HUMAN HEALTH RISK ASSESSMENT OF VOLATILE ORGANIC COMPOUND EMISSIONS FROM A SPRAY APPLIED POLYURETHANE INSULATING FOAM FOR CANADA VOC

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EXECUTIVE SUMMARY

Lalita Bharadwaj, Ph.D. undertook a Human Health Risk Assessment for a spray-applied polyurethane thermal insulating foam developed by Canada VOC. Exova Warren Testing Facilities in Warren, Michigan performed emissions testing of a test specimen (foam sample) of a spray-applied polyurethane foam, identified here in this report as "*Canada VOC polyurethane foam*". Emission testing was conducted in accordance with 'Procedure B' of the Underwriters Laboratories of Canada, CAN/ULC-S774-09 Testing Standard. Headspace and dynamic chamber analyses were performed on a test specimen of "*Canada VOC polyurethane foam*" and volatile organic compound (VOC) emissions were characterized by gas chromatography-mass spectroscopy.

The purpose of the risk assessment was two-fold: 1) to determine whether volatile organic compound (VOC) emissions from the foam sample pose a health risk, and 2) to determine an acceptable residential occupancy time for the polyurethane insulating foam. The health risk assessment was undertaken using guidelines, protocols and methodologies proposed and readily accepted by Health Canada and the Canadian Construction Materials Centre. These guiding principles of risk assessment were utilized to predict the human health risk associated with potential exposure to VOC emissions identified and measured from a test specimen of "*Canada VOC polyurethane foam*".

Careful consideration of all relevant chemical and toxicity data was given to the assessment to determine the potential for health risk. The assessment accounted for the potential for human exposure to maximum indoor air concentrations of each VOC emission product identified through dynamic chamber analysis of the spray-applied polyurethane insulating foam. The assessment took into consideration the chemical nature and toxicity information of the VOC emissions, potential for human exposures, the magnitude, frequency and duration of human exposure to each VOC product, and their individual decay patterns over a 30-day period of dynamic chamber analysis. The assessment also included comparisons (including stringent safety margins) between potential exposure to maximum possible levels and the toxicological profiles of the VOC products emitted.

The decay pattern of the VOC products (up to 30 days), indicate the concentration of individual airborne VOC and the total VOC (TVOC) decrease rapidly over time. Maximum airborne emission concentrations of each individual VOC emission product measured through the process of dynamic chamber analysis was found to be below airborne exposure concentrations considered safe for human exposure.

Considering that VOC emission products were classified as having a low order inhalational toxicity following short term low-level exposures and the maximum emission concentrations were well below the safety standards applied in this risk assessment, it was concluded that airborne concentrations of VOC or TVOC emitted from "*Canada VOC polyurethane foam"* would be considered safe for human exposure.

With the proviso that the 24-hour curing period is respected post-application (mixing and spraying), "Canada VOC polyurethane foam" will not pose a significant human health risk to individuals residing in homes where this material is applied. The VOC emissions from "Canada VOC polyurethane foam" will not pose a health risk to individuals residing in homes or buildings where the Canada VOC spray-applied polyurethane foam is applied.

The present analysis indicates a low risk for adverse inhalational exposures and thus a low potential for residential health risk. Following the post-application curing period, estimated VOC concentrations from "Canada VOC polyurethane foam" were determined to remain within an acceptable range for human exposure. With the expressed provision that the 24-hour curing period (mixing and spraying) is maintained after application, it is suggested that a residential occupancy time of 1 hour be considered for "Canada VOC polyurethane foam".

1.0 INTRODUCTION

Initiated in December 2018, Dr. Lalita Bharadwaj undertook a human health risk assessment to evaluate the potential impacts on human health from exposure to Volatile Organic Compound (VOC) products emitted from a spray-applied polyurethane insulating foam sample identified as "*Canada VOC polyurethane foam*".

Volatile organic compounds (VOCs) are chemicals that contain carbon and hydrogen. Typically, VOCs have high vapour pressures, easily vaporize at normal temperature and pressure and have boiling points that range from 50-250°C. Several thousand compounds both natural and synthetic are classified as VOC. Volatile organic compounds include a wide range of organic compounds with different functional groups (Yu and Crump, 1998 [18]). These include carbon-based molecules such as; aldehydes, ketones, alcohols, amines, aliphatic and aromatic hydrocarbons, some of which are halogenated. Many of these volatile organic compounds are ubiquitously present, at low levels in various indoor air environments (office, home and workplaces). Volatile organic compounds can be emitted into indoor air from a variety of sources. These include and are not limited to the following: cigarette smoke, furnishings, vehicle exhaust, and various building materials such as paint, varnish and glues and household products such as air fresheners (1).

The World Health Organization (WHO) (WHO, 1989, [17]) has classified indoor VOC pollutants into three groups. These include the following: (i) very volatile organic compounds (VVOCs) which have boiling points ranging from <0°C to 50-100 °C, (ii) volatile organic compounds (VOCs) with boiling points ranging from 50-100°C to 240-260°C, and vapour pressures > 10^{-2} kPa, and (iii) semi-volatile organic compounds (SVOCs) with boiling points ranging from 240-260°C to 380-400°C and vapour pressures of 10^{-2} to 10^{-8} kPa.

Standard approaches of risk assessment were utilized to characterize the potential human health risks associated with exposures to VOC emitted from the spray-applied polyurethane insulating foam sample. In this case the risk assessment was based on maximum likely exposures to VOC emission products. It was assumed that individuals would be exposed repeatedly long-term to maximum concentrations of VOC emission products as determined by dynamic chamber analysis of the foam sample *"Canada VOC polyurethane foam"*.

Spray-applied polyurethane foams are commonly utilized in commercial, institutional and residential construction. Currently, there is an incomplete source of toxicity data evaluating the potential human health effects associated with exposures to PU spray foams or to it volatile organic compound (VOC) emission products under conditions other than those associated with occupational exposures. The potential short or long-term health effects associated with exposure to this material in the general population are fundamentally unknown. Due to the lack of detailed toxicity information, the human health risks associated with short and/or long-term exposures to PU spray foams and their emission products are predicted by the application of human health risk assessment protocols (2,3).

Spray-applied PU foam products manufactured and developed for use in residential or commercial buildings must undergo standardized VOC emissions testing before commercialization and approval by the Canadian Construction Materials Centre (4). For polyurethane formulations intended for use in residential spaces, VOC emissions are to be tested in accordance with appropriate methods outlined in the Underwriters Laboratories of Canada, *CAN/ULC-S774-09*; *Standard Laboratory Guide for the Determination of Volatile Organic Compound Emissions from Polyurethane Foam.* These include both Headspace (HS) and dynamic chamber analysis (DCA [Procedure B]) methods. These are briefly described below.

Headspace and dynamic chamber analyses involve the measurements of VOC emissions from test specimens generated from sample panels of polyurethane foam that have been aged for approximately 20 to 24 hours. The test specimen, utilized for headspace and dynamic chamber analyses, is cut from the sample panel. A strict process is followed for the generation of both the sample panel and the test specimens. This process can be reviewed in the client report entitled; "*033761 Canada VOC* " and prepared by Exova (5). Within the body of this report, a brief description of the Headspace and Dynamic chamber analyses conducted on the PU foam sample are outlined below.

