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World Trade Center Indoor Air Assessment: Selecting Contaminants of Potential Concern and Setting Health-Based Benchmarks

Prepared by the Contaminants of Potential Concern (COPC) Committee of the World Trade Center Indoor Air Taskforce Working Group

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NYC-WTC_000199582

NYC 9/11 Public Portal Document

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Table of Contents

Introduction 4

Selecting the Contaminants of Potential Concern (COPCs) 4
Lead and Combustion By-Products (PAHs, Dioxin) 5
Lead 5
PAHs 6
Dioxin 6
Building Materials (Asbestos, Fibrous Glass, Crystalline Silica) 6
Asbestos 7
Fibrous Glass 7
Crystalline Silica 7
Other Substances that Were not Selected to be COPCs 9

Setting Benchmarks for the Contaminants of Potential Concern (COPCs) 10
Developing Risk-Based Criteria for Indoor Air 11
Developing Risk-Based Criteria for Settled Dust 13
Developing Benchmark Levels Based on Occupational Health Standards 15

References 27

APPENDIX A
Hazardous Substances Not Included in Indoor Environment Sampling Program 1

APPENDIX B
World Trade Center Health Effects Screening Criteria for Ambient Air 1

APPENDIX C
Basis for Tier III screening level of 1 E-04 1

APPENDIX D
Assessing Exposures to Indoor Air and to Residues on Indoor Surfaces 1

APPENDIX E
IEUBK Model Results for Lead in Air 1

NYC-WTC_000199583

NYC 9/11 Public Portal Document

Tables

Table 1. Index of NIOSH and OSHA exposure limits and estimated maximum values in Lower Manhattan. 8
Table 2. Exposure parameters for calculating clearance criteria for air samples. 12
Table 3. Exposure parameters used to calculate clearance criteria for wipe samples. 14
Table 4. Lead 17
Table 5. Polycyclic Aromatic Hydrocarbons (PAHs) 18
Table 6. Dioxin 19
Table 7. Asbestos 21
Table 8. Fibrous Glass 23
Table 9. Crystalline silica - respirable fraction of alpha-quartz 25

NYC-WTC_000199584

NYC 9/11 Public Portal Document

World Trade Center Indoor Air Assessment: Selecting Contaminants of Potential Concern And Setting Health-Based Benchmarks

Introduction

Since September 11, 2001, the outdoor environment around the World Trade Center (WTC) site and nearby areas has been extensively monitored by a group of federal, state, and local agencies[1]. The agencies have taken samples of the air, dust, water, river sediments and drinking water and analyzed them for the presence of pollutants that might pose a health risk to response workers at the WTC site, office workers, and local residents. While some people may have experienced acute irritant and respiratory effects from the collapse of the towers and associated fires, extended monitoring of the ambient air at and beyond the perimeter of the WTC site over the past year indicates that contaminant concentrations pose a low risk of long-term health effects. During this same time period, limited investigation of the indoor environment in residential dwellings has occurred [NYCDOH, 2002; Chatfield & Kominsky, 2001]. As the cleanup of the WTC site is coming to an end, governmental health and environmental agencies are directing resources to evaluate the indoor environment for the presence of pollutants that might pose long-term health risks to local residents. Selecting Contaminants of Potential Concern (COPCs) and setting health-based benchmarks will assist the Pilot Cleaning Effectiveness Initiative[2] and inform the selection of contaminants in the Background Study[3].

Selecting the Contaminants of Potential Concern (COPCs)

The assessment of the indoor environment began with a review of historical information on hazardous substances that have been associated with building fires and collapses [Wallace, 1990]. Many compounds, including combustion by-products such as dioxins and polycyclic aromatic hydrocarbons (PAHs) were identified for further investigation, along with building materials such as asbestos and fibrous glass. In addition, ambient air, indoor air, and indoor/outdoor bulk dust monitoring data were reviewed. Data sources included EPA's ambient air and bulk dust/debris monitoring program (www.epa.gov/wtc), OSHA's air/dust monitoring

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[1] Agencies include the U.S. Environmental Protection Agency (EPA), Agency for Toxics and Disease Registry (ATSDR), New York State Department of Health (NYSDOH), New York City Department of Health (NYCDOH), Occupational Safety and Health Administration (OSHA), New York State Department of Environmental Conservation (NYSDEC) and New York City Department of Environmental Protection (NYCDEP).

