be used.

The HEPA vacuum equipment must be pre-conditioned at least once by vacuuming equivalent amounts of Residue Material prior to the first Test Run. Pre-conditioning of HEPA vacuum equipment can be done as part of an (strongly recommended) operator training process that fully duplicates a Test Run, including material spreading and residue vacuuming prior to the first Test Sequence.

Figure 11 illustrates HEPA vacuum and accessories, and Figure 12 illustrates test agency staff vacuuming the Residue Material from the Test Track after the Test Run.

Figure 11: Shop Vac HEPA Vacuums

Figure 12: Vacuuming of Residue Material

6.12 Equipment Used to Monitor Air Quality

A total of eight TSI: Model 8520 DustTrak™ Aerosol Monitor or equivalent must be used to determine the concentration levels of PM_{10} and $PM_{2.5}$ during the testing of the Test Sweepers and evaluate the PM efficiency of the Test Sweepers. Refer to Figure 6 for monitor locations.

The DUSTTRAK™ Aerosol Monitor is a portable, battery-operated laser photometer with real-time mass concentration readout and data logging capability. The monitor provides reliable PM concentration assessment and can varyingly measure particle concentrations, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$.

Figure 13: PM_{10} and $PM_{2.5}$ Monitor

6.13 Test Course Cleaning Methodology

The purpose of the Test Course cleaning methodology is to determine, by vacuuming and subsequently weighing, the amount of Residue Material remaining on the Test Strips as well as Test Material that has been disturbed, during a Test Run, from the Test Strips and deposited on adjacent areas. Systematic cleaning of the Test Course must be undertaken with the HEPA vacuum equipment after each individual Test Run.

One fresh cartridge filter should be used for one complete Test Sequence. Each HEPA cartridge filter must also be weighed before the start of the Test Sequence and after the end of the Test Sequence. Given the small amount of Residue Material collected by the HEPA cartridge filter during the vacuuming, it is deemed acceptable to add one-fourth of the HEPA cartridge filter weight to the weight of total Residue Material of each of the three selected “best” Test Runs.

Sufficient filter bags must be available to capture all of the Residue Material to be vacuumed. The average weight of the unused HEPA filter bags, heavy-duty plastic bags, 23 litre plastic containers and container lids must be established and their weights recorded. Once the HEPA filter bag is removed from the vacuum equipment the HEPA filter bag should be placed in a plastic container with a sealable lid that is lined with a heavy-duty plastic bag for storage. Each plastic container and its contents must be weighed and labelled with the date, time, test number, model and make of Test Sweeper and the weight recorded.

The HEPA filter bags should be checked periodically during the vacuuming and should be replaced once the HEPA filter bags are approximately 50% full in order to prevent the filter bags from breaking inside the vacuum canister and/or when removing an over filled bag. At the completion of each Test Run the vacuum canisters and metal accessories should be thoroughly cleaned of all Residue Material and/or moisture. Figure 14 and 15 illustrate the HEPA cartridge, filter bags and plastic containers respectively.

The Test Course is divided in eight sub-sections for the purpose of vacuuming the Residue Material. The Test Track is divided in four equal sub-sections[2], two Warm-Up/Track-Out Areas sections and two Sidewalk area sections. Each section was vacuumed by one HEPA vacuum and after the Residue Material was removed from the section the HEPA filter bag was removed and a new HEPA filter bag was placed inside the HEPA vacuum prior to vacuuming the next section.

Figure 14: HEPA cartridge and filter bag

Figure 15: Containers

6.14 Weighing the Test Sweeper

Test Sweepers must be weighed immediately prior to, and following, the completion of a Test Run. A portable four pad Axle Weigh Scale (Canadian Scale Company Ltd), capacity of 20,000 lbs at a graduation of 10 lbs, or equivalent should be used to weigh the Test Sweeper. The Axle Weigh Scale should be setup adjacent to the Test Facility, see Figure 16. The weigh scale that is used to weigh the Test Sweeper, should be verified (ability to incrementally weigh the differential weight), ideally this should be verified shortly before any testing commences and preferably checked for consistency with a known truck weight on a daily basis.

[2]These eight subsections are to be used or vacuuming only, as 12 sub-sections used to apply the Test Material.

Figure 16: Portable Axle Weigh Scale

6.15 Weighing of Test Material and Residue Material

A lightweight portable scale (e.g. Cardinal Scale Manufacturing Company, GP Series Digital Low-Profile Scales, GP-400-205 Model) with a capacity of approximately 180 kg at a graduation of 0.1kg, or equivalent equipment should be used to weigh the Test Material and Residue Material in the plastic containers. The portable scale should be setup in the Weighing Area, where the Test Material is stored. The weigh scale should be verified at the beginning and at the end of the weighing of Test Material and Residue Material.

Figure 17: Lightweight Portable Scale for Test Material

6.16 Method Used to Analyze Data

After weighing the Test Material and the Residue Material contained in each of the containers, the total Test Material weight is derived by subtracting the total weight of the garbage bag and the empty Test Material bags, and the total Residue Material is derived by subtracting the average weight of a HEPA filter bag, plastic bag, plastic container and lid. Document all the weights obtained and perform the calculations required to determine the operational performance efficiency of the Test Sweeper for each Test Section. Section 9 contains the basic calculations for each of the PM efficiency criteria.

Appendix A contains the sweeper information forms that should be used to document all data observed and measured during the Test Run for each day of testing.

Appendix B contains the air quality monitoring test events log sheets that identifies the sequence of events, the duration of events and the time gap between events during the Test Run.

Appendix C contains the spreadsheets and the calculations that must be performed in order to obtain the efficiency levels for each PM efficiency criteria.

Appendix E contains the PM_{10} and $PM_{2.5}$ Data Log Summary that contains the method to calculate the Maximum Concentration and Total Concentrations. Maximum Concentration is the highest one second reading of PM_{10} and $PM_{2.5}$. Total Concentration is the concentration for a total of 20 minutes, five minutes prior to the maximum reading and 15 minutes after the maximum reading for PM_{10} and $PM_{2.5}$ respectively.

An average of the three best values calculated for each of the efficiency criteria must be used to determine the performance level.

7.0 OTHER TEST RUN REQUIREMENTS

7.1 Conditioning Run for Test Sweepers

The Test Sweepers must be preconditioned under dry street conditions and without the use of water, either outside or inside the Test Sweeper. The conditioning should take place on an asphalt paved two-lane road with a typically heavy fine road dust for a minimum of six kilometres (sweeping the two kilometre Conditioning Road three times) prior to the weighing of the Test Sweeper and the subsequent Test Run. The pre-conditioning must be repeated for all the subsequent Test Runs in the Test Sequence. A dry dump of the sweepings could be made prior to weighing, should the hopper become filled to capacity - but it should not be necessary. The roadway used to precondition the street sweepers should be of similar road classification and must be external to the Test Facility.

A “sweeper-experienced” test agency representative must accompany the Test Sweeper by riding in the cab.

Monitor and record on video or photographs, from another vehicle, the performance of each Test Sweeper as the Test Sweeper undertaken its Conditioning Run.

The Conditioning Run (see Figure 18) will be exposed to prevailing environmental conditions and to extraneous disturbances (e.g. as from wind or precipitation). Excessive precipitation will warrant the postponement of the testing.

Figure 18: Conditioning Run

7.2 Air Quality Monitoring

Particulate matter concentrations of PM_{10} and $PM_{2.5}$ in the Test Course must be monitored throughout the testing procedures. Such monitoring provides sweeper performance measures of the amount of Test Material disturbed into the air. The evaluation consists of obtaining the Maximum and Total Concentrations of PM_{10} and $PM_{2.5}$.

Eight TSI Dust Track monitors (or equivalent) must be employed to monitor PM_{10} and $PM_{2.5}$. The dust monitors are located inside the Test Facility (albeit in the same building enclosure but separated from it by the Test Track's plastic/coated tarpaulin/tent wall). Monitoring equipment is installed in an area referred to as the Monitoring Enclosure see Figure 19. Special sample collecting flexible Tygon tubing enters the Test Facility at specific locations (see Figure 3 and 6) as follows:

- the centre, left and right monitors (one monitor for PM_{10} and one monitor for $PM_{2.5}$ for each location) should be located at 1.5 metres above ground and collect concentration samples in the air at central, left and right points of the Test Track above the area of the sidewalk; and
- the centre top monitors (one monitor for PM_{10} and one monitor for $PM_{2.5}$) should be located at 3.5 metres above ground and collect concentration samples in the air at a central point of the Test Track above the area of the sidewalk.

Figure 19: Monitoring Enclosure

The total length of the flexible Tygon tubing is 75cm from the nozzle of the monitor to the inside of the enclosed Test Course. There is a vertical separation of 10 cm between the $PM_{2.5}$ and PM_{10} monitors and 10 cm of flexible Tygon tubing projects into the enclosed Test Course. The flexible Tygon tubing is to be secured and encouraged (with aid of duct tape to point the Tygon tubing) down towards the ground to avoid direct dust fall out into the tubes from the air above and from deposits sliding off of the tent walls.

Air concentrations of PM_{10} and $PM_{2.5}$ should be measured every second from prior to the commencement of each Test Run, through the Test Run and until the HEPA vacuum cleaning is completed in order to ensure that concentration levels are at an acceptable level prior to testing agency personnel should enter the Test Course. All personnel entering the Test Facility are required to obtain a Respirator Fit certification from an industrial hygienist and to wear all necessary Personal Protection equipment. No personnel are permitted to enter the Test Facility if the air concentration of PM_{10} is greater than 3,500 $\mu g/m^3$. Air quality changes as a function of disturbance due to HEPA vacuuming are also monitored and similar safety constraints imposed.

Venting of the Test Facility can only occur when the concentration levels are a less than 100 µg/m^3 in order to ensure that Test Material that has been disturbed by the Test Sweepers has settled on the surface of the Test Track and there is no release of pollutants from the Test Facility into the surrounding environment.

The monitored air data is time stamped in accordance with the test events throughout the Test Run. The progress of the Test Sweeper is monitored by a test agency's representative through specially constructed "windows" in the Test Course plastic sheeting and signaling of other staff of its progress throughout the Test Course. The time is noted when each Test Run began and ended and when the Test Sweeper arrives at the following marks: beginning of Test Track, beginning of Test Strip, middle of Test Tracks, end of Test Strip and end of Test Track. Time is recorded to the nearest second and output directly to the computer data file for storage. This also permits the test agency staff to confirm the Test Sweeper's Operating Speed during each Test Run.

Other air quality monitoring must be also undertaken. A 3M- Multi-Gas Personal Monitor (Model 955-100-400) or equivalent, see Figure 19, can detect the following gases: Oxygen, Carbon Monoxide and Nitrous Oxide. The alarm monitors must be located in the Monitoring Enclosure Area and inside the Test Sweeper during the Test Run.

Figure 20: Multi-Gas Personal Monitor

7.3 Weather Conditions

Ambient air temperature, relative humidity and wind strength must be recorded using on-site meteorological equipment and accessing meteorological data from Environment Canada or USA NOAA. Meteorological data (temperature and relative humidity plus wind strength) should be obtained from the on-site meteorological equipment, see Figure 20 and 21. For example, TSI Incorporated Q-Track IAQ Model 8550/8551 equipment can be used to measure Humidity and Temperature. Forecast information (used to predict and avoid initiating a test during unacceptable weather conditions) should be obtained on-line from Environment Canada-Meteorological Service Canada (MSC) or US NOAA. Also, hourly recorded data must be obtained from the nearest weather station for the duration of the testing plus one day prior.

The following activities must be undertaken during the testing:

- Prevailing weather conditions must be recorded before, during and after each Test Run;
- There must be no standing water remaining from precipitation or post precipitation seepage into the Test Course and Conditioning Road – i.e. the Test Track must remain dry; and
- Meteorological instrumentation must either exist or be installed near the Test Course to measure temperature, relative humidity, and permit absolute humidity to be calculated.

The excessive presence of water vapour (moisture) in the air is very likely to have an influence in increasing the moisture content of the test materials which may lead to material "clumping". Essentially, the material becomes both more inherently self-cohesive than if the material were perfectly dry and free-running. (This may be envisaged as being similar to the common clumping of salt grains in the presence of moisture.)

How critical this is to on-street test results obtained is uncertain. The moisture itself will add only marginal mass to samples – but this is corrected for by drying and weighing samples. Particle bonding caused by moisture is likely to be present but may well be insignificant.