A sample panel is produced in accordance with Section 6.1.3 of the testing standard. The thermal insulation panel is produced by spraying the product onto a sheet of high density polyethylene (HDPE) covered aluminum foil. Once created it is sealed in air-tight packaging and then transported via overnight courier to the Exova Testing Facility in Warren, Michigan. The sample panel is removed from its air-tight packaging and is subsequently cut into appropriately sized and shaped pieces to create the test specimen (foam sample). The resulting foam sample is then placed into test chambers for headspace and dynamic chamber analyses. In this case, the sample was created on August 21, 2018 and a test specimen (foam sample) was cut from the sample and produced on August 22, 2018 (exactly 24 hours and 0 minutes following the creation of the sample) and installed into the test chambers (5).

Headspace analysis involves an initial screening of VOC emissions from the test specimen (foam sample). Headspace analysis is advantageous when concentration levels of VOCs, in the 1 and 12 hour testing intervals, are too low for identification by mass spectral library. The Headspace apparatus is known to generate higher concentrations of compounds that volatize quickly. In situations where emission concentrations are of sufficient strength during subsequent DCA testing of products, headspace analysis is not required in the majority of testing situations. VOC emissions, solely detected in these exaggerated conditions of headspace analysis are considered non-typical and are not considered further in the analyses procedures.

Procedure B of the Underwriters Laboratories of Canada, dynamic chamber analysis, determines polyurethane VOC emission profiles over a 30-day period. In accordance with the testing standard, DCA commences 24 hours after the manufacture of the sample panel (CAN/ULC-S774-09; Section 6.1.2). In general, DCA is a procedure used to identify, quantify, and determine emission rates of VOC(s) released from commercial formulations of spray PU foams once foams have cured over an initial 24-hour period. The results obtained by dynamic chamber analysis of PU test specimen (foam sample) are used to predict potential indoor air concentrations of VOC emission products that could occur in a typical residential or workplace building where spray PU insulating foams are applied. These data provide a quantitative estimate of the potential levels of human exposure to PU-derived VOC emission products and are vital for determining the degree of human health risk associated with exposure to these chemicals in the household, workplace or other inhabited structures.

1.1 Headspace and Dynamic Chamber Analysis

Headspace and dynamic chamber analyses were performed to characterize VOC emissions from the test specimen of the spray applied polyurethane insulating foam "*Canada VOC polyurethane foam*". Analysis was completed by the Exova Building Products Laboratory using procedures outlined in CAN/UCL-S774-09 [Standard Laboratory Guide for the Determination of Volatile Organic Compound Emissions from Polyurethane Foam] (5). Head Space analysis was performed on the test specimen. Using Carbotrap^{TM} 400 absorbent tubes, in conjunction with gas chromatography-mass selective detector analysis; the number, chemical nature and the relative concentrations of VOC products emitted from the test specimen of the spray-applied PU foam was determined.

1.2 Headspace Analysis

Headspace analysis of test specimen "*Canada VOC polyurethane foam*" revealed that forty-four (44) VOC products were emitted from the "*Canada VOC polyurethane foam*" test specimen. The compounds emitted and their respective concentrations are summarized in Section 8.0, Test Results, Table 8.2, Pages 15-16, of the Exova emissions report (5).

Emission products identified through the process of headspace analysis were generally classified as hydrocarbon based compounds. In general terms, a mix of compounds were identified and these included compounds such as: halogenated aliphatic hydrocarbons and aromatic hydrocarbons, siloxanes and a few benzene related compounds. Volatile organic compound emission concentrations range from the lowest airborne concentration of 0.014 mg/m^3 (Benzene, 1,3,5-trimethyl) to the highest airborne concentration 3.790 mg/m^3 (Ethene, 1,2-dichloro (E)-). These emission levels were considered low.

Appropriate and comparable exposure limits, when available and assigned to individual VOCs identified through headspace analysis of the "*Canada VOC polyurethane foam*" specimen were reviewed and utilized as a comparative guideline to gage potential health risks associated with exposures to the airborne concentrations identified by the headspace analysis. Through this review it was found that the airborne emission concentrations were low and would be considered safe under an occupational exposure scenario.

Occupational exposures refer to those exposures that are generally consistent over a work period, are generally higher than the exposures experienced by the general population and occur over a regular work week of 8 hours per day 5 days a week. Under these conditions, exposure limits are established for the protection of human health. The emission concentrations measured through headspace analysis are below occupational exposure limit where they have been established for the various VOCs identified . This suggests that airborne levels measured during headspace analysis are low and should not accumulate to concentrations that would likely pose a risk to human health.

1.3 Dynamic Chamber Analysis

Subsequent to headspace analyses, discrete dynamic chamber analysis was performed on the spray-applied polyurethane foam test specimen "*Canada VOC polyurethane foam*" (5). VOC emission products, identified through DCA, were measured in air samples collected at specified time intervals (1, 12, 24, 48 hours and 4, 7, 14, and 30 days) as prescribed by Section 7.3 of the CAN/UCL-S774-09 Standard. Dynamic chamber analysis was utilized to screen for VOCs emission products derived from the "*Canada VOC polyurethane foam*" test specimen. These emissions can be reviewed in Section 8.4, Tables 8.4.1-8.4.8, pages 17 to 20, of the Exova emissions report (5). The VOC emissions from "*Canada VOC polyurethane foam*" were determined over a 30-day period of testing.

The results obtained by dynamic chamber analysis are summarized below and were utilized as a quantitative estimate of the potential levels of human exposure to "*Canada VOC polyurethane* *foam"*-derived VOC emission products. These data were applied to the risk assessment process to determine the degree of human health risk associated with potential exposures to these specific VOC emissions derived from the spray-applied polyurethane insulating foam (referred to as "*Canada VOC polyurethane foam*").

1.3.1 Unique VOC Emission Products

A total of twenty-five (25) unique VOC emission products were identified through the dynamic chamber analysis of *"Canada VOC polyurethane foam".* Headspace analysis yielded forty-four (44) VOC emission products. Table 1 provides a summary of the twenty-five (25) unique VOC emission products identified through the process of DCA. Data can also be reviewed in the VOC emissions profiling report generated by Exova in Table 9.1 page 22 (5).

Table 1: Unique VOC Emissions Products Identified Through DCA

Number (#)	**Unique VOC Emission Product**
1	1-Propene, 3-bromo-3,3-difluoro
2	Ethyl Chloride
3	Propene, 1-chloro-3,3,3-trifluoro
4	Trichloromonofluoromethane
5	Ethene, 1,2-dichloro (E)-
6	Hexane, 3-methyl
7	Propane, 1,2-dichloro
8	1,3,6-trioxocane, 2-methyl
9	Toluene
10	Benzene, (isothiocyanatomethyl)-
11	Benzene, [(methoxymethoxy)methyl]-
12	Cyclotrisiloxane, hexamethyl-
13	2-Pentenal, 2-methyl
14	Benzene, chloro
15	p-Xylene
16	Benzene, 1-ethnyl-4-methyl-
17	Benzoic acid, 2-[(trimethylsilyl)oxy]-trimethylsilyl ester
18	Cyclotetrasiloxane, octamethyl-
19	Ethanoic acid, bis(trimethylsilyl)ester
20	2-Propanol, 1,1'-oxybis-
21	Propane, 1-chloro-3[2-(2-methoxyethoxy)ethoxy]-
22	Propane, 2-chloro-2-nitro
23	Tetrachloroethylene
24	Trimethylphosphine oxice
25	Trix(3-chloropropyl)

Dynamic chamber analysis demonstrated that twenty-five (25) unique VOCs were emitted from *"Canada VOC polyurethane foam".* A summary of the DCA analysis is provided on page 26 of the Exova emissions report (5). An analysis of DCA test results outlining the number of compounds identified at each testing interval is provided on page 21 Section 9 and tabulated in Table 9.2 "*Table of Rate of Compound Decay",* on page 23, of the Exova publication (5). A brief summary of the DCA results is provided below.

