Addyston Ohio Air Quality Study 2005

Division of Air Pollution Control
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EXECUTIVE SUMMARY

The Ohio EPA, Division of Air Pollution Control (DAPC) has completed an urban air toxic monitoring study in Addyston, Ohio. This study contains the initial results for an ongoing investigation of outdoor (ambient) air health impacts near a large source of volatile organic compounds (VOCs). This study is a cooperative effort with the Hamilton County Department of Environmental Services (HCDOES).

The Lanxess Corporation (Lanxess), located at 356 Three Rivers Parkway, Addyston, Ohio is a major source of VOC compound releases into the ambient air. Lanxess operates various continuous plastic polymerization units that use acrylonitrile, 1,3-butadiene, and styrene (ABS) to make plastic products. These processes routinely release the above chemicals into the air. The Lanxess Corporation was chosen for study due to an Ohio EPA investigation into the cause(s) and environmental consequences of three accidental releases emitting these compounds into the environment during late 2004 and early 2005.

After the three accidental releases, the Ohio EPA / Ohio Department of Health conducted public health evaluation and recommended an ambient air monitoring plan be initiated near the facility. Ambient air samples were collected from the rooftop of the Meredith Hitchens Elementary School across the street from Lanxess beginning in May 2005. This study includes the evaluation of chronic (long-term) health risk. Two compounds (acrylonitrile and 1,3-butadiene) exhibit average measured air concentrations above the level at which Ohio EPA considers protective of public health. No ambient air monitoring conducted by Ohio EPA and HCDOES has indicated any exceedence of any acute (short-term) health risk levels to date, although additional monitoring is necessary, and will be conducted.

The ambient air monitoring results are evaluated in the following inhalation risk assessment. This process estimates the health effects that individuals or populations may experience as a result of prolonged (long-term) exposure to the toxic compounds. In an air pollution monitoring risk assessment, exposure is assumed to be constant inhalation (24 hours per day; 365 days per year; for 30-70 years) to the average of the measured concentrations of the pollutants. Children may be a higher risk.

Within this framework, a range of "acceptable" health risk values for carcinogens is between the one in 1,000,000 (1×10^{-06}) and one in 100,000 (1×10^{-05}). For non-carcinogenic compounds, estimations of risk are evaluated to be either above or below a “no determined health effect” air concentration. The ratio of the individually measured concentration to the no-effect level is the Hazard Quotient (HQ). The sum of the ratio for each chemical defined as the Hazard Index (HI). Concentrations below these “no-effect” levels are generally regarded as "safe." Within the above framework, the non-acceptable risk level defined for an individual carcinogenic compound in ambient air is 1×10^{-4} (one in 10,000). Any individual non-cancer chemical that is above 100% (1.0) HQ is also considered unacceptable and merits further investigation.

The total chronic (long-term) carcinogenic risk in the immediate area of the Lanxess facility area is in the 10^{-4} risk range. The long-term non-carcinogenic risk exceeds the "no health-effects level" level by more than 6 times. Most significant is the fact that the both the cancer and non-cancer risk is driven by the average measured concentrations of 1,3-butadiene and acrylonitrile. The individual risk for 1,3-butadiene is 3.22×10^{-4}, and the individual Hazard Quotient is 501% (5.01) of the no-effects level. Additionally, the individual carcinogenic risk for acrylonitrile is 1.5×10^{-4} and the individual HQ is 111% (1.11). Both individual measured average concentrations and corresponding estimates for long-term risk are well above the "acceptable" risk level, and above the levels at which Ohio EPA takes action to mitigate potential health impacts to the public.

When the risk estimations are totaled for all measured pollutants as monitored on the school roof, the total carcinogenic risk increases to 4.97×10^{-4}, and the total non-carcinogenic risk increases to 621% (6.21), more than 6 times the no health-effects level. The total chronic (long-term) health risks calculated from the measured average ambient air concentrations at the Lanxess facility are well above the "acceptable" risk level, and above the levels at which Ohio EPA takes action to mitigate potential health impacts to the public.

Ohio EPA has identified the air pollution sources within the Lanxess facility most likely responsible for these large ambient air concentrations. The focus for this study is on the primary chemicals used in the manufacturing processes at the facility.