[2] EPA is conducting a pilot program in an uncleaned/unoccupied building at 110 Liberty Street to determine the effectiveness of various cleaning methods for removing asbestos and other contaminants of potential concern from residential dwellings.

[3] Most if not all of the pollutants associated with the collapse of the World Trade Center were present in New York City's environment prior to September 11. To establish a baseline for the presence of these contaminants in affected residences, EPA will collect and analyze samples to look for some of these pollutants in apartments in parts of Manhattan that were not impacted. The Agency will use the data to determine pre-existing or "background" levels of these pollutants in interior spaces in New York City.

NYC 9/11 Public Portal Document

data and the NYCDOH/ATSDR indoor air pilot program [NYCDOH, 2002]. A concerted effort also was made to identify and review additional sources of WTC-related data from other governmental agencies (e.g., U.S. Geological Survey, NYC Board of Education), academic institutions, environmental organizations, and the private sector.

A semi-quantitative screening process was performed on the collected sampling data. Based on frequency-of-detection, concentration and inherent toxicity, contaminants that exceeded health-based screening levels for the ambient air (see Appendix B) were identified. Dioxin and PAHs were added to the COPC list by this process. In addition, building constituents with carcinogenic (asbestos) or irritant effects (fibrous glass, crystalline silica) that were consistently and significantly found in bulk debris and indoor dust samples were identified as COPCs [NYCDOH, 2002] . Finally, lead (Pb) was included based on a comparison of sampling data with existing regulatory standards. Collectively, the resulting group of contaminants are called "contaminants of potential concern" or COPCs in this report.

The list of COPCs is shown in the column at the left, below. Included for each COPC is a data summary that supports its inclusion on the list. For completeness, an additional list is included on the right containing substances that, for various reasons, have created concern, but on closer inspection, were either rarely detected in the ambient air and/or settled dust sampling around the WTC, or routinely found at concentrations below the health-based screening criteria presented in Appendix B.

COPCs	Other Substances
Lead	Benzene
PAHs	PCBs
Dioxin	Chromium
Asbestos	Cadmium
Fibrous Glass	Manganese
Crystalline Silica	Mercury
	Particulate Matter
	Refractory Ceramic Fibers
	Mold

Lead and Combustion By-Products (PAHs, Dioxin)

Lead. EPA's ambient air monitoring data detected lead in concentrations that exceeded 1.5 ug/m^3 on five occasions from September 18-27, 2001. It should be noted that the National Ambient Air Quality Standard (NAAQS) for lead is 1.5 ug/m^3, but is based on a three-month average. Since the ambient monitoring program began, no three-month average of the ambient air data for lead exceeded the NAAQS of 1.5 ug/m^3. However, lead was more commonly found at concentrations that exceeded 0.1 ug/m^3, the default value employed in EPA's Integrated Exposure Uptake Biokinetic Model for Lead in Children [EPA, 1994]. This value represents the upper-bound of average of ambient airborne lead concentrations in urban environments. Additional support for including lead as a COPC was provided by a report that characterized the dust that settled over lower Manhattan after the WTC collapse [Lioy, 2002]. The lead

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NYC-WTC_000199586

NYC 9/11 Public Portal Document

concentration in settled dust ranged from 101 - 625 parts per million (ppm). By itself, this range does not represent extraordinarily high concentrations, but in combination with the mass of material released from the collapse of the towers, it represents a potentially significant increase in the mass of lead deposited in lower Manhattan. Therefore, lead is included as a COPC.