In summary, twenty-five (25) unique VOCs were identified as emission products of *"Canada VOC polyurethane foam".* Maximum airborne concentrations of eighteen (18) of the twenty-five (25) unique VOC products (#s 1-11 and 13-19), as numbered above in Table 1 of this report, were detected at the 1 hour DCA testing interval. The maximum emitted airborne concentrations of these 18 unique VOCs and measured at the 1 hour testing interval, ranged in concentration from 0.005 mg/m^3 to 0.741 mg/m^3. These emissions concentrations are considered to be low.

Reported personal exposure levels of polyurethane applicators have been found to range in concentration from 0.120 mg/m^3 to 0.570 mg/m^3 (7-9). Maximum emission concentrations of one (1) of the 18 unique VOCs (#5 or Ethene, 1,2-dichloro-(E)) measured at the 1-hour DCA testing interval was measured at a concentration slightly above (0.741 mg/m^3) the reported personal exposure levels of polyurethane applicators. The maximum concentration for this VOC (#5 or Ethene, 1,2-dichloro-(E)) dropped well below reported personal exposure levels within the next, 12-hour, DCA testing interval. Furthermore, Ethene, 1,2-dichloro-(E) emissions dropped to undetectable at the 24 hour DCA testing interval. These data suggest that although Ethene, 1,2-dichloro-(E) emissions were initially exaggerated at the 1-hour interval, the emissions rapidly dropped to zero within a 24 hour period. These data suggest that these emissions are not sustained over the 30-day period of DCA testing and would not accumulate to levels that would pose significant risk to individuals residing in homes where the spray-applied polyurethane foam would be applied. These data also suggest that 72% of the maximum emission concentrations measured for the Unique VOCs over the 30-day DCA identified from "*Canada VOC polyurethane foam*", were emitted within the 1-hour DCA testing period. Emission concentrations measured at intervals subsequent to the 1-hour testing interval were well below the highest emission level of 0.741 mg/m^3. None of the maximum emissions concentrations were sustained over the testing period.

Emissions of three (3) of the 25 VOCs measured during DCA were measured at the 12-hour testing interval. Emission concentrations of these three (3) VOCs ranged in concentration from 0.009 mg/m^3 to 0.027 mg/m^3 and were well below maximum levels observed a the 1-hour testing interval. identified within this 12-hour DCA interval.

Six (6) unique VOC emission products were identified at the 24-hour DCA testing interval. Maximum emission concentrations of two (2) of the 25 unique compounds were measured at the 24 hour interval. The maximum emission concentrations were similar and were measured as 0.008 mg/m3. This maximum emission concentration observed at the 24-hour time interval falls well within, and at the lower range, of personal exposure levels of polyurethane applicators suggesting that emissions are not exaggerated, typical for polyurethane applications and are relatively low.

The DCA at 2-days revealed that seven (7) of 25 unique VOCs were emitted. At the 2-day testing interval there was one (1) maximum measured emission concentration identified. The maximum airborne concentrations measured at the 2-day interval was observed at a concentration of 0.005 mg/m^3. This maximum emission concentration was well within personal exposure levels of applicators.

Dynamic chamber analysis at testing intervals of 4-day, 7-day, 14-day and 30-day yielded 7, 3, 3 and 1 unique VOCs respectively. Maximum emission concentrations of three (3) VOCs were emitted at the 4-day DCA testing interval. However, levels were very low in magnitude and did not persist. In fact, there was a steady decline in the number of VOCs emitted as well as the concentrations measured over the 30-day testing period. These data suggest that VOC emissions, at the maximum levels, generally occur immediately within the first hour of DCA and dissipate to levels well below maximum over the 30-day testing period.

In summary the DCA data suggest that 25 unique VOCs are emitted from *"Canada VOC polyurethane foam"*. Emission concentrations measured within 1 hour of DCA are very low. DCA analysis reveal that VOC emissions from *"Canada VOC polyurethane foam"* very quickly dissipate from maximum measured concentrations to zero or levels well below the highest observed concentrations. The total number of VOC (TVOC) measured and identified at the 1 hour DCA period, is never exceeded and the TVOCs drop over time. These data suggest that maximum VOC concentrations are emitted early following the initiation of DCA (within an 1 hour), maximum emission concentrations are not persistent and these dissipate to undetectable or levels well below respective maximum concentration levels. DCA analysis indicates that VOC emission concentrations are very low and are within an acceptable range for personal exposure.

Maximum VOC emission concentrations of each unique VOC emission product identified through DCA are outlined in Table 2 below. The time within the period of DCA where maximum VOC emission concentration for each of the 25 emission products is summarized in Table 2.

In summary, twenty-five (25) unique VOC compounds were identified as emission products. Dynamic chamber analysis data suggest that VOCs derived from *"Canada VOC polyurethane foam"* are transiently emitted and rapidly fall to zero within the 30-day DCA period of testing. The maximum VOC emission concentrations identified for each VOC identified is considered low in magnitude.

Table 2: provides a summary of the VOCs identified through DCA of *"Canada VOC polyurethane foam"* their maximum airborne concentration and the time in which the maximum emission levels were detected.

Table 2: Maximum Airborne Concentrations of VOC Emissions from *"Canada VOC polyurethane foam"* and Time of Detection.

VOC #	VOC Emission Identified	Maximum Airborne Concentration (mg/m^3)	Time of Detection (hours)
1	1-Propene, 3-bromo-3,3-difluoro	0.006	1
2	Ethyl Chloride	0.005	1
3	Propene, 1-chloro-3,3,3-trifluoro	0.024	1
4	Trichloromonofluoromethane	0.057	1
5	Ethene, 1,2-dichloro-, (E)-	0.741	1
6	Hexane, 3-methyl	0.006	1
7	Propane, 1,2-dichloro	0.048	1
8	1,3,6-Trioxocane, 2-methyl	0.019	1
9	Toluene	0.203	1
10	Benzene, (isothiocyanotomethyl)	0.019	1
11	Benzene, [(methoxymethoxy)methyl]-	0.007	1
12	Cyclotrisiloxane, hexamethyl	0.022	4-days
13	2-Pentenal, 2-methyl	0.007	1
14	Benzene, chloro	0.022	1
15	p-Xylene	0.007	1
16	Benzene, 1-ethynyl-4-methyl-	0.005	1
17	Benzoic acid, 2-[trimethylsilyl)oxy]-trimethylsilyl ester	0.019	1
18	Cyclotetrasiloxane, octamethyl	0.006	1
19	Ethanedioic acid, bis(trimethylsilyl)ester	0.009	1
20	2-Propanol, 1,1'-oxybis-	0.008	24
21	Propane, 1-chloro-3-[2-methoxyethoxy)ethoxy]-	0.008	24
22	Propane, 2-chloro-2-nitro-	0.005	4-days
23	Tetrachloroethylene	0.008	4-days

24	Trimethylphosphine oxide	0.006	4-days
25	Tris(3-chloropropyl) phosphate	0.033	4-days

Review of DCA indicates that the majority of the maximum measured emission concentrations for these unique VOCs were detected within 1 hour of DCA. Through review of DCA testing, it is evident that 25 VOC compounds are emitted from "*Canada VOC polyurethane foam",* the majority (72% or 18/25) of the highest observed concentration for each respective compound is emitted within the first 1 hour of DCA. The chemical nature of the VOCs identified varied as well as airborne emission concentrations. Maximum VOC emissions were not maintained over the 30-day period of DCA. Additionally, overtime there was a rapid decline in the total number of VOC emissions detected over the 30-day period. In general, airborne concentrations of VOCs measured and emitted from "*Canada VOC polyurethane foam",* are very low and not persistent.