Introduction

The Ohio EPA, Division of Air Pollution Control (DAPC) has completed an urban air toxic monitoring study for the Addyston, Ohio area. This study contains the initial results of an ongoing investigation of the ambient air health impacts near a large source of volatile organic compounds (VOCs). This study is the responsibility of the Air Toxics Unit (ATU) of the Division of Air Pollution Control and the Hamilton County Department of Environmental Services (HCDOES), the local air agency commissioned by Ohio EPA with responsibility for the air program in Butler, Clermont, Hamilton, and Warren counties.

The Lanxess Corporation (Lanxess), located at 356 Three Rivers Parkway, Addyston, Ohio is a major source of VOC compound releases into the ambient air. Lanxess operates various continuous plastic polymerization units using acrylonitrile, 1,3-butadiene, and styrene (ABS) for plastic production with boilers and/or a thermal oxidizer for VOC emission control, and a wet scrubber and baghouse to control particulate emissions. Lanxess operates a batch polymerization process for ABS (predominant product), and acrylonitrile styrene acrylate (ASA) plastics with a flare as the emissions control device. Vapors from the 1,3-butadiene unloading and processing operations and vapors from the reactors are vented to the flare for combustion. These processes release these compounds into the ambient air.

Lanxess was chosen for ambient air monitoring after three accidental releases emitted toxic compounds into the environment. On October 2 - 4, 2004, a reported malfunction allowed 1,122 pounds of acrylonitrile, 34 pounds of 1,3-butadiene, and 387 pounds of styrene into the atmosphere. On December 15 - 16, 2004, a plastic batch process was not conducted properly, resulting in a release of 700 pounds of acrylonitrile over an 8-minute period. On February 23, 2005, another malfunction allowed approximately 7,650 pounds of 1,3-butadiene to be released over a 2+ hour period. On April 8, 2005, HCDOES sent a Notice of Violation (NOV) to Lanxess for the three releases. The NOV required Lanxess to develop a plan to prevent future malfunctions at the facility.

As a result of the accidental releases at Lanxess, the Ohio Department of Health (ODH) and Ohio EPA conducted a brief health study of the potential impacts of the releases (Public Health Review and Evaluation of Chemical Release Incidents, Lanxess, Inc. Facility, Addyston, Ohio; May 2005). The study concluded the Lanxess accidental releases were not likely to have significantly impacted the health of area residents, including children at the Meredith Hitchens School, but the nature of the chemicals released and the occurrence of three of these release events in the short period of time were of major concern to the Ohio Department of Health and Ohio EPA.

As a direct result of the Ohio EPA and ODH investigation, an ambient air sampling plan was initiated near Lanxess. A rooftop sampling unit was sited at the Meredith Hitchens Elementary School (school), 190 Main Street, Addyston, Ohio beginning May 10, 2005. The three compounds cited specifically above are classified as Hazardous Air Pollutants (HAPs) by U.S. EPA in the Clean Air Act.

Additionally, Ohio EPA limits the amount of these pollutants allowed to be emitted into the atmosphere as part of its strategy to control emissions of toxic air pollutants. In particular, the compounds of acrylonitrile and 1,3-butadiene are considered highly toxic, as defined by their ability to cause cancer and other non-carcinogenic health effects. The pollutants measured on the school roof exhibit long-term average air concentrations above the level at which Ohio EPA considers protective of public health. The air monitoring data and the toxicological interpretation of the data are the subject of this air quality report.

Methods

Volatile Organic Compound Sampling and Analysis

This study consists of ambient air sampling for volatile organic compounds (VOCs). These are defined as compounds that are generally found in the vapor state at normal temperatures, and can be chlorinated or simple hydrocarbons. VOC samples are collected using a whole-air sampling system that pumps ambient air into an evacuated stainless steel canister. The canister acts as a storage container which allows the air sample to be maintained virtually unchanged until it is analyzed. Beginning May 10, 2005, samples were collected four times a month (once every 6th day) for a 24-hour period, midnight to midnight, on the school roof. Sampling is being conducted by HCDOES staff, with laboratory analysis being performed by a contract laboratory. For the canister analysis, the standard procedure of using a gas chromatograph (GC) in combination with mass spectrometer (MS) is being used (U.S. EPA / Ohio EPA Method TO-14A / TO-15). Currently the method measures over 80 VOCs, including the compounds of concern for the Lanxess facility.