However, based on prudent avoidance it is recommended that test materials not be laid down or swept up in conditions with a relative humidity (air) greater than 90%. Further, if the moisture content of materials to be spread exceeds 15% (i.e. is approaching saturation), such materials should be spread out to air-dry until the moisture content percentage by weight is less than 20%. These two values may be modified if after specific testing for clumping and moisture content of materials, it is deemed appropriate to do so at higher relative humidity levels or higher material moisture content levels.

These following values are provided to identify conditions above or below which weather will adversely impact the Test Material or the measurements or its removal. Consideration is also given to ensure combinations of weather factors do not combine to create unacceptable conditions. The following conditions must be present:

- Air temperature needs to be above freezing, (otherwise loose material might be bound by ice forming in interstices);
- Air temperature should be below levels at which any Test Material is baked into cohesive or partially cohesive wholes. This value will vary with relative humidity;
- The suggested test operating temperature range is from 5°C to 30°C with additional restrictions depending on Relative Humidity and Precipitation to ensure material is consistently and reproducibly dry and loose;
- Test Material should not be laid down or swept up in conditions with a relative humidity (air) greater than 90%, if the moisture content of materials to be spread exceeds 15% (i.e. is approaching saturation), the Test Material should not be laid down and the Test Materials should not be laid down;
- During the test, wind speeds in the Test Facility must be below 15 km/hr so as not to disturb and remove the Test Material from the Test Track; and

- Though a very light mist like rain may be tolerated if of very short duration. A longer period of very light rain or mist should be followed by a substantial drying period to allow for all pavement surfaces to dry completely and **no moisture or a wet Test Sweeper is permitted to contact the Test Track**;

The presence of significant amounts of rainfall , temperature below 5°C or above 30°C, relative humidity greater than 90%, and wind in excess of 15 km/hr inside the Test Facility on the test day will lead to the Test Run being postponed until the next day and/or a subsequent days when suitable environmental conditions exist.

Figure 21: Meteorological Equipment (Q-Track)

Figure 22: Anemometer

7.4 Recording of Test Runs

It is advisable to maintain a good visual record of all test procedures throughout the test day. Agency staff should set-up remotely operating video recorders at both ends of the Test Course. The digital signal from the video cameras can be fed to a television monitor outside the Test Facility for the benefit of visitors/observers, who lack Respirator Fit certification and Personal Protection equipment, and can observe the testing.

An additional digital camera can be used to record all key components of the test, including the demonstration of Test Sweeper, conditioning of Test Sweeper, weighing of Test Sweeper, weighing of all test materials, application of all test materials, Individual Tests, vacuuming of Residual Material, weighing of Residual Material, post test weighing of Test Sweeper and its clean-up.

7.5 Safety Requirements

All necessary safety equipment and requirements as specified by the Occupational Health and Safety regulatory agency responsible for the jurisdiction where the test is being implemented must be employed, including all requirements in respect to the handling, storage and disposal of the Test Material and working in the road right-of-way. All personnel should wear the appropriate safety equipment as required when working at the Test Site, such as: hard hats, safety vests, safety boots, goggles/sun glasses, gloves, sunscreen and mosquito repellent.

Additional safety requirements must be employed in the handling the selected Test Material (e.g. Camel Wite). The obvious possibility of exposure to the very high concentrations of airborne particulate matter impacting driver operators, and HEPA vacuum operators – it is advisable to encourage several precautions to be firmly instituted, as follows:

- The Test Facility should be locked and out of bounds to all personnel other than those engaged in the Street Sweeper Testing Project;
- HEPA filter equipped respirators should be “Fit Tested” to all personnel engaged in the project and worn by all personnel when inside the Test Facility. Respirators and Respirator Fit Testing must be stipulated and undertaken by a qualified Industrial Hygenist; and
- All personnel must wear safety protective clothing when working on the site of the Test Facility (hard hats, safety vests and safety boots) plus project specific clothing (North Model respirators with HEPA filtration, Tyvek suits, goggles, and gloves) when inside the Test Facility, see Figure 22.

Figure 23: Personal Protection Equipment

8.0 TEST RUN PROCEDURE SUMMARY

8.1 Procedure Prior to the Test

Performed Days Prior to the Test	Prepare and weigh all the Test Material bags required for each Test Run;
	Review all tasks, roles and responsibilities with test agency staff;
	Clean the Test Track Surface of the Test Course, so that the surface is interaction free and dry;
	Condition the Test Track Surface of the Test Course with the Test Material by performing the Test Run with other agency sweepers;
	Condition the HEPA vacuums with the Test Material by performing a Test Run prior to initiating the official Test Sequence; and
	Perform a dry run of all the key tasks, such as spreading of Test Material, operating the monitoring equipment, vacuuming of Residue Material and documentation procedures.
Performed One Day Prior to the Test	The night (6-18 hours) before the test, a best available sweeper sweeps the Conditioning Road and the Test Track three times on each side of the street.
Morning of the First Test Run	Identify the Test Track markings for each of the areas: the mid point (solid blue line) of the Test Track, and the beginning and end of each Test Strip (solid pink line), the Test Strip sections defined (dashed pink line) and the beginning and end of the Test Track (solid green line);
	Prepare Test Track by covering the specific catch basins;
	Set-up all necessary equipment and materials in the Monitor Area, Weighing Area and Rest Area, including: Test Material spreader, vacuums, cameras, masks, weather monitor, tables, all prepared Test Material, garbage containers, water cooler, water, shovels/brooms, two rakes, PC's and other miscellaneous supplies and equipment; and
	Ensure all staff comply with all safety equipment requirements : safety boots, vest, hard hats, gloves, sun screen, mosquito repellant, respirators with HEPA filtration, Tyvek suits, goggles and bottled water.

8.2 Test Run Procedure

- **The test procedure should be implemented over four consecutive days (weather permitting). If there are prevailing environmental conditions that prevent the implementation of four consecutive days of testing, then testing will be postponed and will proceed on the next consecutive day when the environmental conditions are acceptable;**
- **Postponement of the testing due to weather is not considered to void the test;**
- **The test must be completed on consecutive test days for all operational settings by completing the full Test Run on each day. Only the three best overall performances will be used to establish the performance levels for each of the PM efficiency criteria; and**
- **If shrouds (or skirts) are not permitted on the Test Sweeper's gutter brooms during the test, the flexible portion of the shrouds need to be removed and no portion of the shrouds (flexible or non-flexible) are to be in contact with the curb during the Test Run.**

	Key Steps
Immediately Prior to Test Run	Meet and greet the manufacturers and review safety equipment requirements with the Vendor's representative(s);
	Vendor's representative(s) demonstrate the Test Sweeper at an appropriate location;
	A Test Agency representative will accompany the Test Sweeper at all times;
	Start the videotaping and taking of still shots to record all necessary information;
	Test Agency staff and vendor representative(s) inspect the Test Track and review the Test Run procedure;
	Perform the Diesel Test Run; and
	Perform the Conditioning Track Run;
Test Run	Each replicated Test Run will include two passes by the Test Sweeper through the Test Course. A Test Sequence includes the completion of all four Test Runs;
	Obtain the pre-test weight of Test Sweeper;
	Apply all the Test Material along the curb for a width of 2.75 metres on each of the two Test Strips;
	Test Sweeper must meet the following requirements: • operate with steel-bristled gutter brooms; • main brooms can be either poly-bristled or steel-bristled; • use standard gutter broom operating procedures regarding the proximity to curb, rotation speed, angle of attack, when deploying their gutter brooms;

	• operated in accordance with manufacturer/supplier recommended maintenance schedules, safety checks, and daily operational checks; and • application of water on the gutter brooms or inside the hopper is not permitted during the Test Runs.
Test Run continued	Apply the Test Material on the two Test Strips by using a fertilizer spreader to spread approximately 272 kg (+/- 5 kg) of Test Material on both of the Test Strips, each Test Strip a length of 30 metres by 2.75 metres width;
	Brooms are to be used to move a small amount the Test Material close to the curb to obtain consistent depths at the curb in each of the sub-sections;
	Test Sweeper operational settings must be recorded and confirmed to be in compliance for each Test Section. All operating settings and configurations will be recorded by a "sweeper experienced" test agency representative riding in the cab with the Test Sweeper operator;
	Test Sweeper Test Run • Test Sweeper will be positioned in the Warm-Up Track Area and ensure all operational settings and configurations are set and functioning; • The Test Sweeper will activate all operational settings and configurations and be in full street sweeping mode at optimal operating speed, before the pink line (beginning of the Test Strip) and continue to sweep along the Test Strip in full sweeping mode; • The Test Sweeper will continue to sweep through the Test Track and enter the Track-Out Area, where the sweeper will stop all sweeping systems before exiting the Track-Out Area (solid green line); • The Test Sweeper will exit the Test Facility turn around and re-enter the Test Facility, activate all operational settings and configurations in the Warm-Up Track Area and be in full street sweeping mode at optimal operating speed, before the pink line (beginning of the Test Strip) and continue to sweep along the Test Strip in full sweeping mode; • Test Sweepers are to operate at speeds within the manufacturers' specified range, if no manufacturer's "official" specifications are available – a sweeper will operate at an operating speed within the range of 5–10 km per hour along the Test Track applying all operational setting, including but not limited to: the main and side brooms, vacuum and filtration system; and • Test Sweeper's operating speed must be consistently maintained throughout the Test Run and independently recorded;
	Video record all Test Runs so as to show general performance of Test Sweeper in the Test Track and also specifically record action of gutter broom sweeping Test Material in each Test Strip;
	Obtain the post Test Run weight of the Test Sweeper;
Test Run	Test agency staff and vendor representatives inspect the Test Track for Residue Material;

continued	
	Dispose the street sweepings from the hopper of the Test Sweeper in an enclosed street sweepings pit. A light mist of water should be sprayed from a hose onto the material as the hopper is being emptied;
	Clean the Test Sweeper, park and lock the Test Sweeper inside a secure building;
	Vendor's representatives cannot remove the Test Sweeper from the test agency's premises for the duration of the Testing Sequence;
	Vacuum to collect the Residue Material inside the Test Track using four or more Shop-Vac vacuums or equivalent. The Test Agency staff will vacuum the full Test Course (80-100 metres by 10 metres of Test Track Surface area) including Test Track, Warm-Up/Track-Out Areas and Sidewalk areas;
	Use Shop-Vac vacuums with HEPA filter bags and HEPA filter cartridges to collect the Residue Material from the surface of the road;
	After vacuuming each Test Section, remove HEPA filter bags from the Shop-Vac vacuums and wipe the vacuum canisters and inlet with Swifter dust wipes or equivalent and store in sealed plastic containers;
	Replace the HEPA filter bags for every vacuum section in the Test Track (a total of eight sections), replace the HEPA filter cartridges after completing vacuuming of the Test Track for each the Test Runs; and
	Residue Material containers will be weighed, labeled and documented at the weigh station.
Immediately After the Test	The disposal of Residual Material from a Test Sweeper's hopper must follow all applicable regulations and is to be removed from the Test Sweeper's hopper after the completion of the Test Run;
	Remove all equipment from the Test Course;
	Download all air quality data from the monitors; and
	Clean and store all equipment.

8.3 Procedure After the Test

Analysis Performed	Edit and condense all the video footage and photo shots; and
	Document all the weights obtained and perform the weight and air quality calculations to obtain the PM efficiency for each Test Run for each of the criteria.

9.0 BASIC CALCULATIONS

The following calculations are completed for each Test Run. The performance levels for each of the six PM efficiency criteria are calculated by averaging the results of the overall three best Test Runs.

9.1 Removal Efficiency (%)

Removal of Test Material from Surface Efficiency (%) is defined as the amount of Test Material removed from the Test Track Surface of the Test Course by the Test Sweeper as a percentage of the total Test Material applied on the surface.

Removal Efficiency (%)

$$RE_{removal}=((W_{base}-W_{test})/W_{base})x100$$

where,

$RE_{removal}$ = Test Sweeper sweeping efficiency of removing Test Material from the Test Course using the vacuum method (%)
W_{base} = weight of Test Material spread over Test Strips before the Test Run (kg)
W_{test} = weight of Residue Material vacuumed from Test Course after Test Run (kg)

9.2 Deposit on Sidewalk Efficiency

Deposit on Sidewalk Efficiency (%) defined as the amount of Test Material disturbed during the street sweeping process and deposited on the adjacent sidewalk as a percentage of the total Test Material applied on the surface.