In summary, DCA data suggests the following: the total number of VOCs emitted from *"Canada VOC polyurethane foam"* is 25. Maximum emission concentrations are very low, generally measured within 1-hour of testing and not maintained throughout the 30-day period of testing. Emissions fluctuate rapidly from detectable to non-detectable. There was only one VOC emitted at the end of the DCA testing (30-day interval) and this concentration is considered very low. Review of the DCA data for *"Canada VOC polyurethane foam"* also indicate that peak concentrations of VOC emission products would likely be reached within 25 hours following the mixing, spraying and direct application of this foam.

The maximum indoor air concentrations, summarized above in Table 2, and determined through DCA analysis, represent the highest estimated level of human exposure to VOC products emitted from "*Canada VOC polyurethane foam"*. The time in which maximum VOC concentrations were detected specifies the point in time when maximum concentrations would be reached in a residence following the 24-period when the components of the spray-applied PU foam were mixed, sprayed and applied (ie. it is assumed that individuals residing in homes would be exposed to these emission levels within 25 hours after the products application). The maximum measured concentrations of each VOC emission product were utilized in the process of a human health risk assessment to evaluate the potential human health risks that may be associated with exposures to maximum airborne VOC emissions derived from the *"Canada VOC polyurethane foam"* polyurethane insulating foam.

The toxicity of each VOC emission product was addressed in the assessment. The human health risk assessment was conducted using conservative assumptions that would lead to an overestimation of potential exposure and risk. Thus in this case, a "worst case scenario" was applied to the assessment. In this scenario it was assumed that human exposure levels are equal to the maximum measured airborne VOC concentrations detected by DCA of the *"Canada VOC polyurethane foam"* test specimen.

Few experimental assessments have been conducted to evaluate exposure levels to VOC emissions during the spraying and application process of spray-applied polyurethane foam insulations. Of the studies conducted to date, personal exposure levels to VOC emissions have been evaluated for spray-gun operators and their helpers during the application of PU foams to houses and office buildings (6). Recorded personal VOC exposures reported in exposure assessment studies were found to be in the range of 0.120 mg/m^3 to 0.570 mg/m^3 (7-9). These personal exposure levels are within the range of maximum measured airborne concentrations (0.005 mg/m^3 to 0.741 mg/m^3) identified through the process of DCA of the spray-applied PU foam sample.

The personal exposure data reported in these studies provide an indication of the range of VOC concentrations occupants may typically be exposed to following the application of a spray-applied PU insulating foam to a residential structure. A lower range of VOC concentrations may be experienced by residents with the application of a foam considering the process of, and primary purpose of the application, timing of application as well as occupancy related factors. The personal exposure data observed in previous studies provide an indication of the range of concentrations that could typically be experienced by polyurethane applicators and the helpers of those applicators or even by-standers in the home. These exposure levels represent typical occupational exposures and provide guidance towards evaluating health risk in this case. Furthermore, the occupational exposure levels provide some support towards the utilization of maximum measured airborne emissions in the application of the risk assessment process that is aimed primarily at evaluating health risk in a worst case scenario. Although, DCA reveal that maximum levels are not maintained in air for extended periods, the assumption that human exposures are equal to maximum measured airborne concentrations provides an ample margin of safety to assess risk to human health. These assumptions were utilized in the assessment of human health risk. The following questions were addressed in this particular risk assessment process.

1) Will exposure to maximum indoor air concentrations of VOC emission products from *"Canada VOC polyurethane foam"* (outlined in Table 2) pose a significant human health risk to applicators or residents of homes or buildings where this construction material is applied?
2) What is the limiting residential occupancy time for "*Canada VOC polyurethane foam"*? (ie. When is it safe for individuals to reside or re-enter buildings following the application of "*Canada VOC polyurethane foam"*?).

2.0 RISK ASSESSMENT

Risk assessment is a process that involves the characterization of the probability of adverse human health effects that may be associated with exposure to environmental chemicals (2,3,6). This process was used here to predict the potential for human health risk associated with an exposure to VOC products emitted from the polyurethane product "*Canada VOC polyurethane foam".* A risk assessment evaluates a product's potential to produce adverse human health effects. Emission data obtained from environmental chamber testing is used to predict human exposure concentrations of contaminants, and these concentrations are assessed for their potential to produce cancer and non-cancer risks. The data is reviewed according to standards and guidelines available from occupational exposure limits. These limits are available from numerous governmental organizations. The EPA and Health Canada's carcinogenic and non- carcinogenic risk levels, and sensory irritation and odorant limits are also considered in the risk assessment process. Risk assessment is an obligation for those manufacturers who want to understand potential health risks associated with use of their products. The risk assessment process is divided into four major steps; hazard identification, dose-response assessment, exposure assessment and risk characterization and each step is briefly outlined below.

The first step, hazard identification, involves the identification of Contaminants of Potential Concern (COPC). In this step of the risk assessment process, VOC emission products were evaluated for their safety through review of available toxicity data. The maximum measured concentration of each VOC emission product was compared to levels of exposure that have been accepted as "safe" for industrial workers. Accepted levels of exposure signify Threshold Limit Values (TLV) and/or Occupational Exposure Limits (OEL). These values of exposure are assigned by governing occupational agencies such as the American Conference of Industrial Hygienists [ACGIH] (10), National Institute for Occupational Safety and Health [NIOSH] (11) and the Occupational Safety and Health Administration [OSHA] (12). However, there are cases in which TLV values have not yet been assigned to chemicals. For example, chemicals that may be identified as VOC emission products. Thus in this case where an exposure guideline has not been developed, maximum indoor air concentrations, of the VOC emission product identified, were compared to a no observed adverse effect levels (NOAEL) derived from animal/human toxicity data (2,3,6) or a TLV value assigned to the parent compound or a compound similar in chemical nature to the identified VOC product.

In addition to the identification of COPC, the first step of the risk assessment process involves the review of pertinent toxicity data (which may include inhalational, reproductive, developmental, carcinogenic, mutagenic and/or genotoxic information), and the chemical characteristics and occupational exposure limits of each VOC emission product identified.

In the second step of the risk assessment process the dose-response relationship is evaluated for the COPC identified. Generally, adverse health effects will only occur when an agent is absorbed by a human receptor and distributed to target organs/tissues at concentrations and for durations of exposure sufficient to elicit toxicity. Therefore, the nature of the relationship between the received dose and the probability of an adverse biological response is evaluated in the dose-response step of the risk assessment. In this step the relationship between the magnitude of the received dose and the occurrence of an adverse health response is characterized (2,3,6). The dose-response assessment considers whether exposure to maximum measured concentrations of airborne COPC would result in an absorbed dose likely to pose a risk to human health.