Compound measurements below the detection limit are calculated as follows. The detection limit is the lowest measurement the procedure can accurately quantify as a true measurement of the ambient air concentration. If a compound was detected once or more during the sampling period, the arithmetic mean (average) contains a value for any non-detect measurement(s) as half the detection limit. Other options for handling values below the detection limit are available, such as using the detection limit itself, or using a value of zero for the measurement result. Using values of half the detection limit is common U.S. EPA practice because values of zero may underestimate the true air concentration, while values of the detection limit itself may over-estimate the true air concentration.

Results

In this study, the compounds of acetone, acrylonitrile, 1,3-butadiene, methylene chloride, 2-propanol, styrene, benzene and toluene are reported. **Data Table A** (located at the end of this report) lists the results of 27 samples collected at the Meredith Hitchens Elementary School from May 2005 until November 2005. The table lists the compound name and the measured concentration for the sample collection date. All units are micrograms per cubic meter air volume (ug/m^3). Samples collected during a period when the ABS process unit was shut down for maintenance (September 25, October 1, 7, & 13) are not included in the average listed in Data Table A.

Discussion

The data generated by this study's sampling program represent the measured concentrations for VOCs sampled on the roof of the Meredith Hitchens Elementary School, Addyston, Ohio. The ambient air monitoring results are evaluated by an inhalation risk assessment. This process uses current available toxicological information as a basis for estimating the health effects that individuals or populations may experience as a result of prolonged exposure to the measured substances. Ohio EPA generally follows the risk assessment guidelines provided by the U.S. EPA and the National Academy of Science (NAS). Risk-based screening levels are based upon U.S. EPA's Integrated Risk Information System (IRIS) unit risk factors for carcinogens and reference concentrations [RfCs] for non-carcinogenic effects. A risk assessment produces a numerical prediction of the probability of an adverse health effect, such as carcinogenicity and / or systematic toxicity, that may occur as a result of long-term exposure to air polluta nts.

In an air pollution monitoring risk assessment, exposure is assumed to be constant inhalation (24 hours per day; 365 days per year; for 30-70 years) to the average of the measured concentrations of the pollutants. Average annual ambient air measurements are usually measured every 13th day (two times per month). These assumptions are conservative in general, in order to ensure that the actual risks will be no greater than the estimated risk. In fact, the actual risks will most likely be less than those estimated by the process. The average exposure concentration is calculated from the total collected samples, including periods of higher and lower concentrations. For this study, measurements were taken at twice that frequency (every 6th day, roughly four times per month) for over 7 months. Currently there is no reason to suspect the data collected does not represent the ambient air concentrations near the Lanxess facility during the routine operations of the facility.

Toxicity of the Chemicals of Concern

The following health effects information is a brief summary of data collected from the U.S. EPA's IRIS and Technology Transfer Network Air Toxics hazard summaries. The Agency for Toxics Substances and Disease Registry (ATSDR - part of the national Center for Disease Control [CDC]) also supplies information concerning the potential health effects caused by toxic air pollutants. Ohio EPA risk assessment procedures follow guidelines provided by the NAS and U.S. EPA (Risk Assessment Guidance for Superfund - Volume 1 - Human Health, December 1989) and the recently revised U.S. EPA Air Toxics Risk Assessment Library (Volumes 1-3, 2005).

ACRYLONITRILE

Acrylonitrile is classified as a Hazardous Air Pollutant (HAP) under Title III of the Clean Air Act Amendments. Acute (short-term) exposure to high concentrations of acrylonitrile through inhalation can lead to nose and throat irritation, breathing difficulties, nausea, dizziness, weakness, headaches, and convulsions. Symptoms typically disappear when acute exposure is stopped. Chronic (long-term) non-cancer health effects also include headaches, fatigue, and nausea. The primary long-term carcinogenic health effect associated with human exposure to acrylonitrile is lung cancer.

1,3-BUTADIENE

1,3-butadiene is also classified by U.S. EPA as a HAP. Short-term exposure to high levels of 1,3-butadiene causes irritation of the eyes, nasal passages, throat and lungs. Breathing very high levels of this chemical for a short period of time can cause central nervous system damage, blurred vision, nausea, fatigue, headache, decreased blood pressure and pulse rate, and unconsciousness. Chronic (long-term) non-cancer health effects include cardiovascular diseases and effects on the blood. Animal studies indicate the potential for reproductive effects. The consistent long-term carcinogenic effect from exposure to 1,3-butadiene is cancer of the blood (leukemia), although other cancers are associated with exposure to the toxin.