Sidewalk Efficiency (%)

$$SE_{deposit}=(W_{sd}/W_{base})x100$$

where,

$SE_{deposit}$= Test Sweeper sweeping efficiency of depositing Test Material on the Sidewalk Area using the vacuum method (%)
W_{base} = weight of Test Material spread over Test Strips before the Test Run (kg)
W_{sd} = weight of Test Material vacuumed from Sidewalk Area after Test Run (kg)

9.3 Air Contamination PM_{10} – Maximum Concentration

PM_{10} Air Contamination – Maximum Concentration (mg/m^3/kg) defined as the 1 second peak exposure reading of PM_{10} during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper as derived by using the vacuuming method.

$$PM_{10}AC_{max}=MCPM_{10}/M_{derived}$$

where,

$PM_{10}AC_{max}$ = PM_{10} Air Contamination – Maximum Concentration (mg/m^3/kg)
$MCPM_{10}$ = Maximum reading of PM_{10} during the Test Run (mg/m^3)
$M_{derived}$ = Test Material picked up and entrained inside the hopper as derived by using the vacuuming method (kg)

9.4 Air Contamination PM_{10} – Total Concentration

PM_{10} Air Contamination – Total Concentration (mg/m^3/kg) calculated by summing the 1200 readings taken at 1 second intervals over a 20 minute period starting at 5 minutes before the maximum PM_{10} reading during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper as derived by using the vacuuming method.

$$PM_{10}AC_{total}=TCPM_{10}/M_{derived}$$

where,

$PM_{10}AC_{total}$ = PM_{10} Air Contamination – Total Concentration (mg/m^3/kg)
$TCPM_{10}$ = Total of 1 second readings of PM_{10} for a 20 minute period during the Test Run (mg/m^3)
$M_{derived}$ = Test Material picked up and entrained inside the hopper as derived by using the vacuuming method (kg)

9.5 Air Contamination $PM_{2.5}$ – Maximum Concentration

$PM_{2.5}$ Air Contamination – Maximum Concentration (mg/m^3/kg) defined as the 1 second peak exposure reading of $PM_{2.5}$ during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper as derived by using the vacuuming method.

$$PM_{2.5}AC_{max}=MCPM_{2.5}/M_{derived}$$

where,

$PM_{2.5}AC_{max}$ = $PM_{2.5}$ Air Contamination – Maximum Concentration (mg/m^3/kg)
$MCPM_{2.5}$ = Maximum reading of $PM_{2.5}$ during the Test Run (mg/m^3)
$M_{derived}$ = Test Material picked up and entrained inside the hopper as derived by using the vacuuming method (kg)

9.6 Air Contamination $PM_{2.5}$ – Total Concentration

$PM_{2.5}$ Air Contamination – Total Concentration (mg/m^3/kg) calculated by summing the 1200 readings taken at 1 second intervals over a 20 minute period starting at 5 minutes before the maximum $PM_{2.5}$ reading during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper as derived by using the vacuuming method.

$$PM_{2.5}AC_{total}=TCPM_{2.5}/M_{derived}$$

where,

$PM_{2.5}AC_{total}$ = PM_{10} Air Contamination – Total Concentration ($mg/m^3/kg$)
$TCPM_{2.5}$ = Total of 1 second readings of $PM_{2.5}$ for a 20 minute period during the Test Run (mg/m^3)
$M_{derived}$ = Test Material picked up and entrained inside the hopper as derived by using the vacuuming method (kg)

9.7 Other Calculations and Variables (Measured and Derived)

9.7.1 *Weight of Test Material Applied*

Weight of Test Material applied over the Test Strips before the Test Run (kg) = **W_{base}**

9.7.2 *Remaining Efficiency (%)*

$$RE_{remaining}=(W_{test}/W_{base})x100$$

where,

$RE_{remaining}$= Test Sweeper sweeping efficiency of removing Test Material from the Test Course using the vacuum method (%)
W_{base} =weight of Test Material applied over Test Strips before the Test Run (kg)
W_{test} = weight of Residue Material vacuumed from Test Course after Test Run (kg)

9.7.3 *Weight of Residue Material Vacuumed*

Weight of Residue Material Vacuumed from Test Course after Test Run (kg)=**W_{test}**

$$W_{test}=W_{sd}+W_{out}+W_{track}$$

where,
W_{sd} = weight of Residue Material vacuumed from the Sidewalk Area of the Test Course (kg)
W_{out} = weight of Residue Material vacuumed from the Track-Out/Warm-Up Areas of the Test Course (kg)
W_{track} = weight of Residue Material vacuumed from the Test Track Area of the Test Course (kg)

9.7.4 *Material Inside the Hopper (Derived)*

Material Inside the Hopper (Derived) (kg) is calculated by subtracting the weight of Residue Material vacuumed from the Test Course after the Test Run from the Test Material applied over the Test Strips. (**$M_{derived}$**)

$$M_{derived}=W_{base} - W_{test}$$

where,

$M_{derived}$ = Test Material picked up and entrained inside the hopper derived using the vacuuming method (kg)
W_{base} = weight of Test Material spread over Test Strips before the Test Run (kg)
W_{test} = weight of Residue Material vacuumed from Test Course after Test Run (kg)

9.7.5 *Relocated Efficiency*

Relocated Efficiency (%) defined as the amount of Test Material disturbed during the street sweeping process and deposited elsewhere inside of the Test Course as a percentage of the total Test Material applied on the surface.

$$RE_{relocated}=((M_{sd}+W_{out})/W_{base})x100$$

where,

$RE_{relocated}$ = Test Material disturbed and re-deposited efficiency using the vacuuming method (%)
W_{sd} = weight of Test Material vacuumed from Sidewalk Area after Test Run (kg)
W_{out} = weight of Residue Material vacuumed from the Track-Out/Warm-Up Areas of the Test Course (kg)
W_{base} = weight of Test Material spread over Test Strips before the Test Run (kg)

9.7.6 *Weight of Test Sweeper Prior to Test Run*

Average weight of Test Sweeper Before the Test Run(kg)=**M_{base}**

9.7.7 *Weight of Test Sweeper After Test Run*

Average weight of Test Sweeper After the Test Run (kg)=**M_{test}**

9.7.8 *Test Material Inside the Hopper (Dervived)*

Test Material Inside the Hopper (kg)=**M_{hopper}**

$$M_{hopper}=M_{base}-M_{test}$$

where,

M_{hopper} = Test Material inside the hopper (kg)
M_{base} = average weight of Test Sweeper Before the Test Run (kg)
M_{test} = average weight of Test Sweeper After the Test Run (kg)

9.7.9 *PM_{10} Air Contamination – Maximum Concentration*

PM_{10} Air Contamination – Maximum Concentration ($mg/m^3/kg$) defined as the 1 second peak exposure readings of PM_{10} during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper.

$PM_{10}AC_{max}$-hw=$MCPM_{10}/M_{hopper}$

where,

$PM_{10}AC_{max}$-hw = PM_{10} Air Contamination – Maximum Concentration (mg/m^3/kg)
$MCPM_{10}$ = Maximum reading of PM_{10} during the Test Run (mg/m^3)
M_{hopper} = Test Material inside the hopper (kg)

9.7.10 *PM_{10} Air Contamination – Total Concentration*

PM_{10} Air Contamination – Total Concentration (mg/m^3/kg) calculated by summing the 1200 readings taken at 1 second intervals over a 20 minute period starting at 5 minutes before the maximum PM_{10} reading during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper.

$PM_{10}AC_{total}$–hw=$TCPM_{10}/M_{hopper}$

where,

$PM_{10}AC_{total}$–hw = PM_{10} Air Contamination – Maximum Concentration (mg/m^3/kg)
$TCPM_{10}$ = Total of 1 second readings of PM_{10} for a 20 minute period during the Test Run (mg/m^3)
M_{hopper} = Test Material inside the hopper (kg)

9.7.11 *$PM_{2.5}$ Air Contamination – Maximum Concentration*

$PM_{2.5}$ Air Contamination – Maximum Concentration (mg/m^3/kg) defined as the 1 second peak exposure readings of $PM_{2.5}$ during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper.

$PM_{2.5}AC_{max}$–hw=$MCPM_{2.5}/M_{hopper}$

where,

$PM_{2.5}AC_{max}$-hw = $PM_{2.5}$ Air Contamination – Maximum Concentration (mg/m^3/kg)
$MCPM_{2.5}$ = Maximum reading of $PM_{2.5}$ during the Test Run (mg/m^3)
M_{hopper} = Test Material inside the hopper (kg)

9.7.12 *$PM_{2.5}$ Air Contamination – Total Concentration*

$PM_{2.5}$ Air Contamination – Total Concentration (mg/m^3/kg) calculated by summing the 1200 readings taken at 1 second intervals over a 20 minute period starting at 5 minutes before the maximum $PM_{2.5}$ reading during the Test Run and divided by the kilograms of Test Material picked up and entrained inside the hopper.

$PM_{2.5}AC_{total}$–hw=$TCPM_{2.5}/M_{hopper}$

where,

$PM_{2.5}AC_{total}$–hw = $PM_{2.5}$ Air Contamination – Maximum Concentration ($mg/m^3/kg$)
$TCPM_{2.5}$ = Total of 1 second readings of $PM_{2.5}$ for a 20 minute period during the Test Run (mg/m^3)
M_{hopper} = Test Material inside the hopper (kg)

10.0 REPORTING

The following will be included in the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Report prepared by the independent test agency that implemented the testing of the Test Sweeper:

- All Test Dates and times;
- Temperature, Wind Speed, Precipitation, Relative Humidity;
- Manufacturer, Type, Model, Serial Number of the Test Sweeper;
- Detailed Specifications including all components/parts present during the testing of the Test Sweeper;
- Manufacturer's Operator and Representative(s) Names;
- Document all the security measures for the Test Sweeper storage outside the testing times;
- Provide full calibration records of all the weighing balances;
- All Operational Adjustments made to the Test Sweeper during each of the Individual Tests and the Resulting Time Taken for Adjustments;
- Copy of all Calculations Performed;
- Copy of All Recorded Data;
- Comments on any and all Environmental and Operational Conditions;
- Results for each PM Efficiency Criteria; and
- Description of Pavement Distresses

11.0 PROCUREMENT METHOD

This section provides information and shows how a Request for Proposal (RFP) can be successfully used to evaluate sweeper's performance and cost in a comparative manner.

The RFP process consists of three stages. In the first stage, each Proponent is required to submit, as part of their proposal, all the requested information. Once the proposals have been received by the user community staff will check to see that all mandatory requirements, specifically: Operational On-Street Canadian ETV certificate and PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Canadian ETV certificate, as well as street sweeper specifications. If the mandatory requirements are met, the Proponent will qualify for stage two of the process.

The second stage involves the evaluation of the sweeper's performance values provided in the following:

- Operational On-Street Canadian ETV certificate; and
- PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Canadian ETV certificate.

The sweeper can be verified under the Environmental Technology Verification Canadian ETV. Canadian ETV Program credible and independent technology verification of performance claims based on the following two protocols:

- PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test; and
- Operational On-Street Test.

In the last stage, the Proponent must provide the sweeper model and make that received the above ETV certificates to the user community for a further one week of Hands-on Operation and Maintenance evaluation testing. The Hands-on Operation and Maintenance will include the Proponent's providing of an in-depth one day demonstration, training and presentation of the equipment capabilities on the first day of the testing week. The same sweeper will be made available by the Proponent for a further four days, during which time the user community will operate and perform an on-the-job evaluation of the sweeper.

Following the final testing and the results achieved will be evaluated and scored by members of an evaluation committee. The Total Cost of Ownership will be evaluated including maintenance. Therefore a full overall performance and value of the street sweeper to the city will be evaluated. Finally, the Proponent achieving the highest overall score for their proposal, will be selected as the successful Proponent, and will be recommended for the award of the purchase contract for the supply of street sweepers.

12.0 MODIFICATION OF THE PROTOCOL

The Protocol contained herein was prepared by the City of Toronto with input from PAMI and Canadian ETV. This **PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol** is the property of the City of Toronto and cannot be copied and modified without the expressed permission of the City of Toronto. This is the 2nd version of the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol, dated May, 2016.