The third step in the risk assessment process involves defining the type of human exposure to VOC emission products identified as COPC. This step includes [1] describing the magnitude, frequency and duration of exposure to VOC(s) emissions and [2] identifying the possible exposure routes. In the case of emission products from "*Canada VOC polyurethane foam"* [1] the magnitude, frequency and duration of exposure were classified as a short term continuous low-level exposure and [2] the main route of exposure was via the respiratory tract. Dermal and oral exposure routes are considered insignificant in this case.

The potential for human health risk is characterized in the fourth and final step of the risk assessment process. The likelihood that humans may experience toxicological effects under the actual conditions of exposure is determined here. In this case, it was determined whether individuals are at risk of experiencing adverse health effects by residing in buildings where the spray applied polyurethane foam product is applied.

3.0 HAZARD IDENTIFICATION

This section summarizes the contaminants of potential concern that were selected for this assessment. A review of the DCA analysis of "*Canada VOC polyurethane foam"* indicated that there were twenty-five (25) VOCs emitted from the spray polyurethane insulating foam sample. The maximum measured concentrations of each VOC emitted, as identified through DCA of "*Canada VOC polyurethane foam"* were summarized above in Table 2.

3.1 Selection of Contaminants of Potential Concern (COPC)

Based on human health considerations, a selection process was performed to identify contaminants of potential concern (COPC) from the list of VOC products emitted from "*Canada VOC polyurethane foam".* The procedure followed for selection of COPC is described below.

Firstly, contaminants of potential concern were identified by comparing maximum measured concentrations of each VOC to 1% of the American Conference of Government Industrial

Hygienists (ACGIH) 2010 Threshold limit values established for these chemicals. The ACGIH TLV-TWA divided by 100 is industry protocol for establishing chronic human exposure levels suitable for residential scenarios (24 hours per day, 7 days per week). Maximum measured concentrations of VOC emission products at concentrations exceeding the above referenced guideline were considered COPC. In other words, these VOC emission products were considered to demonstrate a potential to cause adverse health outcomes under prolonged or repeated exposure. Maximum concentrations of volatile organic compounds emitted at levels at or below referenced guidelines were considered safe for human exposure.

Exposure levels that are considered to be acceptable ("safe") for human exposure such as the TLV-TWA® are usually allocated to various chemicals by the American Conference of Governmental Industrial Hygienists [ACGIH], however other agencies such as the National Institute for Occupational Safety and Health [NIOSH], Occupational Safety and Health Administration [OSHA] and other governing bodies of occupational and industrial hygiene assign exposure limits to chemicals. As a further step in the risk assessment process, maximum measured airborne concentrations of COPC were compared to occupational exposure limits assigned by agencies other than the ACGIH. Occupational exposure limits do not represent a fine line between safe and dangerous concentrations, nor are they a relative index of toxicity. For the purposes of this risk assessment occupational exposure limits were used to facilitate the risk assessment process and help to predict the potential for human health risk associated with an exposure to VOC emission products. It is not generally recommended that occupational exposure limits be used as standards for indoor air quality in the home and for this reason the occupational exposure limits were reduced by a suitable safety factor to err on the side of caution when assessing the potential human health risks associated with this particular case. The magnitude of this safety factor depends primarily on the number, the toxicity and the relative quantity of VOC emission products and other contaminants ordinarily present in the home (2,3,6,10).

In summary, if no TLV-TWA® guideline is established or available for an individual VOC emission product, then maximum airborne concentrations were compared to either a TLV-TWA® ÷ 100 derived for the parent compound, a chemically similar compound, a guideline value established by another governing agency other than the ACGIH, and/or an inhalational No Observed Effect Levels ÷ 100 [(NOEL)- an airborne concentration that produced no observed adverse effects in exposed animals] derived from animal toxicity studies. If measured concentrations were found to be below the NOEL ÷ 100 value then the VOC emission product was dropped for further consideration. VOC emission products measured at concentrations exceeding the above guidelines or derived levels (NOEL ÷ 100; when no TLV-TWA® guidelines were available) were selected for further consideration and deemed COPC.

Table 3, summarizes the VOC emission products, their maximum measured concentrations and their respective ACGIH TLV-TWA® (or regulatory limits) values divided by 100.

Table 3: Maximum Indoor Airborne Concentrations of VOC Emission Products from *"Canada VOC polyurethane foam"* and ACGIH TLV-TWA® (regulatory limit) ÷ 100.

VOC Emission Product Identified	Maximum Indoor Air Concentration (mg/m^3)	ACGIH TLV-TWA® (regulatory limit) ÷ 100
1-Propene, 3-bromo-3,3-difluoro	0.006	[a]1.00
Ethyl Chloride	0.005	2.63
Propene, 1-chloro-3,3,3-trifluoro	0.024	[b]42.53
Trichloromonofluoromethane	0.057	56.0
Ethene, 1,2-dichloro-, (E)-	0.741	7.93
Hexane, 3-methyl	0.006	[c]1.80
Propane, 1,2-dichloro	0.048	0.46
1,3,6-Trioxocane, 2-methyl	0.019	[d]NA
Toluene	0.203	0.75
Benzene, (isothiocyanatomethyl)-	0.019	[e]3.20
Benzene, [methoxymethoxy)methyl]-	0.007	[e]3.20
Cyclotrisiloxane, hexamethyl	0.022	[f]1.21
2-Pentenal, 2-methyl	0.007	[g]1.75
Benzene, chloro	0.022	0.46
p-Xylene	0.007	4.35
Benzene, 1-ethynyl-4-methyl	0.005	[e]3.20

Benzoic acid, 2-[(trimethylsilyl)oxy]-trimethylsilyl ester	0.019	[h]NA
Cyclotetrasiloxane, octamethyl	0.006	[f]1.21
Ethanedioic acid, bis(trimethylsilyl) ester	0.009	[i]0.01
2-Propanol, 1,1'-oxybis	0.008	[j]2.45
Propane, 1-chloro-3-[2-(2-methoxyethoxy)ethoxy	0.008	[k]1.49
Propane, 2-chloro-2-nitro	0.005	[l]0.10
Tetrachloroethylene	0.008	1.70
Trimethylphosphine oxide	0.006	[m]0.004
Tris(3-chloropropyl) phosphate	0.033	[n]NA

Note:
NA- Unavailable

Maximum Indoor Air Concentration Exceeds Exposure Limit ÷ 100

Unless specified in the notes below, regulatory limits utilized in the above table have been derived by the ACGIH and are representative of the ACGIH-TLV-TWA® for each specific compound listed in the table. For those chemicals with guideline values that are not available a surrogate level was utilized and an explaining note on the toxicity was provided.