STYRENE

Styrene is less toxic than acrylonitrile and 1,3-butadiene, but results in similar temporary adverse health effects when people inhale in styrene vapors at high levels. These include depression, concentration problems, weakness, fatigue, and nausea plus possible eye, nose, and throat irritation. Chronic (long-term) non-cancer effects from breathing styrene include effects on the central nervous system, with some effects on the kidneys and blood. There is some evidence for reproductive effects caused by this chemical. Long-term cancer health effects include increased risk of leukemia and lymphoma, although the human evidence is not as robust as for acrylonitrile and 1,3-butadiene.

It is important to note that the development of cancer is usually associated with long-term, constant exposures (estimated for risk assessment purposes to be between 30-70 years for adults). Note that children may be at higher risk. Human studies verifying carcinogenicity (the ability to cause cancer) in general come from exposure to these chemicals in occupational settings. Acute (short-term) exposure symptoms described above are unlikely to lead to any lasting or chronic adverse health effects. Acute is defined as a brief exposure to relatively high concentrations of the toxic compound.

It is also important to clarify that during the ambient air monitoring performed by Ohio EPA and HCDOES, no concentrations collected by the 24-hour samples on the school roof exceeded the acute (short-term) health-based exposure levels normally associated with the health effects cited above. The school roof data analyzed here is being used for the chronic (long-term) exposure estimations for health effects caused by 30-70 years of breathing these toxic chemicals. Ohio EPA and HCDOES will conduct alternate methods for monitoring the acute (short-term) air concentrations around the Lanxess facility. This concurrent short-term monitoring will be used to evaluate whether or not any acute health risks exist for the school or general population as a result of the routine batch processes used in the ABS production at the facility.

Risk Assessment Summary; Risk Calculation

Risk is analyzed in two phases. Carcinogenic risk assumes no safe exposure limit, and all exposure increases the possibility of a health effect. Non-cancer health effects include a presumed exposure level below which there is no appreciable health risk. The toxicity of the carcinogenic and non-carcinogenic compounds is determined using unit risk factors (URFs) for carcinogenic compounds and reference dose/reference concentrations (RfDs/RfCs) for non-carcinogens. Current toxicity information is obtained from U.S. EPA's IRIS database. URFs and RfCs listed as of November 2005 are used in the calculations. Route to route extrapolation was conducted to estimate RfCs from RfDs (reference doses) where no RfCs were available.

Carcinogenic Risk

The cancer URF is a toxicity value that defines quantitatively the relationship between dose and response. Multiplying the URF by the long-term average daily dose (average ambient air concentration) will produce the probability of developing a cancer as a result of toxic exposure. This is defined as the excess lifetime cancer risk - the extra risk added to an individual's risk by exposure to the toxic air pollutant. The result is expressed numerically as a probability, for example, one in 1,000,000 (1×10^{-6} or 1 E-06).

The current method of estimating the total health effects risk from exposure to mixtures of carcinogenic compounds consists of adding individual risk numbers to approximate the total risk. This summation is based upon the principle that the addition of each risk produces a combined total risk estimate. This is the method currently recommended by the U.S. EPA, although exposure to combinations of carcinogens may cause greater or lesser risk than can be explained by merely the summation of the individual exposure risks.

Non-carcinogenic Risk

The non-cancer, long-term (chronic) RfCs are estimates of daily exposure levels for which people, including sensitive subpopulations, may be exposed constantly for long periods without an appreciable risk of adverse health effects. Safety factors are especially developed to be protective for long-term exposures. Non-carcinogenic risks are individually evaluated by the use of a Hazard Quotient (HQ), which is the ratio of the average ambient air concentration compared to the RfC for each compound (the measured concentration is divided by the RfC). If the HQ exceeds 1.0 (100% of the RfC) for any individual compound, there may be potential health effect(s) as a result of exposure to the compound. An HQ over 100% (1.0) initiates further investigation by Ohio EPA.

To evaluate combined (total) non-carcinogenic adverse health effects, the total risk is described by the use of the Hazard Index (HI). The HI is the summation of the individual HQs for each compound in the mixture. If the totaled HI exceeds 100% for the mixture of compounds, there may be potential health effects as a result of exposure to the group of compounds. An HI over 100% (1.0) initiates further investigation by Ohio EPA.