APPENDIX A

Sweeper Information Sheet

Sweeper Information Sheet

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:**

Testing Agency Operator's Name:
Sweeper Operator's Name:

Manufacturer's Representatives

Name:	**Title:**
Name:	**Title:**
Name:	**Title**

Distributor's Representatives

Name:	**Title:**
Name:	**Title:**
Name:	**Title**

Demonstration of the Sweeper by Distributor:

Time Started Time Completed

Inspection of Test Facility and Review of Test Sequence

Time Started Time Completed

Conditioning of Test Sweeper

Time Started Time Completed

Operational On-Street Test

Time Started Time Completed

Testing Agency Recorder's Name: Signature:
Verification Witness' Name: Signature:

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:**

Weight of Test Material Applied

	Gross Bag Weight (g)
Bag 1	
Bag 2	
Bag 3	
Bag 4	
Bag 5	
Bag 6	
Bag 7	
Bag 8	
Bag 9	
Bag 10	
Bag 11	
Bag 12	
Total Weight of Material and Bags	
Weight of Empty Bags	
Weight of Empty Bags	
Total Weight of Material Applied	

	Average Weight (g)
Container + Plastic Bag + Filter Bag + Lid	
Container + Plastic Bag + Filter Bag + Lid + Cartridge	

Weight of Test Material Inside the Test Sweeper Hopper

	Front Axle (kg)	**Rear Axle (kg)**	**Total Weight (kg)**
Pre-Test			
Post-Test			
Net Weight of Test Material Collected			

Testing Agency Recorder's Name: Signature:
Verification Witness' Name: Signature:

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:**

Operating Condition of Test Sweeper

	During Diesel Run	During Conditioning of the Sweeper	During the Test First Pass	During the Test Run Second Pass
Time Started				
Time Completed				
Speed (km/hr)				
RPM				
Water Use On Gutter Broom (y/n)				
Water Inside Hopper				
Braking during sweeping/vacuuming				
Pick-up Head On/Off				
Vacuum On/Off				
Vacuum Up/Down/Off				
Pick-up Head Up/Down/Out				
Set-up Mode of Pick-up Head				
Main Broom On/Off				
Main Broom Up/Down				
Left Gutter Broom On/Off				
Left Gutter Broom Up/Down				
Right Gutter Broom On/Off				
Right Gutter Broom Up/Down				
Dustless System On/Off				

Other Comments:

Testing Agency Recorder's Name: Signature:
Verification Witness' Name: Signature:

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:**

Weight of Test Material Collected

Container Number	Bag Number	Test Facility Vacuum Sections	Weight (g)	Container + Lid + Filter Bag and/or Cartridge Weight* (g)	Total Net Weight (g)
1	1	Pink-Top			
2	2	Pink-Bottom			
3	1	Green-Left			
4	2	Green-Right			
5	1	Blue-Right/Top			
6	2	Blue-Right/Bottom			
7	3	Blue-Left/Top			
8	4	Blue-Left/Bottom			
Total					

Summary of Test Material Collected

Weight of Material Inside the Hopper (measured)	
Weight of Test Material left behind on the Test Track	
Weight of Test Material left behind on the Warm-up Track	
Weight of Test Material left behind on the sidewalk portion of the Test Track	
Total Weight Left Behind	
Total Weight of Test Material Applied	
Total Weight of Test Material Picked-up by Test Sweeper (calculated)	
Variance between Material Inside the Hopper and Material Picked-up	

Testing Agency Recorder's Name: Signature:
Verification Witness' Name: Signature:

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:**

Environmental Conditions During the Test Run-A

	Time	Humidity	Temperature
Hourly Readings from Environment Canada Website			
Date	4:00 a.m.		
	5:00 a.m.		
	6:00 a.m.		
	7:00 a.m.		
	10:00 a.m.		
	11:00 a.m.		
	12:00 p.m.		
	1:00 p.m.		
	3:00 p.m.		
	4:00 p.m.		
Date	4:00 a.m.		
	5:00 a.m.		
	6:40 a.m.		
	7:00 a.m.		
	8:00 a.m.		
	9:00 a.m.		
	10:00 a.m.		
	11:00 a.m.		
	12:00 p.m.		

Testing Agency Recorder's Name: Signature:
Verification Witness' Name: Signature:

Date:
Test No.:
Sweeper Make and Model:
Serial No.: License No.:

Environmental Conditions Inside and Outside Test Facility-B

	Time Interval	Actual Time	Temp °C	Relative Humidity	Notes
1st Reading at 7:00 a.m.	0				
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				
2nd Reading, only if necessary					
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				
3rd Reading Pre-Diesel	0				
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				
4th Reading During Ventilation					
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				
5th Reading Application of Test Material					
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				

Testing Agency Recorder's Name: Signature:
Verification Witness' Name: Signature:

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:**

	Time Interval	Actual Time	Temp °C	Relative Humidity	Notes
6th Reading, Prior to Test Run					
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				
7th Reading, After Test Run					
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				
8th Reading, During Vacuuming					
Monitoring Room	+5				
Outside Test Building	+10				
Inside Test Facility	+15				
Monitoring Room	+20				

Testing Agency Recorder's Name: Signature:
Verification Witness' Name: Signature:

APPENDIX B

Air Quality Monitoring Test Events Log Sheets

TORONTO

Air Quality Monitoring Test Events Log Sheet

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:** **VIN:**

TIME = by Macro (i.e. Ctrl N) **Insert In Green Highlight Fields Only**
SPEED = by Formula **Speeds calculated based on the front of sweeper crossing green, pink and blue lines**

DIESEL TEST and DRIVER AWARENESS ***(performed on Day 1 of Test Sequence Only)***

Event #	SWEEPER LOCATION	TIMES	COMMENTS		
1	1st Door Opens & Test Sweeper Enters	A		**Duration Between Events 7-3 (sec)**	
2	1st Door Closes	B		Time Taken	**H=G-C**
3	Test Sweeper Crosses Start [First Green Line Right Side]	C	1st		
4	Test Sweeper Enters into Pink Material Section Right Side	D			
5	Test Sweeper Crosses Centre Blue Line	E		**Calculated Speeds**	
6	Test Sweeper Exits from Pink Material Section Right Side	F		**I=(50/H)*(3600/1000)** km/h	**J=I**
7	Test Sweeper Crosses End [Last Green Line Right Side]	G	2nd	**K=J/1.64** m/h	
8	2nd Door Opens & Test Sweeper Exits, Turns and Re-Enters	K		**Duration Between Events 14-10 (sec)**	
9	2nd Door Closes	L		Time Taken	**R=Q-M**
10	Test Sweeper Crosses Start [First Green Line Left Side]	M	3rd		
11	Test Sweeper Enters into Pink Material Section Left Side	N			
12	Test Sweeper Crosses Centre Blue Line	O		**Calculated Speeds**	
13	Test Sweeper Exits from Pink Material Section Left Side	P		**S=(50/R)*(3600/1000)** km/h	**T=S**
14	Test Sweeper Crosses End [Last Green Line Left Side]	Q	4th	**U=T/1.64** m/h	
15	1st Door Opens & Test Sweeper Exits	V			
16	1st Door Closes	W			

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:** **VIN:**

	Following Events Occur on ALL THREE TEST DAYS		
Event #	**TUNNEL VENTING PERIOD [15 minutes]**	**TIMES**	**COMMENTS**
17	Both Doors Open	**X**	
18	Both Doors Close	**Y**	
	FIRST SETTLING PERIOD [15 minutes]		
19	Begins (at End of Venting)	**AA**	
20	Ends	**AB**	
	MATERIAL SPREADING [approx. 20-30 minutes]		
21	Begins (at End of Settling)	**AD**	
22	Ends	**AE**	
	SECOND SETTLING PERIOD [30 minutes]		
23	Begins (at End of Spreading)	**AG**	
24	Ends	**AH**	

Duration Between Events 18-17 (sec)	
Time Taken	**Z=Y-X**
Duration Between Events 20 – 19 (sec)	
Time Taken	**AC=AB-AA**
Duration Between Events (22 - 21) sec	
Time Taken	**AF=AE-AD**
Duration Between Events (24 - 23) sec	
Time Taken	**AI=AH-AG**

Date:
Test No.:
Sweeper Make and Model:
Serial No.: **License No.:** **VIN:**

Event #	*Following Events Occur on ALL THREE TEST DAYS* SWEEPER LOCATION	TIMES	COMMENTS
25	1st Door Opens & Test Sweeper Enters	AJ	
26	1st Door Closes	AK	
27	Test Sweeper Crosses Start [First Green Line Right Side]	AL	5th
28	Test Sweeper Enters into Pink Material Section Right Side	AM	
29	Test Sweeper Crosses Centre Blue Line	AN	
30	Test Sweeper Exits from Pink Material Section Right Side	AO	
31	Test Sweeper Crosses End [Last Green Line Right Side]	AP	6th
32	2nd Door Opens & Test Sweeper Exits, Turns and Re-Enters	AU	
33	2nd Door Closes	AV	
34	Test Sweeper Crosses Start [First Green Line Left Side]	AW	7th
35	Test Sweeper Enters into Pink Material Section Left Side	AX	
36	Test Sweeper Crosses Centre Blue Line	AY	
37	Test Sweeper Exits from Pink Material Section Left Side	AZ	
38	Test Sweeper Crosses End [Last Green Line Left Side]	BA	8th
39	1st Door Opens	BF	
40	1st Doors Closes	BG	

Duration Between Events 31-27 (sec)	
Time Taken	AQ=AP-AL

Calculated Speed		
AR=(50/AQ)*(3600/1000)	km/h	AS=AR
AT=AS/1.64	m/h	

Duration Between Events 38-34 (sec)	
Time Taken	BB=BA-AW

Calculated Speed		
BC=(50/BB)*(3600/1000)	km/h	BD=BC
BE=BD/1.64	m/h	

Event #	*(includes: re-zeroing, calibration, convert to 30 second logging and reinstallation)*				
	MONITORS	**TIMES**	**COMMENTS**	**Duration Between Event 42 – 41 (sec)**	
41	Begin FIRST Downloading	**BH**		Time Taken	**BJ=BI-BH**
42	End FIRST Downloading	**BI**			
	THIRD SETTLING PERIOD [15 hours minimum]	*Doors remain CLOSED overnight!*			
43	Begins (at End of Sweeper Test)	**BK**		**Duration Between Event 44 – 43 (sec)**	
44	"Safe to Enter" Check Ends	**BL**		Time Taken	**BM=BL-BK**
	Occurs simultaneously with vacuuming includes: cleaning, re-zeroing, calibration, convert to 1 second logging and reinstallation				
	MONITORS			**Duration Between Event 46 – 45 (sec)**	
45	Begin SECOND Downloading	**BN**		Time Taken	**BP=BO-BN**
46	End SECOND Downloading	**BO**			
	At least two monitors to operate at all times during vacuuming (for worker safety reasons)				
	VACUUMING			**Duration Between Event 48 – 47 (sec)**	
47	Begins	**BQ**		Time Taken	**BS=BR-BQ**
48	Ends	**BR**			
	TUNNEL INSPECTION			**Duration Between Event 50 – 49 (sec)**	
49	Begins	**BT**		Time Taken	**BV=BU-BT**
50	Ends	**BU**			
51	**END OF TEST DAY**				

APPENDIX C

Air Quality Monitoring Calculations Performed

Calculations for Each Test Run

			Sweeper Make					
			Sweeper Model					
			Sweeper Technology					
			Test Date	**Day #**				
	PM Threshold Criteria	**Equation**	**Unit**	**Left Monitor A**	**Centre Monitor B**	**Top Monitor C**	**Right Monitor D**	**Average Day #**
1	**Removal Efficiency % - $RE_{removal}$**	((A-F)/A)*100						**Sum ((A-D)/4)**
2	**% Sidewalk Efficiency - $SE_{deposit}$**	(C/A)x100						**Sum ((A-D)/4)**
3	***Air Contamination PM_{10}*** **Max Concentration - $PM_{10}AC_{max}$**	K/B	$[mg/m^3]/kg$					**Sum ((A-D)/4)**
4	**Total Concentration - $PM_{10}AC_{total}$**	L/B	$[mg/m^3]/kg$					**Sum ((A-D)/4)**
5	***Air Contamination $PM_{2.5}$*** **Max Concentration – $PM_{2.5}AC_{max}$**	M/B	$[mg/m^3]/kg$					**Sum ((A-D)/4)**
6	**Total Concentration – $PM_{2.5}AC_{total}$**	N/B	$[mg/m^3]/kg$					**Sum ((A-D)/4)**
7	**% Remaining Efficiency - $RE_{remaining}$**	(F/A)x100						**Sum ((A-D)/4)**
8	***Air Contamination PM_{10}*** **Max Concentration - $PM_{10}AC_{max}$-hw**	K/H	$[mg/m^3]/kg$					**Sum ((A-D)/4)**
9	**Total Concentration - $PM_{10}AC_{total}$–hw**	L/H	$[mg/m^3]/kg$					**Sum ((A-D)/4)**
10	***Air Contamination $PM_{2.5}$*** **Max Concentration – $PM_{2.5}AC_{max}$-hw**	M/H	$[mg/m^3]/kg$					**Sum ((A-D)/4)**
11	**Total Concentration – $PM_{2.5}AC_{max}$-hw**	N/H	$[mg/m^3]/kg$					**Sum ((A-D)/4)**