[a]100 mg/m^3 Canada/Alberta Occupational Exposure Limit for Allyl Bromide http://datasheets.scbt.com/sc-280596.pdf
[b]WEEL 800 ppm (42.53 mg/m^3) https://www.tera.org/OARS/WEELS/1233zdE%20HCFO%20OARS%20WEEL%20FINAL.pdf
[c]NIOSH Recommended Exposure Limit of 180 mg/m^3
[d]NA Methyltrioxocane is classified as an irritant. An irritant is defined by the OHSA as a chemical which is not corrosive, but which causes a reversible inflammatory effect on living tissue by chemical action at the site of contact. A more general definition of an irritant is a substance which on immediate, prolonged or repeated contact with normal living tissue will induce local inflammatory reactions. Skin contact may cause skin irritation with discomfort or rash. Eye contact may cause eye irritation with discomfort, tearing, or blurring of vision. Inhalation may cause irritation of the upper respiratory passages, with coughing and discomfort. In general, irritation to mucous membranes typically involves high levels of exposure. Animal studies suggest that toxicity of irritants is associated with repeated exposures to very high airborne concentrations. Concentrations that are significantly above the reported maximum emission concentration measured in this case. Taking into consideration the classification of methyltrioxocane, the concentrations and exposure scenarios known to elicit toxicity, this VOC product was not considered COPC in this case or further in the risk assessment process.
[e-]OSHA- maximum time-weighted average (TWA) exposure limit is 1 part of benzene vapor per million parts of air (1 ppm) for an 8-hour workday or 3.20 mg/m^3
[f]Cyclotrisiloxane, hexamethyl: A Workplace Environmental Exposure Limit has been derived for cyclic siloxane chemicals at the following exposure limit 10 ppm http://www.tera.org/OARS/D4%20OARS%20WEEL%20FINAL.pdf
[g]Recommended Exposure Limit: NIOSH- for Pentanal- 10 Hr Time-Weighted Avg: 50 ppm (175 mg/cu m).
[h]NA No exposure limit for benzoic acid has been established. However, benzoic acid as it exists in a white powder may cause irritation to the eyes, skin and respiratory tract on contact and in the event of a short-term exposure. Additionally there is no data to provide an accurate estimation of the rate in which a harmful concentration in air is reached on evaporation of benzoic acid at 20°C. Considering benzoic acids boiling point of 240°C and vapour density of 4.2 (air =1) it does not appear to be readily volatile and the vapour if produced is denser than air suggesting vapour is heavier than air and would not be maintained within the breathing zone of an individual in a standing position.
[i]ACGIH TLV-TWA Ethanedioic acid.
[i]ACGIH TLV-TWA Propanol
[l]ACGIH TLV-TWA 1-Chloro-1-Nitropropane
[m]ACGIH TLV-TWA for phosphine. Note that trimethylphosphine was only emitted on days 2 and 4 of DCA testing. The emissions were low and transient and were not maintained for extended periods. The occupational exposure level is extremely stringent and exposure scenarios in a residence would not be similar to those under occupational exposure conditions. Although the maximum emission concentration of trimethylphosphine is slightly above the TLV-TWA value divided by 100, the emission is not considered significant in the context of human health risk under a residential exposure scenario.
[n]NA Tris(1-chloro-2-propyl) phosphate (TCPP) is a colourless liquid used as a flame retardant, mainly in polyurethane foams. It is not volatile. TCPP is classified has having a low to moderate acute toxicity by the oral (LD50 in rats = 1017–4200 mg/kg body weight), dermal (LD50 in rats and rabbits is > 5000 mg/kg body weight) and inhalation routes (LC50 in rats is > 4.6 mg/litre) suggesting that under conditions of low levels short term exposures it is unlikely to produce adverse effects in exposed

individuals. TCPP has been demonstrated to be very mildly irritating in rabbit eye and skin irritancy tests and does not produce skin sensitization. http://www.who.int/ipcs/publications/ehc/who_ehc_209.pdf

As summarized above in Table 3, the VOC emission products emitted from "*Canada VOC polyurethane foam*" have available ACGIH TLV-TWA® and/or other suitable exposure limits to be applied as comparative levels for the identification of COPC and for the assessment of their potential human health risks.

Based on the industry protocol for establishing chronic human exposure levels suitable for residential scenarios (ie. by application of a safety factor of 100 to the ACGIH TLV-TWA®, or the exposure limits accepted in this case, the assessment of toxicity data and the qualitative characterization of risk) the maximum emission concentrations, measured for the VOCs identified as emissions from the "*Canada VOC polyurethane foam*" test foam are considered safe. Thus, the VOC emission products were not considered as COPC for the purpose of this risk assessment.

4.0 DOSE-RESPONSE ASSESSMENT

The relationship between the potential received dose and the probability of adverse health effects is evaluated in the dose-response step of the risk assessment process. The intention of this risk assessment is to determine the relationship between exposure to maximum indoor air VOC concentrations and the potential for an adverse human health effect. Possible durations of exposure will be considered below.

4.1 Threshold Limit Values and Dose Response Assessment

In order to determine whether the maximum indoor air concentrations of VOC emission products pose a significant health risk to an individual residing in a home where "*Canada VOC polyurethane foam*" is applied, a comparison of this value was made with an exposure level that is considered acceptable ("safe") for human exposure. This "safe" level represents the ACGIH-Threshold Limit Value-Time Weighted Average® ÷ 100 (TLV-TWA® ÷ 100), a NOEL ÷ 100 or an exposure limit derived from another regulatory body such as NIOSH, or OSHA. The safe levels for human exposure were determined in the hazard identification step of the risk assessment process. A safety factor of 100, applied to the TLV-TWA® or other derived exposure limits provides an ample margin of safety in this case. Thus, it is assumed here that a repeated long-term to levels of the TLV-TWA®, or other relevant and appropriate exposure limit divided by (÷) 100 would not pose a significant health risk to occupants of a home where "*Canada VOC polyurethane foam*" is applied. In addition and for those compounds where an exposure limit was not available a qualitative assessment of risk was made. The qualitative assessment of those chemicals that had no established "safe level" considered available toxicity information to characterize risk. Considering the toxicity data, the low emission levels and the transient nature of the maximum airborne VOC emissions of all VOC observed through DCA of *"Canada VOC polyurethane foam";* an acute, subacute, sub-chronic or chronic exposure to these VOC is unlikely to occur and result in any appreciable risk to human health.

There are several factors supporting the use of a relevant exposure limit, such as the TLV-TWA® ÷ 100, and NOEL, NOAEL or other relevant quantitative and qualitative toxicological information as a reasonable comparative value for the current assessment of "*Canada VOC polyurethane foam*". Occupational exposures in the work environment are generally higher than exposures that occur in a home environment. They are also considered continuous exposures that occur more frequently and for longer duration. In addition, exposures in a work environment are generally more consistent and tend to occur over an 8-hour work shift over a 5-day work week. Exposures to chemicals in the home may be more random, intermittent and sporadic. Through the hazard assessment step of the risk assessment it was determined that "*Canada VOC polyurethane foam*" –derived VOC emissions will not pose significant inhalational toxicity under conditions where individuals would be exposed to low airborne concentrations (inhalation being considered the primary route of exposure since the emission products are expected to exist primarily in the vapour phase). The emission concentrations are not likely to produce significant adverse systemic injury, and animal toxicity data indicate the risk of significant adverse effects following acute, sub-chronic or chronic exposure to low-levels of "*Canada VOC polyurethane foam*" –derived VOC emissions is insignificant.

A review of relevant human and animal studies indicated that toxicity is associated with repeated exposures to extremely high airborne concentrations. The dynamic chamber analysis demonstrates emission levels are very low and maximum levels are not persistent. Therefore, the potential for exposures to concentrations and for durations of exposure that are likely to be associated with adverse effects are improbable in this case. In any scenario, potential exposure is likely to be of a short term duration, to low levels, rapid high levels of absorption into the human body is not likely, the accumulation to acute toxic concentrations in the ambient air, and/or in the body following absorption, is also very low, and exposure should not lead to a chronic or an acute adverse outcome.