PAHs. Limited ambient air sampling was conducted for PAHs during the period of time (September through December, 2001) when combustion processes were occurring at the site. However, concentrations in bulk dust [EPA, 2002a and Lioy, 2002] exceeded the removal guidelines for soil in EPA's Hazard Evaluation Handbook [EPA, 1997] of 9 ppm based on benzo(a)pyrene equivalents. This value is risk-based, equating to an excess lifetime cancer risk of $1x10^{-4}$ over a 30-year exposure duration for residential settings. Therefore, PAHs are included as a COPC.

Dioxin. Ambient air samples exceeded EPA's screening criteria (see Appendix B) at various sampling stations during September and October, 2001. Data trend analysis for dioxin in ambient air [EPA, 2002a] showed that concentrations significantly exceeded the risk-based screening level of 0.001 - 0.005 ng/m^3. This range was based on an excess lifetime cancer risk of $1x10^{-4}$ over a 30 year exposure duration for residential settings, using both the existing cancer Slope Factor [Integrated Risk Information System (IRIS), 2002] and proposed cancer Slope Factor in EPA's draft dioxin reassessment [EPA, 2001]. Therefore, dioxin (and related congeners) is included as a COPC.

Building Materials (Asbestos, Fibrous Glass, Crystalline Silica)

The evaluation of building materials for inclusion as COPCs required a different approach than that used for the combustion by-products. Those compounds (PAHs, dioxin) benefit from consensus toxicity criteria (i.e., IRIS-established cancer Slope Factors) that allow for a quantitative screening paradigm. With the exception of asbestos, the building materials evaluated (including fibrous glass, crystalline silica, mica, portlandite, calcite and gypsum) do not have IRIS inhalation toxicity criteria from which to perform quantitative risk assessments. Complicating this matter is the knowledge that many of these substances were deposited in a large cloud from the collapse of the towers. Thus, the settled dust may serve as a reservoir for re-suspension and eventual inhalation exposure. In addition, materials such as fibrous glass can also cause contact irritation when exposed directly to the skin.

The potential for exposure to building materials in the indoor environment was assessed by reviewing sampling data on the constituent composition of the indoor/outdoor bulk dust and indoor/ambient air [EPA, 2002c; USGS, 2001; NYCDOH, 2002; Chatfield & Kominsky, 2001].

Toxicity criteria for building materials (with the exception of asbestos) were obtained from occupational sources, such as the Occupational Safety and Health Administration's permissible exposure limits (OSHA PELs), and the American Conference of Governmental Industrial Hygienists threshold limit values (ACGIH TLVs). The evaluation of exposure potential coupled with toxicity information identified three COPCs (asbestos, fibrous glass and crystalline silica).

CITY_21MC100_002452158

NYC-WTC_000199587

NYC 9/11 Public Portal Document

Asbestos. In the days immediately following the disaster, EPA analyzed the settled bulk dust/debris for asbestos content. More than one third of the approximately 150 samples registered an asbestos concentration greater than 1% [EPA 2002c]. Since that time, EPA has taken the position that WTC-related dust should be considered potentially asbestos-contaminated and handled accordingly. Additionally, indoor settled dust samples collected from residential buildings in November and December 2001 indicated that 18% of the indoor locations sampled contained measurable levels of asbestos [NYCDOH, 2002]. Therefore, asbestos is included as a COPC.

Fibrous Glass. Analysis of WTC bulk dust/debris has consistently identified fibrous glass to be a major constituent of the material [Lioy 2002, USGS 2001]. In addition, an NYCDOH/ATSDR study [NYCDOH, 2002] found fibrous glass in the interior settled dust in 41% of the locations sampled at concentrations up to 35%. Air samples collected in areas with fibrous glass in settled dust indicate no fiber levels of immediate concern. Although fiber counts were found in four areas with slightly greater than background (0.004-0.006 f/cc), subsequent re-analysis indicated actual fibrous glass concentrations from these areas as 0.00004 to 0.00026 f/cc. Air samples from remaining areas showed a maximum 0.003 f/cc total fiber count by PCM. These wools may be skin, eye, and respiratory tract irritants. Although there are no standards to evaluate the settled dust content, the presence of fibrous glass in settled dust does indicate a potential for exposure. Therefore, fibrous glass is included as a COPC.