		Sweeper Make						
		Sweeper Model						
		Sweeper Technology						
		Test Date		**Day #**				
	Variables	**Equation**	**Unit**	**Left Monitor A**	**Centre Monitor B**	**Top Monitor C**	**Right Monitor D**	**Average Day #**
A	**Test Area Material Applied - W_{base}**		Kg					**Sum ((A-D)/4)**
B	**Material Inside the Hopper (Derived) - $M_{derived}$**	A-F	Kg					**Sum ((A-D)/4)**
C	**Sidewalk Residual - W_{sd}**		Kg					**Sum ((A-D)/4)**
D	**Track-out/Warm-up Residual - W_{out}**		Kg					**Sum ((A-D)/4)**
E	**Test Track Area Residual - W_{track}**		Kg					**Sum ((A-D)/4)**
F	**Total Test Run Residual - W_{test}**	C+D+E	Kg					**Sum ((A-D)/4)**
G	**% Relocated - $RE_{relocated}$**	((C+D)/A)x100	%					**Sum ((A-D)/4)**
H	**Material Inside the Hopper - M_{hopper}**	J-I	Kg					**Sum ((A-D)/4)**
I	**Average Weight of Sweeper Pre-Test - M_{base}**		Kg					**Sum ((A-D)/4)**
J	**Average Weight of Sweeper Post-Test - M_{test}**		Kg					**Sum ((A-D)/4)**
K	**PM_{10} Maximum Concentration - $MCPM_{10}$**		mg/m^3					**Sum ((A-D)/4)**
L	**PM_{10} Total Concentration - $TCPM_{10}$**		mg/m^3					**Sum ((A-D)/4)**
M	**$PM_{2.5}$ Maximum Concentration – $MCPM_{2.5}$**		mg/m^3					**Sum ((A-D)/4)**
N	**$PM_{2.5}$ Total Concentration – $TCPM_{2.5}$**		mg/m^3					**Sum ((A-D)/4)**

TORONTO

Calculations for Each Monitor Location

			Sweeper Make				
			Sweeper Model				
			Sweeper Technology				
			Test Date	Day 1 A	Day 2 B	Day 3 C	Average for Specific Monitor Location
	PM Threshold Criteria	Equation	Unit	One Location (L,C,T or R) Monitor			
1	Removal Efficiency % - $RE_{removal}$	((A-F)/A)*100					Sum ((A-C)/4)
2	% Sidewalk Efficiency - $SE_{deposit}$	(C/A)x100					Sum ((A-C)/4)
3	*Air Contamination PM_{10}* Max Concentration - $PM_{10}AC_{max}$	K/B	[mg/m^3]/kg				Sum ((A-C)/4)
4	Total Concentration - $PM_{10}AC_{total}$	L/B	[mg/m^3]/kg				Sum ((A-C)/4)
5	*Air Contamination $PM_{2.5}$* Max Concentration – $PM_{2.5}AC_{max}$	M/B	[mg/m^3]/kg				Sum ((A-C)/4)
6	Total Concentration – $PM_{2.5}AC_{total}$	N/B	[mg/m^3]/kg				Sum ((A-C)/4)
7	% Remaining Efficiency - $RE_{remaining}$	(F/A)x100					Sum ((A-C)/4)
8	*Air Contamination PM_{10}* Max Concentration - $PM_{10}AC_{max}$-hw	K/H	[mg/m^3]/kg				Sum ((A-C)/4)
9	Total Concentration - $PM_{10}AC_{total}$–hw	L/H	[mg/m^3]/kg				Sum ((A-C)/4)
10	*Air Contamination $PM_{2.5}$* Max Concentration – $PM_{2.5}AC_{max}$-hw	M/H	[mg/m^3]/kg				Sum ((A-C)/4)
11	Total Concentration – $PM_{2.5}AC_{max}$-hw	N/H	[mg/m^3]/kg				Sum ((A-C)/4)

TORONTO

			Sweeper Make				
			Sweeper Model				
			Sweeper Technology				
			Test Date	**Day 1 A**	**Day 2 B**	**Day 3 C**	**Average for Specific Monitor Location**
	Variables	**Equation**	**Unit**	**One Location (L,C,T or R) Monitor**			
A	**Test Area Material Applied - W_{base}**		kg				**Sum ((A-C)/4)**
B	**Material Inside the Hopper (Derived) - $M_{derived}$**	A-F	kg				**Sum ((A-C)/4)**
C	**Sidewalk Residual - W_{sd}**		kg				**Sum ((A-C)/4)**
D	**Track-out/Warm-up Residual - W_{out}**		kg				**Sum ((A-C)/4)**
E	**Test Track Area Residual - W_{track}**		kg				**Sum ((A-C)/4)**
F	**Total Test Run Residual - W_{test}**	C+D+E	kg				**Sum ((A-C)/4)**
G	**% Relocated - $RE_{relocated}$**	((C+D)/A)x100	%				**Sum ((A-C)/4)**
H	**Material Inside the Hopper - M_{hopper}**	J-I	kg				**Sum ((A-C)/4)**
I	**Average Weight of Sweeper Pre-Test - M_{base}**		kg				**Sum ((A-C)/4)**
J	**Average Weight of Sweeper Post-Test - M_{test}**		kg				**Sum ((A-C)/4)**
K	**PM_{10} Maximum Concentration - $MCPM_{10}$**		mg/m^3				**Sum ((A-C)/4)**
L	**PM_{10} Total Concentration - $TCPM_{10}$**		mg/m^3				**Sum ((A-C)/4)**
M	**$PM_{2.5}$ Maximum Concentration – $MCPM_{2.5}$**		mg/m^3				**Sum ((A-C)/4)**
N	**$PM_{2.5}$ Total Concentration – $TCPM_{2.5}$**		mg/m^3				**Sum ((A-C)/4)**

Calculations for the Test Sequence

			Sweeper Make					
			Sweeper Model					
			Sweeper Technology					
			Test Date	**Average of Three Test Runs**				**Test Sequence Average**
	PM Threshold Criteria	**Equation**	**Unit**	**Left A**	**Centre B**	**Top C**	**Right D**	
1	**Removal Efficiency % - $RE_{removal}$**	((A-F)/A)*100						**Sum ((A-D)/4)**
2	**% Sidewalk Efficiency - $SE_{deposit}$**	(C/A)x100						**Sum ((A-D)/4)**
3	***Air Contamination PM_{10}*** **Max Concentration - $PM_{10}AC_{max}$**	K/B	[mg/m^3]/kg					**Sum ((A-D)/4)**
4	**Total Concentration - $PM_{10}AC_{total}$**	L/B	[mg/m^3]/kg					**Sum ((A-D)/4)**
5	***Air Contamination $PM_{2.5}$*** **Max Concentration – $PM_{2.5}AC_{max}$**	M/B	[mg/m^3]/kg					**Sum ((A-D)/4)**
6	**Total Concentration – $PM_{2.5}AC_{total}$**	N/B	[mg/m^3]/kg					**Sum ((A-D)/4)**
7	**% Remaining Efficiency - $RE_{remaining}$**	(F/A)x100						**Sum ((A-D)/4)**
8	***Air Contamination PM_{10}*** **Max Concentration - $PM_{10}AC_{max}$-hw**	K/H	[mg/m^3]/kg					**Sum ((A-D)/4)**
9	**Total Concentration - $PM_{10}AC_{total}$–hw**	L/H	[mg/m^3]/kg					**Sum ((A-D)/4)**
10	***Air Contamination $PM_{2.5}$*** **Max Concentration – $PM_{2.5}AC_{max}$-hw**	M/H	[mg/m^3]/kg					**Sum ((A-D)/4)**
11	**Total Concentration – $PM_{2.5}AC_{max}$-hw**	N/H	[mg/m^3]/kg					**Sum ((A-D)/4)**

			Sweeper Make					
			Sweeper Model					
			Sweeper Technology					
			Test Date	Average of Three Test Runs				Test Sequence Average
	Variables	Equation	Unit	Left A	Centre B	Top C	Right D	
A	Test Area Material Applied - W_{base}		kg					Sum ((A-D)/4)
B	Material Inside the Hopper (Derived) - $M_{derived}$	A-F	kg					Sum ((A-D)/4)
C	Sidewalk Residual - W_{sd}		kg					Sum ((A-D)/4)
D	Track-out/Warm-up Residual - W_{out}		kg					Sum ((A-D)/4)
E	Test Track Area Residual - W_{track}		kg					Sum ((A-D)/4)
F	Total Test Run Residual - W_{test}	C+D+E	kg					Sum ((A-D)/4)
G	% Relocated - $RE_{relocated}$	((C+D)/A)x100	%					Sum ((A-D)/4)
H	Material Inside the Hopper - M_{hopper}	J-I	kg					Sum ((A-D)/4)
I	Average Weight of Sweeper Pre-Test - M_{base}		kg					Sum ((A-D)/4)
J	Average Weight of Sweeper Post-Test - M_{test}		kg					Sum ((A-D)/4)
K	PM_{10} Maximum Concentration - $MCPM_{10}$		mg/m^3					Sum ((A-D)/4)
L	PM_{10} Total Concentration - $TCPM_{10}$		mg/m^3					Sum ((A-D)/4)
M	$PM_{2.5}$ Maximum Concentration – $MCPM_{2.5}$		mg/m^3					Sum ((A-D)/4)
N	$PM_{2.5}$ Total Concentration – $TCPM_{2.5}$		mg/m^3					Sum ((A-D)/4)

APPENDIX D

Key Components of the Test Protocol

Key Components of Test Protocol

Test Facility	Material and Equipment
Design 1.2 Test Course – Tarpaulin enclosed on all three sides (sides and top of track) that contains defined test areas, ideally 80-100 metres in length by 10 metres in width; 1.3 Tarpaulin/tent material should have a smooth surface in order to minimize the loss/absorption of Test Material; 1.4 Test Course includes Test Track, Test Strips, Sidewalk Area and Warm-Up/Track-Out Areas; 1.5 Test Course – level as possible with an elevation difference not exceeding 0.3 metres; 1.6 Test Course must be covered with an aged asphalt surface representative of an aged city street (include cracking, potholes and/or crevices are desirable); 1.7 The surface of Test Course must be completely dry and kept dry throughout the testing, paints or any other materials that would interact with the test material must be removed or appropriate cleaning undertaken to ensure the surface is interaction-free; 1.8 Test Facility includes Test Course, Monitoring and Storage areas; 1.9 The Test Track should have an average roof height of 4.5 metres, +/- 10% over the test track, the structure must accommodate the sweeper; 1.10 Tarpaulin/tent material must be fastened to the Test Course asphalt in a way that forms a seal and minimizes the loss of Test Material; 1.11 Ensure adequate lighting is available for safe visual operations and the use of video/camera for recording and monitoring; 1.12 Use portable curbs to simulate a two-lane curbed roadway and these are placed the full length of the Test Track; 1.13 Electrical power must be available (110-volt line/receptacle and/or portable generator); 1.14 Any portable generators must be located outside the enclosed Test Course; 1.15 Test Track – Test Sweeper is to sweep at normal operating speed, range of 5-10 km/hr and in keeping with specified operating	***Environmental Conditions*** 2.1 The internal areas of the Test Facility must not be exposed to external environmental conditions and there must not be any extraneous disturbance of the applied Test Material; 2.2 Precipitation that would result in a paved road surface being wet and wind in excess of 10km/hr during the day of the test warrants the postponement of the testing; 2.3 Light precipitation of short duration resulting in the paved road surface quickly drying may cause a delay in testing; 2.4 Adequate lighting for safe visual operations and the use of video/camera equipment for recording and monitoring; ***Test Sweeper*** 3.1 Test Sweeper must operate with steel-bristled gutter brooms. Main brooms may be either poly-bristled or steel-bristled; 3.2 It is beneficial for the manufacturers to test their sweepers in as many operating configurations as deemed appropriate taking into consideration the specific operational requirements by the user community; ***Test Material*** 4.0 A surrogate Fine Road Dust material to be applied to Test Strip(s), approximately 272 kg of "Camel Wite" calcium carbonate paint filler (manufactured by Debro Chemical & Pharmaceuticals) with a mean diameter size of 3 microns or other material scientifically shown to have equivalent PM characteristics; ***Personal Protection*** 5.1 All personnel participating in the test must follow their organizations and the practices of the applicable Health and Safety jurisdiction; 5.2 Personnel are permitted to enter the Test Course for the purpose of inspecting the Test Course, vacuuming etc, after the completion of the Test Run, only when the air concentration of PM_{10} is less than 3,500 ug/m^3, with one exception, during the Test Run the personnel (wearing personal