Overall, exposure to maximum measured concentrations of VOC emissions derived from "*Canada VOC polyurethane foam*" *are not likely to result in a received human dose that would result in adverse human health effects.*

5.0 EXPOSURE ASSESSMENT

A chemical agent will not produce adverse effects in biological systems unless the agent (or agent's metabolite) reaches appropriate sites in the body at a concentration and for a length of time sufficient to produce the adverse effect. Thus, whether a toxic response occurs is not only dependent on dose, but is also dependent on the chemical and physical properties of the agent, the exposure situation and the susceptibility of the subject. Thus to characterize fully the potential hazard associated with exposure to the emission products from "*Canada VOC polyurethane foam*", information on the exposure situation is also required. In the following section of this risk assessment the exposure to VOC emission products in general, will be addressed. This step of the risk assessment process is designed to describe and characterize the likelihood, the extent, the magnitude, the duration and the route of exposure to the VOC emission products identified in Section 1.0.

The likelihood and the extent of human exposure to VOC emissions from "*Canada VOC polyurethane foam*" or polyurethane material in general, depend on several factors and these include: [1] the chemical nature of the VOC products, [2] the characteristics of the residential structure (size and air-tightness of the house) and [3] the activity patterns of the residents, or time spent indoors, [4] the susceptibility of the exposed individuals and [5] the purpose and intended use of the polyurethane product (6). These factors will be considered here to assess the degree of exposure to VOC products emitted from "*Canada VOC polyurethane foam*".

Generally, VOC products when released into the indoor environment of a residence are expected to exist solely as vapours (3,5). Thus, the respiratory system constitutes the primary route of exposure to each of the VOC emission products identified through emissions testing. VOC vapours within the ambient atmosphere are likely to be degraded quickly (6). For example, many VOC are degraded in the atmosphere by reaction with photo-chemically produced hydroxyl radicals. Typically, the estimated half-life for VOC vapours range between a few minutes to several hours or even days in some cases (eg. benzene). Therefore, it is expected that in a home, these VOC emissions will be degraded, their ambient levels will decrease over time and accumulation to a potentially toxic level in the ambient air of a residential building is not likely. Therefore, in this case, the duration of exposure to low-level emission products is relatively short and repeated exposure to maximum emission levels would not be maintained and extended for long periods of time. Additionally, acute exposures to low-levels are not associated with adverse health impacts.

It is important to note that in general the majority of maximum emission concentrations of VOCs were measured within the 1-hour testing interval and were measured at levels well below the safety guidelines applied to evaluate health risk in this case, suggesting that concentrations emitted should not reach a significant concentration in indoor air and pose a risk to health.

Fluctuations in the number (profile) and concentration of VOCs measured through the DCA analysis may be related to the curing process of the polyurethane foam. Curing of spray polyurethane foams (SPF) essentially means that the chemicals used and mixed to formulate the product react to generate the foam intended for subsequent spraying. SPF may appear hardened or "tack-free" within a range of a few seconds to a few minutes after application to a residential space. During this range of time the SPF may still emit VOCs. Following the curing process however, SPF is considered to be relatively inert in terms of volatility. The DCA takes this issue into account because the chemical components of the SPF ("*Canada VOC polyurethane foam*") are mixed and sprayed to produce a foam test panel 24-hours prior to analysis. The foam test panel is subsequently cut immediately prior to installation into the dynamic chambers exposing the interior surface of the SPF product. Exposure to the interior surface of a SPF is not likely to occur following its application to a residence suggesting that the profile and concentrations of VOCs emitted from the foam test panel in DCA are much higher than those experienced in practical application.

In some practical application scenarios (installation of wiring, maintenance work, building renovations, demolition etc.) potentially involving cutting and heating of material, it is conceivable that interior surfaces of cured foam are exposed and may emit VOCs. Depending on the level and duration of such work, exposure and risk mitigation measures should be considered, including personal protective equipment for occupational workers, adequate cleaning and ventilation, securement of work areas, and in some cases temporary removal of residents.

In the worst-case scenario, the maximum potential level of human exposure to VOCs emitted from "*Canada VOC polyurethane foam*" could be as high as the maximum indoor air concentrations determined by dynamic chamber analysis and outlined in Tables 1 and 2. The maximum indoor air concentrations of VOC products emitted from "*Canada VOC polyurethane foam*" are predicted based on a 500 m^3 house with a ventilation rate of 0.3 air exchanges/ hour (4). By applying this low estimate for air exchange rate, the dynamic chamber analysis provides a very conservative estimate for maximum indoor air concentrations of the VOC products. Thus, even immediately after application of the polyurethane foam, the actual maximum indoor air concentrations in most structures would likely be lower than those predicted through DCA and outlined above in Tables 2 and 3. Individuals would likely be exposed intermittently, for a short period of time in the case of a residential environment. It can safely be assumed that the actual level of human exposure "*Canada VOC polyurethane foam*"-derived VOC emission products would be considerably lower than the maximum indoor air concentrations applied in the process of this risk assessment. The combined factors of low levels of VOC emission relative to safe levels, short duration of VOC emissions and the low potential for repeated chronic exposure by occupants, to levels associated with toxicity, suggest a low risk for adverse health effects posed by exposure to airborne emission products of "*Canada VOC polyurethane foam*".

6.0 RISK CHARACTERIZATION

Risk characterization is the final step in the risk assessment process. It involves integrating all information developed through hazard identification, dose response assessment and exposure assessment (toxicity, measured air concentrations, exposure pathway information, inhalation route), for the purpose of estimating risk to humans. Throughout this assessment, procedures have been used to err on the side of caution in estimating the potential health risk associated with "*Canada VOC polyurethane foam*" -derived VOC emission products.

This analysis has revealed that VOC products emitted from "*Canada VOC polyurethane foam*" *should not pose a health risk to individuals residing in buildings insulated with this material*.

A number of factors support this conclusion:

[1] All maximum airborne concentrations of VOC emission products were below the very conservative safety guidelines applied in the risk assessment process (100 x below the occupational safety standard). Airborne concentrations were measured at levels well below those concentrations associated with any reported health risk. The majority of the maximum measured airborne concentrations of each VOC were detected within the 1-hour DCA testing interval and emission concentrations subsequent to this sample period never exceeded the maximum. The VOCs, where maximum emission levels were measured at days subsequent to 1 hour were significantly below the safety guidelines applied in this risk assessment.

[2] In general VOC emission products from "*Canada VOC polyurethane foam*" at concentrations determined through DCA, are of low order toxicity under conditions of low-level intermittent exposures, possess a low inhalational toxicity at low level airborne concentrations and have not been demonstrated to pose a significant carcinogenic risk to the general population at intermittent low levels of exposure. Acute high levels of exposure, well above the maximum emission

concentrations observed through DCA, have been associated with adverse health effects. In addition, repeated high levels for long-term durations have been associated with adverse health effects, a scenario of exposure not likely to occur under the conditions of application or within a residential exposure scenario.

[3] Based on the decay pattern of the VOC emission products (up to 30 days), ambient indoor VOC air concentrations decrease very rapidly over time and should not accumulate to a toxic concentration in the home or in any other residential building. Although, it was observed that three VOCs were emitted and detected in air samples collected at testing intervals beyond 4 days, these levels were well below safety guidelines applied in the process of this risk assessment. Acute exposures to low-levels are not associated with adverse impacts to human health.