Risk Assessment Summary; Acceptable Risk

A range of "acceptable" health risk values for carcinogens has been defined by U.S. EPA and implemented by Ohio EPA in the examination of toxic air pollutants in the State. Historically, acceptability ranges from a target goal of one in 1,000,000 (1×10^{-06}) for regulation of certain source categories of individual toxic air pollutants, to some source categories routinely operating in the one in 100,000 (1×10^{-05}) range. For non-carcinogenic estimation of Hazard Indexes, a calculated HI below 1.0 (100%) is generally regarded as a "safe" level of exposure.

To put risk in perspective, most large urban areas in the United States exhibit aggregate or total carcinogenic risks in the 10^{-05} to 10^{-06} range. The totaled HQ for some of these areas may slightly exceed a value of 100% (1.0). While it is common for industrial or light industrial areas to have risks greater than those, some smaller suburban and rural areas have combined carcinogenic risks in the 10^{-06} to 10^{-08} range. Areas of higher risk characteristically may also contain large volumes of automobile traffic. While workers in such areas routinely are exposed only during working hours, and return to residential areas of decreased exposure concentrations during non-working hours, individuals living in these areas may be constantly exposed to these higher levels of pollutants. While it is certainly desirable to have these aggregate risks minimized to the lowest possible level, a no-risk scenario would be impossible to achieve in an industrial area.

Within the above framework describing acceptable risk, the non-acceptable risk level defined for an individual carcinogenic compound in ambient air is 1.0×10^{-4} (one in 10,000). Any individual non-cancer HQ above 100% (1.0) is considered potentially unacceptable (although non-cancer risks are not so clearly defined) [U.S. EPA Risk Assessment Guidelines 1989 & 2005]. The evaluation of appropriate risk takes into consideration the exposure and duration of the populations affected. Dedicated industrial areas could accept more risk than a residential area, or an area with more susceptible populations such as children, the elderly or persons with respiratory impairments.

Table 1 (below) contains the average ambient air concentrations and corresponding carcinogenic and non-carcinogenic risk near the Lanxess facility. Table 1 indicates the total carcinogenic risk for the Lanxess facility area (measured on the school roof) is in the 10^{-4} range (the risk totaled for the compounds acetone, acrylonitrile, 1,3-butadiene, methylene chloride, 2-propanol, styrene, benzene and toluene). The Hazard Quotient (HQ) for the site is also above 100% (1.0). More significantly, however, is the fact that both the cancer and non-carcinogenic risk is primarily driven by the ambient air concentration of 1,3-butadiene and acrylonitrile. The individual risk for 1,3-butadiene is 3.22×10^{-4}, and the individual Hazard Quotient is 501% (5.01) of the no-potential effects level. Additionally, the individual carcinogenic risk for acrylonitrile is 1.5×10^{-4} and the individual HQ is 111% (1.11). Both individual measured average concentrations and corresponding estimates for chronic (long-term) risk are well above the “acceptable” level, and above the levels at which Ohio EPA takes action to mitigate potential health impacts to the public.

Table 1: Summary of Health Effects Risk for Addyston, Ohio, 2005

COMPOUND	AVERAGE CONCENTRATION ($\mu g/m^3$)	CARCINOGENIC RISK	NON-CARCINOGENIC RISK
acetone	2.28		0.00
acrylonitrile	2.21	1.50E-04	1.11
benzene	2.90	2.26E-05	0.10
1,3-butadiene	10.72	3.22E-04	5.01
methylene chloride	0.96	4.51E-07	0.00
2-propanol	0.95		
styrene	2.71	1.54E-06	
toluene	0.46		0.01
TOTAL		**4.97E-04**	**6.21**

When the risk estimations are totaled for all measured pollutants on the school roof, the total carcinogenic risk is 4.97×10^{-4}, and the non-carcinogenic HQ risk (Hazard Quotient) is 621% (6.21), over 6 times the no health-effects level. The total chronic (long-term) health risks calculated from the measured average ambient air concentrations at the Lanxess facility are well above the “acceptable” level, and above the levels at which Ohio EPA takes action to mitigate potential health impacts to the public.