conditions; 1.16 Test Track – includes two Test Strips; 1.17 Test Strip(s) – 30 metre area located in the centre of each of the 50 metre Test Track, where Test Material is applied; 1.18 Each Test Strip is divided into six 5 metre sections along the length of the Test Strip; 1.19 Catch basins or manhole covers must be temporarily covered and sealed over the top for the duration of the Test Sequence; 1.20 The pavement condition of the Test Course is determined by two types of distresses: surface defects and cracking. Surface defect distress includes raveling. Cracking distresses include longitudinal and meandering, alligator and transverse cracking;	protection) are allowed to enter the Test Course; 5.3 Venting of the Test Facility can only occur when the concentration levels are a less than 100 µg/m^3; 5.4 All staff entering the Test Facility are required to obtain a Respirator Fit certification by an industrial hygienist; 5.5 All personnel are required to wear protective clothing when inside the Test Facility at all times (hard hats, safety vest and safety boots) plus project specific clothing (north Model respirators with N100 HEPA cartridges, Tyvek suits, goggles and gloves);
Test Facility	**Material and Equipment**
1.21 Warm-up Track /Track-Out Areas – with minimum length of 15 metres located between the entrance to the Test Course and the Test Track; 1.22 Sidewalk Area – areas located within the Test Course adjacent to the curb running the full length of the Test Track; 1.23 Conditioning Track – a two kilometre length of two lane roadway external to the Test Facility. 1.24 Monitoring Enclosure – an area that is protected from environmental conditions, outside the enclosed Test Course, but adjacent to the Test Track where air quality monitoring equipment are located and continual observation throughout the testing can be undertaken by the Testing Agency staff; 1.25 Storage Enclosure – an area that is protected from environmental conditions, outside the enclosed Test Course, preferably adjacent to the Test Course, where Test Material and equipment is stored and a weighing station is located; 1.26 Eight TSI Dust 8520 monitors are employed to monitor the concentration levels for $PM_{2.5}$ and PM_{10}, located inside the Monitoring Enclosure area, adjacent to the tarpaulin/tent material of the Test Course; 1.27 Special sample collection Tygon tubing is used appropriate to and as provided with the PM monitoring equipment, the Tygon tubing	***Equipment*** 6.1 Use four Canister-type vacuum equipment – Shop-Vac Contractors, equivalent or better; 6.2 Use HEPA high efficiency disposable filter bags and HEPA high performance cartridge filters; 6.3 Use Stainless steel accessories and metal brushes to be used for the Shop-Vacs; 6.4 Sweeper Axle Weigh Scale (portable four pad scale) capacity of 20,000 lbs at graduation of 10 lbs; 6.5 Sweeper Axle Weigh Scale to weigh the Test Sweeper should be calibrated, daily; 6.6 A lightweight portable scale capacity of 180 kg at graduation of 0.1kg or equivalent should be used to weigh the Test Material; 6.7 The Test Material weigh scale should be calibrated at the beginning and end of the weighing and after every 3rd weighing; 6.8 Plastic containers and lids must be used to store the heavy-duty plastic bags, cartridges and filter bags containing Residue Material; 6.9 A professional grade manually powered and operated large fertilizer spreader must be used to spread the Test Material; 6.10A designated operator should use a garden rake to move the Standard Test Material into the curb; 6.11A minimum of two laptops are required

is connected to the monitors and entering the Test Course through the tarpaulin material at a "nose level" at 1.5 metres above ground for the centre monitor and 1.0 metre for the right and left monitors. Two additional centre top monitors were placed at 3.5 metres above ground. Monitors are located at the 7.5 metre, 15 metre and 22.5 metre mark along the Test Track; 1.28 The total length of the Tygon tubing is 75 cm. Maintain a vertical separation of 10 cm between the $PM_{2.5}$ and PM_{10} monitors, and ensure the 10 cm of Tygon tubing projects into the enclosed Test Course and points downward to the road surface;	throughout the test day to be used to backup the monitors, event and time logs of the test; 6.12A 3M- Multi-Gas Personal Monitor (Model 955-100-400, or equivalent) detect the following gases: Oxygen, Carbon Monoxide, Hydrogen Sulphide and Nitrous Oxide. Alarm Monitors must be located in the Monitoring Enclosure Area and inside the Test Sweeper during the Test Run; ***City of Toronto's specific operational requirements are that sweepers must provide levels of performance without using shrouds/skirts on the gutter brooms and/or main brooms.***
Procedures	**Procedures**
Test Facility 7.1 Test Run – an individual replicable test that evaluates the Test Sweeper's ability to remove Test Material from the Test Strips and deposit it into its hopper and its ability to minimize the disturbance of Test Material into the air; 7.2 Test Sequence – a combination of consecutive Test Runs, the Test Sweeper will have an opportunity to complete four Test Runs and analyze data from only the three best Test Runs in order to determine the efficiency for all criteria; 7.3 Selecting the best Test Runs includes reviewing the overall performance of all six criteria for one day of testing, using data for criteria from multiple days of testing is unacceptable; 7.4 Diesel Test – a Test Run that does not include the laying down and sweeping of Test Material from the Test Strips, but includes the monitoring of air concentrations in the Test Course in order to provide background ambient concentration resulting from Test Sweeper diesel exhaust; 7.5 Conditioning Run – A Test Sweeper will be "conditioned" by sweeping the pre-swept Conditioning Track, at normal operating speed with specified Operating Conditions, Test Sweeper sweeps the Conditioning Track three times; 7.6 Conditioning Track is pre-swept by a best available sweeper, three times, on both sides of the road, on the day of the testing;	***Test Sweeper*** 10.1 Test Sweeper Operating Speed 5 to 10 km/hr; 10.2 Test Sweeper must operate with steel-bristled gutter brooms, main brooms may be either poly-bristled or steel-bristled; 10.3 Test Sweeper is not permitted to leave the test site for the duration of the Test Sequence; 10.4 Operating Conditions – to sweep using all operating systems, including but not limited to: the main and side brooms, vacuum, regenerative-air vacuum and filtration system and must sweep without the use of water on any and all gutter brooms, main brooms and inside the hopper; 10.5 It is beneficial for the manufacturers to test their sweepers in as many operating configurations as deemed appropriate taking into consideration the specific operational requirements by the user community; 10.6 During the Diesel Test – Test Sweeper will operate at normal operating sweeping speed without sweeping; 10.7 The Diesel Test will be performed on the first Test Run of the Test Sequence; 10.8 Test Sweeper will sweep the Conditioning Track prior to being weighed and prior to the Test Run; 10.9 Test Sweeper will be weighed after completing the Conditioning Run and prior to the Test Run;

7.7 Prior to initiating testing, the Test Sweeper operating systems and components will be inspected by testing agency staff and the testing agency and Test Sweeper representatives will inspect the Test Facility and all equipment; 7.8 Pre-conditioning of the Test Course surface and enclosed tunnel with the Test Material should be undertaken as part of Test Facility preparation and staff training component that needs to be undertaken for at least two consecutive days and prior to testing of the Test Sweeper; 7.9 Open both doors of the garage and leave open for a period of 15 minutes, after the Diesel Test; 7.10 Close both doors and allow settling time of 15 minutes; 7.11 The Test Facility must be locked and entry is prohibited to all personnel other than key supervisory test agency staff; 7.12 No personnel are permitted to enter the Test Facility if the air concentration of PM_{10} is greater than 3,500 µg/m^3;	10.10 The weight of the Test Sweeper before and after the Test Sequence is used only as a quick assessment that illustrates the efficiency (or lack of) for any Test Sequence, if a significant amount of Residue Material such that vacuuming procedures may not be initiated and the Test Day will be aborted and deemed null and void; 10.11 Test Track is swept as part of one day's Test Run, once the Test Sweeper initiates sweeping in a Test Course, no stopping is permitted, except for specific times and locations as required during the Test Run; 10.12 All Test Sweeper's operating systems must be recorded and confirmed to be in compliance by an "experienced sweeper operator" riding inside the cab; 10.13 During the Conditioning Run the test agency representatives follow the Test Sweeper in another vehicle and monitor and record the performance of the Test Sweeper on video;
Procedures	**Procedures**
Other Equipment 8.1 The HEPA vacuum equipment must be pre-conditioned at least once with the Standard Test Material prior to the first Test Sequence; 8.2 One fresh cartridge filter must be used for one complete Test Sequence; 8.3 At the completion of each Test Run the vacuum canisters and metal accessories should be thoroughly cleaned; 8.4 Each container/lid containing the heavy duty plastic bag, filter and/or cartridge must be weighed, recorded and labelled with the date; time and test number and the weight recorded less the weight of the average weight of the filter bag, plastic bag, cartridge, and container/lid; 8.5 Test Course is divided into eight sections for the purpose of cleaning the surface and determining the location of the residual and displaced Test Material that is left behind by the Test Sweeper; 8.6 Sidewalk Area includes two sections that are vacuumed as separate sources; 8.7 Track Out/Warm Up Areas included two	***Test Sweeper continued*** 10.15 After completing the Test Run and weighing the Test Sweeper, the Test Sweeper will proceed to the enclosed sweeping pit and empty out the contents of the hopper; 10.16 The process of emptying the Test Sweeper will include the application of water inside the hopper prior to emptying the hopper and applying water on the Test Material as it is being released from the hopper; 10.17 Once the Test Sweeper is empty, the Test Sweeper must undergo initial cleaning using hydrant pressure hose; 10.18 Final thorough cleaning of the Test Sweeper is performed in wash bay facility, including all systems (i.e. filters) and prepared to perform a subsequent test the next day; 10.19 During the Test Sequence no parts of the Test Sweeper will be replaced; ***Test Material*** 11.1 All Test Material must be weighed and documented prior to the application of

sections that are vacuumed as separate sources; 8.8 Test Track includes 4 equal sub-sections, 25 m by 3.5 m that are vacuumed as separate sources; 8.9 Use laptop computers to download air concentration levels and log test events; 8.10 TSI Dust Track monitor data is analyzed to obtain the peak concentrations and total area under the curve for a 20 minute period with 5 minutes prior to maximum reading at the start of the Test Run and 15 minutes after the maximum reading, the data is collected at 1 sec. intervals; 8.11 Background air concentration levels are measured each second during all test events; 8.12 Air concentration monitoring should be stopped before the start of surface vacuuming (the morning following the day of testing) and monitors must be cleaned and calibrated daily; 8.13 The air concentration data must be time stamped throughout the testing recording the time a specific event occurs at a specific location along the Test Track, refer to the Test Events Log for more detailed information; 8.14 A video recorder is employed at both ends of the Test Facility recording all aspects of the testing, and a digital signal is also fed to a television monitor outside of the Test Facility for the benefit of visitors who lacked Respirator Fit Certification; 8.15 Time must be synchronized between the laptops and the air quality monitors;	the material, the weight of the bag(s) containing the Test Material is subtracted from the total weight of Test Material; 11.2 All Test Material is consistently applied to the Test Strip sections (30 metres by 2.75 metres) surface with a greater depth of test material close to the curb; 11.3 After the application of the Test Material allow 30 minutes of settling prior to initiating the Test Run; 11.4 Given the small amount of Test Material that is collected on the cartridge filter it is deemed acceptable to add one third of the amount of additional material added from the cartridge filter to the weight of residual remnant for each of the three “best” Test Runs; 11.5 The cartridge filters are weighed separately and the net total is divided by three and added to the total Test Track residue quantity;
Procedures	**Procedures**
Environmental Conditions 9.1 Air temperature, humidity (relative and absolute) and wind direction should be recorded using on site equipment and by accessing standard national **meteorological** data; 9.2 Wind speed should be below 10km/hr; 9.3 Conditioning Track must not have standing water remaining from precipitation or post precipitation seepage;	***Documentation*** 12.1 See diagrams of the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Course (Figure 1); Locations of Monitors (Figure 2); and Detailed Marking of Test Track (Figure 3); 12.2 Test Sequence Summary of procedures during one day of testing can be found in Section 8 of the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol; 12.3 Appendix A contains the PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test – Sweeper Information Sheet that can be

	used to collect all the records and measurements during the testing; 12.4 Appendix B contains the air quality monitoring test events log sheets; 12.5 Appendix C contains the statistical analysis performed on applied and vacuumed Test Material; 12.6 Appendix D contains the key components of the test protocol; 12.7 Appendix E contains the PM_{10} and $PM_{2.5}$ data log summary; 12.8 Appendix F contains the description of key flexible pavement distresses; 12.9 Appendix G contains MSDS Sheet for the Test Material; and, 12.10 Appendix H contains pre-cast concrete curb design.