[4] Exposure to maximum potential indoor air concentrations of VOC emission products was demonstrated through the risk assessment process to possess a low potential for human health risk under the conditions of exposure outlined in the Exposure Assessment Section of the document.

[5] Short-term low-level exposures to VOC products emitted from "*Canada VOC polyurethane foam*" are not associated with acute or chronic adverse health effects.

Presently there are no Canadian or U.S. human exposure standards for total volatile organic compounds (TVOC), however a target of 1 mg/m^3 and 5 mg/m^3 respectively, are being discussed for indoor office environments. The European Community has prepared a target guideline value for TVOC of 0.3 mg/m^3 for office environments. TVOC concentrations (calculated based on maximum emission concentrations of 25 unique VOCs identified) are below the recommended guideline for Canadian and U. S. office environments.

Exposure to potential VOCs and consideration of re-occupancy time following the application of spray applied polyurethane foam is also dependent on a factors, including SPF formulation, the amount of foam applied per volume of space, temperature, humidity, the degree of ventilation and other variables. Dynamic chamber analysis of "*Canada VOC polyurethane foam*" provides a VOC emissions profile under a case scenario where there are exposed interior surfaces of SPF, relatively high temperature (40^{o}C), uncontrolled humidity low and low air flow rates. It is likely that the profile and concentrations of VOCs emitted from the foam test panel in DCA are much higher than those experienced in practical application.

Overall, the concentrations of airborne VOC and TVOC decrease rapidly over time and are not likely to accumulate in ambient air to toxic concentrations. Thus in this case, exposure to maximum airborne concentrations of VOC or TVOC, will not pose a significant human health risk. Following the post-application curing period, estimated VOC concentrations from "Canada VOC polyurethane foam" were determined to remain within an acceptable range for human exposure. Based on the integration of all information presented in the steps of the risk assessment process.

The DCA provides VOC emission concentrations following a 24 hour period after which the spray foam is applied (a 24 hour period following the mixing and spraying of the product). Considering DCA and the results thereof, it *is suggested that a residential occupancy time of 1 hour be considered for* "*Canada VOC polyurethane foam*" *with the expressed provision that the 24-hour curing period (mixing and spraying) is maintained after application.*

7.0 RECOMMENDATIONS

Indoor exposures to VOCs from building materials are of obvious concern. The potential for off-gassing of volatile chemicals from spray polyurethane foam is not fully understood and is an area where more research is needed. Since there are numerous sources of VOC in building material and home furnishings, it is clear that regulatory improvements to indoor VOC standards in residential buildings will not be achieved by singling out individual products, but rather through an assessment of all potential components of such residences. Significant improvements in the indoor air of individual VOC could be achieved by establishing an overall limit in the amount of total VOC contributed by all housing materials used in the construction of new buildings. This limit could then be maintained through adequate ventilation.

In some practical application scenarios (installation of wiring, maintenance work, building renovations, demolition etc.) potentially involving cutting and heating of material, it is conceivable that interior surfaces of cured foam are exposed and may emit VOCs. Depending on the level and duration of such work, exposure and risk mitigation measures should be considered, including personal protective equipment for occupational workers, adequate cleaning and ventilation, securement of work areas, and in some cases temporary removal of residents.

The current risk assessment indicates that there is a low human health risk associated with exposure to VOC emission products from "*Canada VOC polyurethane foam*". Since no significant threat to health can be associated with an exposure to low-levels of these emission products, maximum levels are transient and do not persist at levels exceeding safety limits over the 30-day period of dynamic chamber analysis, it is suggested that *a residential occupancy time of 1 hour be considered for* "*Canada VOC polyurethane foam*" *with the expressed provision that the 24-hour curing period (mixing and spraying) is maintained after application.*

8.0 CLOSURE

A Human Health Risk Assessment (HHRA) has been completed as authorized. This report has been prepared for the exclusive use of Canada VOC and its agents for specific application to the polyurethane spray foam "*Canada VOC polyurethane foam*". It has been prepared in accordance with generally accepted toxicological practices and no other warranty, expressed or implied, is made. Any use, which a Third Party makes of this report, or any reliance on decisions to be made based on it, is the responsibility of such Third Parties. Dr. L. Bharadwaj accepts no responsibility for damages, if any, suffered by any Third Party as a result of decisions made or actions based on this report.

I trust that this report fulfils your requirements for this project. Should you require additional information, please contact Dr. Lalita Bharadwaj.

Yours very truly,

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9.0 REFERENCES

1. Health Canada, http://www.hc-sc.gc.ca/ewh-semt/air/in/poll/construction/organi-eng.php, April 2009.

2. Canadian Environmental Protection Act (1994) Human Health Risk Assessment for Priority Substances. ISBN 0-662-22126-5. Cat. No. En40-215/41E. Health Canada On Line: http://www.hc-sc.gc.ca/english/index.html

3. US EPA (1989) Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A). EPA/540/1-89/002.

4. National Research Council: Canadian Construction Materials Center (CCMC) National Standard of Canada. CAN/ULC-S705.1-01-Standard for Thermal Insulation Spray Applied Rigid Polyurethane Foam, Medium Density, Material-Specification. CAN/ULC-S774-09-Standard Laboratory Guide for the Determination of Volatile Organic Compound Emissions from Polyurethane Foam.

5. Exova Confidential Report (2018) 033761 Canada VOC.

6. Amdur, M.O., Doull, J., Klaassen, C.D., Casarett and Doull's Toxicology: The Basic Science of Poisons 4th edition. Pergamon Press New York, New York 1991.

7. Crespo J., Galan, J., (1999) Exposure to MDI during the process of insulating buildings with spray polyurethane foam. Ann Occup Hyg 43:415-419.

8. Hosein, H.R., and Farkas, S., (1981) Risk associated with the spray application of polyurethane foam. Am Ind Hyg Assoc 42:663-665.

9. Lesage, J., Stanley J., Karoly, W.J., Lichtenber, F.W., (2007). Airborne methylene diphenyl diisocyanate (MDI) concentration associated with the application of polyurethane spray foam in residential construction. J Occup Environ Hyg 4(2): 145-155.

10. The American Conference of Governmental Industrial Hygienists. 2010 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indicies. http://www.acgih.org

11. Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards website: http://www.cdc.gov/niosh/npg/npg.html.

12. US Department of Labor Occupational Health and Safety Administration. http://www.osha.gov

13. Snyder, R., Andrews, L.., (1996) Toxic effects of solvents and vapors. In Cassarett and Doull's Toxicology: The Basic Science of Poisons (C.D. Klaassen, Ed.). McGraw Hill, New York.

14. Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982., p. 3163.

15. OECD SIDS (2006) 1,2,-Difluoroethane (HFC-152a) SIDS Initial Assessment Report for SIAM 22 Paris, France 18-21, April 2006.

16. EPA (2010) Toxicological Review of cis and trans- 1,2-dichloroethene: In support of summary information for the Integrated Risk Information System. September 2010. USEPA Washington, DC.

17. WHO (1989) Indoor air quality: Organic Pollutants. EURO reports and studies No III, World Health Organization, Copenhagen Denmark.

18. Yu, C., Crump., D., (1998) A review of the emission of VOCs from Polymeric Materials used in Buildings. Building and Environment, 33:(6) 357-374.