Risk Assessment Summary; Conclusions

Ohio EPA has documented unacceptably high concentrations of the VOCs 1,3-butadiene and acrylonitrile on the roof of the elementary school across the street from the Lanxess facility. Ohio EPA has identified the source or sources from the Lanxess facility most likely responsible for these high concentrations. Other pollutants potentially emitted from this facility, such as particulate matter and metals, were not evaluated this study. While the evaluation of more compounds emitted from the facility could increase any risk evaluation or estimation accordingly, this study centers on the compounds released during the previous three accidents from the manufacturing processes at the facility.

Currently, both the long-term carcinogenic and non-carcinogenic risk associated with the ambient air measurements taken near the Lanxess site are above the acceptable or “safe” levels determined by Ohio EPA to be protective of public health. Ohio EPA will continue to conduct air monitoring to evaluate changes that result from additional pollution control devices Lanxess plans to install.

For more information

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Data Table 1: Summary of data collected in Addyston, Ohio, 2005

May 2005-November 2005

	Concentration: µg/m3							
Date:	**Acetone**	**Acrylonitrile**	**1,3-Butadiene**	**Methylene chloride**	**2-Propanol**	**Styrene**	**Benzene**	**Toluene**
May 10	0.59	**1.30**	**1.11**	**3.47**	**7.5**	**2.56**	0.80	0.19
May 22	0.59	**6.51**	**15.49**	0.87	**2.50**	**4.26**	0.80	0.19
May 28	0.59	0.54	0.55	0.87	0.62	1.06	0.80	0.19
June 3	0.59	0.54	**6.64**	0.87	0.62	1.06	0.80	0.19
June 9	0.59	0.54	0.55	0.87	0.62	**3.41**	**6.39**	0.19
June15	0.59	0.54	0.55	0.87	0.62	1.06	**6.39**	0.19
June 21	0.59	0.54	**30.97**	0.87	0.62	**4.26**	**6.39**	0.19
June 27	0.59	0.54	**4.42**	0.87	0.62	**0.98**	**6.39**	0.19
July 3	0.59	0.54	**6.64**	0.87	0.62	**0.94**	**3.19**	0.19
July 9	0.59	0.54	**2.88**	0.87	0.62	1.06	**6.39**	0.19
July 15	0.59	0.54	**5.97**	0.87	0.62	1.06	**6.39**	**3.77**
July 22	0.59	0.54	**5.53**	0.87	0.62	**1.02**	**3.19**	**3.77**
July 28	**2.38**	0.54	0.55	0.87	0.62	1.06	**3.19**	0.19
Aug 3	**23.75**	**3.91**	**33.18**	0.87	0.62	**3.49**	**6.39**	0.19
Aug 9	0.59	**1.30**	**6.42**	0.87	0.62	1.06	**6.39**	0.19
Aug14	0.59	0.54	0.55	0.87	0.62	1.06	0.80	0.19
Aug 20	0.59	**2.02**	0.55	0.87	0.62	**3.02**	0.80	0.19
Aug 26	**21.38**	**3.69**	**8.41**	0.87	0.62	**4.69**	**3.19**	0.19
Sept 1	0.59	**1.30**	**33.18**	0.87	0.62	**3.02**	**3.19**	0.19
Sept 7	0.59	**1.58**	**3.54**	0.87	0.62	**3.36**	0.80	0.19
Sept 13	0.59	**16.71**	**20.35**	0.87	0.62	**2.26**	0.80	0.19
Sept 19	0.59	**1.95**	**19.91**	0.87	0.62	**1.06**	0.80	0.19
Oct 19	0.59	**1.95**	**17.70**	0.87	0.62	**2.56**	0.80	0.19
Oct 25	0.59	0.54	0.55	0.87	0.62	1.06	0.80	0.19
Oct 31	0.59	**2.60**	**5.75**	0.87	0.62	**6.39**	0.80	0.19
Nov 6	0.59	**3.91**	**33.18**	0.87	0.62	**12.78**	0.80	0.19
Nov 12	0.59	**3.91**	**24.33**	0.87	0.62	**3.58**	0.80	0.19
Average	**2.28**	**2.21**	**10.72**	**0.96**	**0.95**	**2.71**	**2.90**	**0.46**

* Measurements above the method detection limit are listed in bold. Measurements below the detection limit, counted as ½ the detection limit, are listed in regular type.