APPENDIX E

PM_{10} and $PM_{2.5}$ Data Log Summary

PM_{10} and $PM_{2.5}$ Data Log Summary Table

Maximum Concentration is the highest one second reading of PM_{10} and $PM_{2.5}$.
Total Concentration is the concentration for a total of twenty minutes, five minutes prior to the maximum reading and 15 minutes after the maximum reading for PM_{10} and $PM_{2.5}$ respectively.

Test No.:	
Sweeper Make and Model:	
Serial No.	
License No.:	VIN:

						PM_{10}	$PM_{2.5}$
		Total Concentration for 20 minutes				SUM(F6:F1205)	SUM(G6:G1205)
				Maximum Reading		MAX(D6:D1206)	MAX(E6:E1206)
No.	Time	Test Date	Actual Time	Actual PM_{10}	Actual $PM_{2.5}$	Average PM_{10}/Second	Average $PM_{2.5}$/Second
	(sec)		(sec)	(µg)	(µg)	(D4+D3)/2*(A4-A3)	(E4+E3)/2*(A4-A3)

Sample

	A	B	C	D	E	F	G
1	0:00:00		14:13:13				
2	0:00:01		14:13:14				
3	0:00:02		14:13:15				
4	0:00:03		14:13:16				
5	0:00:04		14:13:17				
6	0:00:05		14:13:18				
7	0:00:06		14:13:19				
8	0:00:07		14:13:20				
9	0:00:08		14:13:21				
10	0:00:09		14:13:22				
11	0:00:10		14:13:23				
12	0:00:11		14:13:24				
13	0:00:12		14:13:25				
14	0:00:13		14:13:26				
15	0:00:14		14:13:27				
16	0:00:15		14:13:28				
17	0:00:16		14:13:29				
18	0:00:17		14:13:30				
19	0:00:18		14:13:31				
20	0:00:19		14:13:32				
21	0:00:20		14:13:33				
22	0:00:21		14:13:34				
23	0:00:22		14:13:35				
24	0:00:23		14:13:36				
25	0:00:24		14:13:37				
26	0:00:25		14:13:38				

APPENDIX F

Description of Key Flexible Pavement Distresses

Description of Key Flexible Pavement Distresses

The following provides detailed description of the key pavement distresses that are being used to determine the pavement condition of the Test Track. The two types of distresses are surface defects and cracking. Surface defect distress includes raveling. Cracking distresses include longitudinal and meandering, alligator and transverse cracking.

Also, included is the City of Toronto's, Pavement Distress Manifestations Summary Table for Composite and Flexible Pavements summarizing the pavement distress types, the severity and extent criteria.

1. Raveling and Weathering:

a. Definition:

Weathering and raveling occur when the pavement surface is worn away due to loss of fine asphalt particles or asphalt cement and dislodged aggregate particles. These types of distress indicate that the asphalt binder has hardened or that a poor-quality mixture was used.

b. Causes:

Raveling may be caused by traffic loading from tracked vehicles as well as a lack of bond between aggregate particles and mortar. Frost action on concrete that is not fully cured may also cause raveling. Dislodging of the aggregates and softening of the surface due to spillage are also included under raveling. This type of distress is often worse in the wheel tracks of the riding surface.

c. Measurement:

Weathering and raveling are measured in *square metres of surface.*

d. Classification:

Raveling Severity Levels

Severity Level	Description
Slight	Barely noticeable, with some loss of pavement material. Minor loss of fines.
Moderate	Pavement has a pockmarked appearance with marks well spaced. There is a shallow disintegration of the pavement surface. Minor loss of coarse aggregate.
Severe	Pavement has a pockmarked appearance with large, shallow marks closely spaced, progressing to potholes. Severe loss of coarse aggregate.

Raveling Extent Levels

Extent Level	Description- % of Total Area
1	0-10%
2	10-20%
3	20-40%
4	40-60%
5	60-100%

e. Physical Appearance:

Figure 1a Slight Raveling

Figure 1b Moderate Raveling

Figure 1c Severe Raveling

2. Longitudinal and Meandering Cracking

a. Definition:

The relatively straight pavement longitudinal cracking occurs in a direction parallel to the pavement centreline. Meandering cracking tends to weave its way across the pavement but in a general direction parallel to the centre line. The location of either crack within the lane (e.g. wheel path, non-wheel path) is significant because it is created by different causes.

Longitudinal cracks associated with the beginning of alligator cracking are generally discontinuous, broken, and occur in the wheel path. Any longitudinal crack that is clearly within the wheel path should be rated.

b. Causes:

Wheel path cracking is generally caused by shear forces created by heavy loading from heavy tucks and tractor trailers. Non-wheel path cracking is generally related to a paving cold construction joint.

c. Measurement:

Cracking is generally measured in *metres of length.*

d. Classification:

Longitudinal Cracking Severity Levels

Severity Level	Description
Slight	A crack with a mean width < 12 mm, or a sealed crack with a sealant material in good condition and with a width that cannot be determined.
Moderate	Any crack with a mean width between 12 mm and 25 mm Or any crack with a mean width < 25 mm and adjacent low severity random cracking.
Severe	Any crack with a mean width > 25 mm, Or any crack with a mean width < 25 mm and adjacent to high severity random cracking.

Longitudinal Cracking Extent Levels

Extent Level	Description- Length per 2 lanes
1	<1 full length crack
2	1 to 2 full length cracks
3	2 to 3 full length cracks
4	3 to 4 full length cracks
5	> 4 full length cracks

e. Physical Appearance:

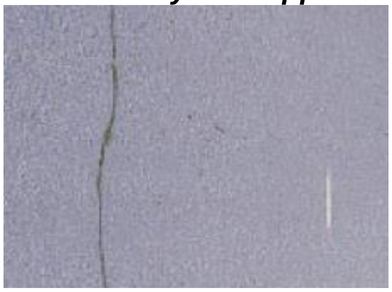


Figure 2a Slight Longitudinal Cracking

Figure 2.b Moderate Longitudinal Cracking

Figure 2.c Severe Longitudinal Cracking

Non-wheel path cracking should be recorded separately, for each severity level. The length in metres with sealant in good condition should also be recorded, at each severity level.

3. Transverse Cracking

a. Definition:

This type of distress refers to cracks that are predominantly perpendicular to the pavement centerline and, in composite pavements, are not located over the joints of the Portland cement concrete base underneath. (Distress of the latter type is known as reflection cracking). They may extend partially or fully across the roadway.

b. Causes:

They may be caused by surface shrinkage due to low temperatures, hardening of the asphalt, or cracks in underlying pavement layers such as cracked asphalt layer or PCCP slabs, in the case of composite pavements.

c. Measurement:

Cracking is generally measured in *metres of length.*

The number and length in metres of transverse cracks at each severity level should be recorded. The entire crack should be rated at the highest severity level present for at least 10% of the total length of the crack.

The length of cracks with sealant in good condition at each severity level should also be recorded. Only record this quantity when the sealant is in good condition for at least 90% of the length of the crack.

d. Classification:

Transverse Cracking Severity

Severity Level	Description
Slight	An unsealed crack with a mean width < 12 mm, or a sealed crack with a sealant material in good condition and with a width that cannot be determined.
Moderate	Any crack with a mean width between 12 mm and 25 mm Or any crack with a mean width < 25mm and adjacent low severity random cracking.
Severe	Any crack with a mean width > 25 mm, Or any crack with a mean width < 25 mm and adjacent to high severity random cracking.

Transverse Cracking Extent Levels

Extent Level	Description- Space between cracks
1	> 25m
2	15-25m
3	10-15m
4	5-10m
5	0-5m

e. Physical Appearance:

Figure 3a Slight Tranverse Cracking

Figure 3b Moderate Transverse Cracking

Figure 3c Severe Transverse Cracking

4. Alligator Cracking

a. Definition:

This type of distress (also known as fatigue cracking) consists of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading. Cracking begins at the bottom of the asphalt surface where the tensile stress and strain are the highest under load. The cracks then propagate to the surface as a series of parallel longitudinal cracks, which eventually connect to form sharp-angled pieces, which resemble the skin of an alligator.

b. Causes:

This type of cracking is normally associated with poor drainage, where the moisture softens the supporting base thus allowing high deflections in the pavement. The greater the deflection, the greater the strain and tensile stress experienced by the pavement.

Alligator cracking occurs only in areas that are subjected to repeated traffic heavy loads, such as in wheel paths and edge of pavements where parking is allowed.

c. Measurement:

Alligator cracking is measured in *square metres of surface area*.

A major difficulty in measuring this type of distress is that several levels of severity can exist within the same distressed area. If the different severity levels can easily be distinguished, they should be measured and recorded separately. If not, the entire area should be rated at the highest severity level present.

If alligator cracking and rutting occur in the same area, each is recorded separately.

d. Classification:

Alligator Cracking Severity Levels

Severity Level	Description
Slight	Cracks with a mean width between < 12mm. Fine, longitudinal hairline cracks running parallel to each other with no or few interconnecting cracks. The cracks are not spalled. Pumping is not evident.
Moderate	Cracks with a mean width between 12mm to 25mm. Light alligator cracks into a pattern or network of cracks, which may be lightly spalled. Cracks may be sealed. Pumping is not evident.
Severe	Cracks with a mean width between > 25mm. A network or pattern of cracks that has progressed to the point that the pieces are well defined and spalled at the edges. Some of the pieces may rock under traffic. Pumping may be evident.

Alligator Cracking Extent Levels

Extent Level	Description- % of Total Area
1	0-4%
2	4-10%
3	10-30%
4	30-60%
5	60-100%

e. Physical Appearance:

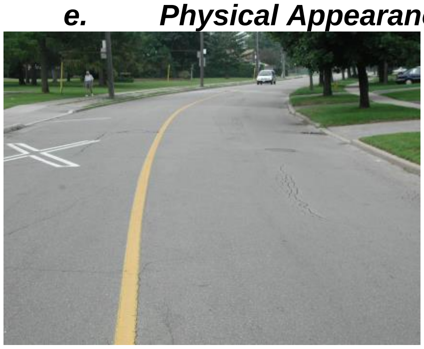


Figure 4a Slight Alligator Cracking

Figure 4b Moderate Alligator Cracking

Figure 4c Severe Alligator Cracking

PAVEMENT DISTRESS MANIFESTATIONS SUMMARY TABLE FOR COMPOSITE AND FLEXIBLE PAVEMENTS
Transportation Infrastructure Asset Management, Transportation Services, City of Toronto

DISTRESS TYPE	EVALUATION CRITERIA								
	SEVERITY			EXTENT					MEASURE
	Slight (0)	Moderate (1)	Severe (2)	1	2	3	4	5	
Surface Defects									
Raveling	Minor Loss of Fines	Minor loss of CA	Severe Loss of CA	0-10%	10-20%	20-40%	40-60%	60-100%	% of Total Area
Bleeding	Interconnected Veining	Free Asphalt	Wet looking	0-10%	10-20%	20-40%	40-60%	60-100%	% of Total Area
Patching	Good Condition	Fair Condition	Failure	0-10%	10-20%	20-40%	40-60%	60-100%	% of Total Area
Potholes	<75mm	<300mm no base mat'l	>300mm w base mat'l	1PHs <0.1%	2PHs 0.1-0.5%	3PHs 0.5-1%	4PHs 1-5%	>5 PHs >5%	Count per 30m Length % of Total Area
Surface Deformations									
Wheel Track Rutting	<12mm	12mm to 25mm	>25mm	<10% <¼ of WTs	10-25% ¼ of WTs	25-50% ½ of WTs	50-75% ¾ of WTs	75-100% All WTs	% of Affected Wheel Path Area
Distortion	<50 mm Dev	50mm to 100mm Dev	>100mm Dev	0-10%	10-20%	20-40%	40-60%	60-100%	% of Total Area
Rippling/Shoving	Decrease in Rideablity	Rough Ride	Very Rough Ride	0-10%	10-20%	20-40%	40-60%	60-100%	% of Total Area
Excessive Crown	2-3% CF	3-4% CF	>4% CF	0-10%	10-20%	20-40%	40-60%	60-100%	% of Total Area
Cracking									
Alligator	Cracks are <12mm	Cracks 12mm to 25mm	Cracks are ≥ 25mm	0-4%	4-10%	10-30%	30-60%	60-100%	% of Total Area
Longitudinal	Cracks are <12mm	Cracks 12mm to 25mm	Cracks are ≥ 25mm	<1 FLC	1 to 2 FLC	2 to 3 FLC	3 to 4 FLC	>4 FLC	Length per 2 Lanes
Transverse	Cracks are <12mm	Cracks 12mm to 25mm	Cracks are ≥ 25mm	>25m	15-25m	10-15m	5-10m	0-5m	Space Between Cracks
Block	Cracks are <12mm	Cracks 12mm to 25mm	Cracks are ≥ 25mm	0-4%	4-10%	10-30%	30-60%	60-100%	% of Total Area
Edge	< 0.3m to EP	0.3m to 0.5 to EP	> 0.5m to EP	0-4%	4-10%	10-30%	30-60%*	60-100%**	Edge Length
Joint Reflection Cracks	Cracks are <12mm	Cracks 12mm to 25mm	Cracks are ≥ 25mm	>25m	15-25m	10-15m	5-10m	0-5m	Space Between Cracks

Note: WT = Wheel Track
PH = Pothole
CF = Cross Fall
CA = Coarse Aggregate
EP = Edge of Pavement
Dev = Deviation
FLC = Full Length Crack
* = Continuous one side
** = Continuous on both sides

APPENDIX G

MSDS Sheets for the Test Material

Material Safety Data Sheet

WHMIS (Pictograms)	WHMIS (Classification)	Protective Clothing
	Not controlled under WHMIS (Canada).	

Section 1. Chemical Product and Company Identification

Product Name/ Trade name	**Camel-Wite**	Code	113803
Supplier	Debro Chemicals 11 Automatic Drive Brampton (Ontario) L6S 4K6 (905) 799-8200 2055 Hymus Blvd Dorval (Quebec) H9P 1J8 (514) 684-9775	CAS #	1317-65-3
Synonym	Calcium Carbonate	DSL	CEPA DSL: Limestone, extracted mechanically.
Chemical Name	Not applicable.	CI#	Not available.
Chemical Family	Not available.	Validation Date	9/8/2000
Chemical Formula	Ca-C-O3	Print Date	9/27/2000
Manufacturer		In Case of Emergency	CHEMTREC: 1-800-424-9300
Material Uses	Not available.		

Section 2. Composition and Information on Ingredients

Name	CAS #	% by Weight	Exposure Limits	LC_{50}/LD_{50}
1) Limestone	1317-65-3	100	Not available.	ORAL (LD50): Acute: 6450 mg/kg [Rat].
2) Quartz (Crystalline silica)	14808-60-7	<0.1	Not available.	Not available.

Section 3. Hazards Identification

Potential Acute Health Effects	Hazardous in case of eye contact (irritant). Slightly hazardous in case of skin contact (irritant), of inhalation (lung irritant). Non-hazardous in case of ingestion.
Potential Chronic Health Effects	CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to upper respiratory tract, eyes. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4. First Aid Measures

Eye Contact	In case of contact with eyes, rinse immediately with plenty of water. If irritation persists, seek medical attention.
Skin Contact	Wash contaminated skin with soap and water. If irritation persists, seek medical attention.
Inhalation	If inhaled, remove to fresh air. If not breathing, give artificial respiration. Get medical attention. Oxygen may be administered if breathing is difficult.
Ingestion	If ingested in large amounts, seek immediate medical attention.

Continued on Next Page

Section 5. Fire Fighting Measures	
Products of Combustion	Not available.
Fire Fighting Media and Instructions	Non-flammable substance. Use extinguishing media suitable for surrounding materials.
Special Remarks on Fire Hazards	Non combustible.
Special Remarks on Explosion Hazards	Not available.
	Not applicable.
	Not applicable.

Section 6. Accidental Release Measures	
Small Spill and Leak	Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.
Large Spill and Leak	Our data base contains no additional information in case of a spill and/or a leak of the product. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.
Personal Protection in Case of a Large Spill	Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Section 7. Handling and Storage	
Precautions	Avoid generating dusts. After handling, always wash hands thoroughly with soap and water.
Incompatibility	Reactive with acids.
Storage	Keep container tightly closed in a cool, well-ventilated place.

Section 8. Exposure Controls/Personal Protection		
Engineering Controls		Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.
Personal Protection	*Eyes*	Safety glasses.
	Body	Lab coat.
	Respiratory	Dust respirator. Be sure to use an approved/certified respirator or equivalent.
	Hands	Gloves (impervious).
	Feet	Not applicable.
Protective Clothing (Pictograms)		

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Exposure Limits	TWA: 15 (mg/m³) from OSHA (PEL) [United States] Inhalation Total. TWA: 5 (mg/m³) from OSHA (PEL) [United States] Inhalation Respirable. TWA: 10 (mg/m³) from ACGIH [United States] Inhalation Total. TWA: 5 (mg/m³) from ACGIH [United States] Inhalation Respirable. Consult local authorities for acceptable exposure limits.

Section 9. Physical and Chemical Properties

Physical State and Appearance	Solid. (Powdered solid.)	Odor	Odorless.
Molecular Weight	Not applicable.	Taste	Not available.
pH (1% Soln/Water)	9 to 10 [Basic.]	Color	White.
Boiling/Condensation Point	Not available.		
Melting/Freezing Point	825°C (1517°F)		
Critical Temperature	Not available.		
Instability Temperature	Not available.		
Specific Gravity	2.71 (Water = 1)		
Vapor Pressure	Not applicable.		
Vapor Density	Not available.		
Volatility	Not available.		
Evaporation Rate	Not available.		
Odor Threshold	Not available.		
Viscosity	Not available.		
$LogK_{ow}$	Not available.		
Ionicity (in Water)	Not available.		
Dispersion Properties	Is not dispersed in cold water, hot water.		
Solubility	Very slightly soluble in cold water, hot water.		
The Product is:	Non-flammable.		
Auto-ignition Temperature	Not applicable.		
Flash Points	Not applicable.		
Flammable Limits	Not applicable.		
Fire Hazards in Presence of Various Substances	Not applicable.		
Explosion Hazards in Presence of Various Substances	Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.		

Continued on Next Page

Section 10. Stability and Reactivity	
Stability	The product is stable.
Conditions of Instability	Not available.
Incompatibility with Various Substances	Reactive with acids.
Corrosivity	Not considered to be corrosive for metals and glass.
Hazardous Decomposition Products	Calcium oxide, carbon dioxide
Special Remarks on Reactivity	Incompatible with fluoride, magnesium (Limestone)
Special Remarks on Corrosivity	Not available.

Section 11. Toxicological Information	
Routes of Entry	Ingestion. Eye contact.
Toxicity to Animals	Acute oral toxicity (LD50): 6450 mg/kg [Rat]. (Limestone).
Acute Effects on Humans	
Eyes	Hazardous in case of eye contact (irritant).
Skin	Sensitization of the product: Not available. Slightly hazardous in case of skin contact (irritant). Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.
Inhalation	Slightly hazardous in case of inhalation (lung irritant).
Ingestion	Non-hazardous in case of ingestion.
Chronic Effects on Humans	**CARCINOGENIC EFFECTS**: Not available. **MUTAGENIC EFFECTS**: Not available. **TERATOGENIC EFFECTS**: Not available. **DEVELOPMENTAL TOXICITY**: Not available. The substance may be toxic to upper respiratory tract, eyes. Repeated or prolonged exposure to the substance can produce target organs damage.
Special Remarks on Toxicity to Animals	Not available.
Special Remarks on Chronic Effects on Humans	Not available.
Special Remarks on Other Toxic Effects on Humans	Not available.

Section 12. Ecological Information	
Ecotoxicity	Not available.
BOD5 and COD	Not available.
Products of Biodegradation	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.
Toxicity of the Products of Biodegradation	Not available.
Special Remarks on the Products of Biodegradation	Not available.

Continued on Next Page

Section 13. Disposal Considerations

Waste Information	Waste must be disposed of in accordance with federal, state and local environmental control regulations.
Waste Stream	Not available.

Section 14. Transport Information

TDG Classification	Not controlled under TDG (Canada).	
PIN	Not applicable.	
Maritime Transportation	Not available.	
Special Provisions for Transport	Not applicable.	

Section 15. Other Regulatory Information and Pictograms

WHMIS (Classification)	Not controlled under WHMIS (Canada).	
Regulatory Lists	CEPA DSL: Limestone, extracted mechanically	
Other Regulations	Not available. or of its ingredients	

Other Classifications	HCS (U.S.A.)	Not controlled under the HCS (United States).
	USA Regulatory Lists	California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer which would require a warning under the statute: Quartz (Crystalline silica)
	DSCL (EEC)	This product is not classified according to the EU regulations.
	International Regulations Lists	No products were found.

Hazardous Material Information System (U.S.A.)

Health	1
Flammability	0
Reactivity	0
Personal Protection	e

National Fire Protection Association (U.S.A.)

DOT (U.S.A) (Pictograms)

DSCL (Europe) (Pictograms)

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ADR (Europe) (Pictograms)

Section 16. Other Information

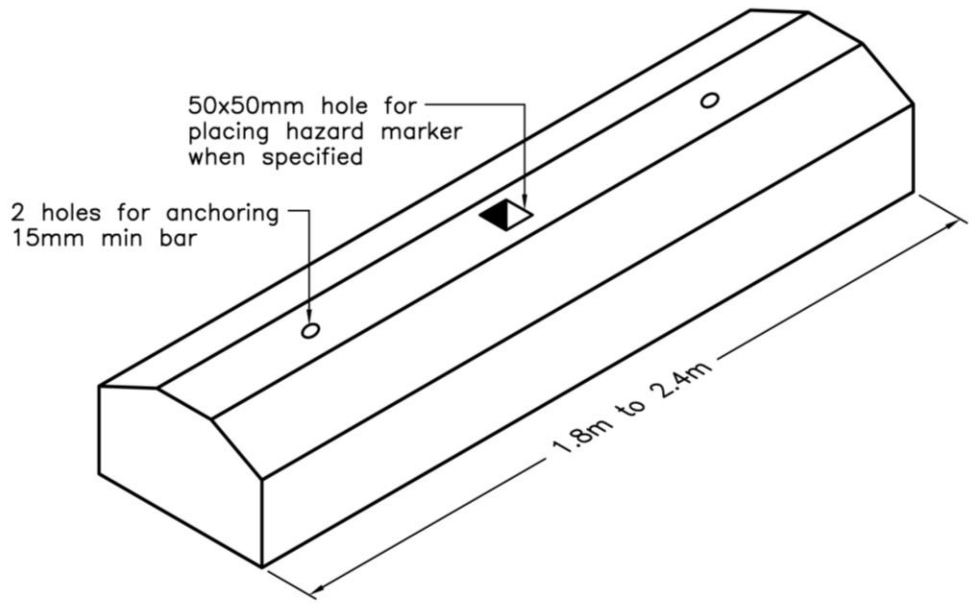
References	-Manufacturer's Material Safety Data Sheet.	
Other Special Considerations	Not available.	
Validated by Regulatory affairs on 9/8/2000.		Verified by Regulatory affairs. Printed 9/27/2000.
Information Contact	Debro Chemicals 11 Automatic Drive Brampton (Ontario) L6S 4K6 (905) 799-8200 2055 Hymus Blvd Dorval (Quebec) H9P 1J8 (514) 684-9775	

<u>Notice to Reader</u>

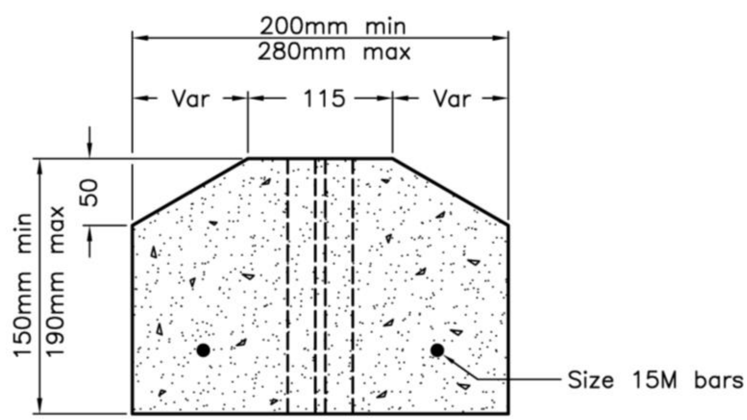
To the best of our knowledge, the information contained herein is accurate. However, neither the above named supplier nor any of its subsidiaries assumes any liability whatsoever for the accuracy or completeness of the information contained herein. Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

APPENDIX H

Pre-cast Concrete Curb



ISOMETRIC VIEW



SECTION

NOTES:

A Class of concrete shall be C2 according to CSA A23.1.

B All dimensions are in millimetres unless otherwise shown.

ONTARIO PROVINCIAL STANDARD DRAWING	Nov 2006	Rev 1
PRECAST CONCRETE CURB	**OPSD 603.020**	