Crystalline Silica. Settled dust and air samples taken in indoor and outdoor areas of residential buildings in November and December of 2001 indicate the presence of alpha-quartz. Other forms of crystalline silica were not found. This is consistent with outdoor dust and debris samples collected by the USGS [USGS, 2001] and subjected to mineral analysis. Quartz was found in approximately 49% of the settled dust samples from indoor areas of residential buildings and all of the associated outdoor areas sampled. Levels of quartz ranged as high as an estimated 31.4% of the dust by weight in a residence. Since quartz is a common material in sand, finding this mineral in a city where there is a great deal of concrete is not unusual. However, quartz in dust from a comparison area unaffected by the WTC collapse ranged from non-detect only up to an estimated 2.2% in the residence [NYCDOH, 2002]. Seventeen residential areas and eleven common areas had quartz levels greater than the associated comparison area. Therefore, quartz was deemed to be elevated in some indoor areas of lower Manhattan relative to the comparison area. Additionally, quartz was found in 13% of the respirable fraction air samples taken in these areas, ranging from an estimated 4-19 ug/m3, demonstrating a potential for exposure. Although below occupational standards, this estimated concentration is above the effective NAAQS standard for the silica fraction of respirable particulate matter. Therefore crystalline silica, measured as alpha-quartz, is included as a COPC.

In addition to crystalline silica, calcite, portlandite and gypsum were the most abundant minerals detected in settled dust samples from residential areas in lower Manhattan following the WTC collapse. Mica was detected with much less frequency, generally at less than 0.1% of the dust. Halite (salt) was also detected at trace levels. Calcite, portlandite, and gypsum are typical components of concrete and gypsum based wallboard products, which were present in the WTC buildings. While high concentrations of these minerals in airborne dust constitute a short-term

CITY_21MC100_002452159

NYC-WTC_000199588

NYC 9/11 Public Portal Document

health concern in the form of eye, nose and throat irritation, persisting adverse heath effects would not be anticipated, unless these minerals remained suspended in high concentrations. Indoor and street-level outdoor air sampling done in November and December of 2001 show that the levels of these chemicals, over a time-weighted sample, were below levels associated with irritant effects (See Table 1). Although there are methodological difficulties in quantifying these materials by X-ray Diffraction (XRD) techniques, a semi-quantitative screening of the results showed that the air levels were orders of magnitude below occupational standards for irritant effects. However, since the presence of minerals in settled dust indicates there is potential for the materials to be resuspended, these minerals should be evaluated qualitatively. Therefore, although no screening levels are developed for these minerals as COPCs, the Pilot Cleaning Effectiveness Initiative mentioned in the Introduction will report qualitatively on the presence of gypsum, calcite and portlandite, while the quantitative analyses for crystalline silica (a COPC discussed above) are being performed by XRD (following NIOSH Method 7500).

Table 1. Index of NIOSH and OSHA exposure limits and estimated maximum values in Lower Manhattan.

Mineral	NIOSH REL (ug/m^3)	OSHA PEL (ug/m^3)	*Maximum Estimated Value (J) in Lower Manhattan (ug/m^3)
Gypsum	10,000 ug/m^3 (total) 5,000 (ug/m^3 resp)	15,000 ug/m^3 (total) 5,000 (resp)	14J (PM100) 15J (PM4)
Portlandite	5,000 ug/m^3	15,000 ug/m^3 (total) 5,000 ug/m^3 (resp)	95J (PM100) 84J (PM4)
Calcite	10,000 ug/m^3 (total) 5,000 ug/m^3 (resp)	15,000 ug/m^3 (total) 5,000 ug/m^3 (resp)	14J (PM100) 10J (PM 4)

NIOSH = National Institute of Occupational Safety and Health, Centers for Disease Control and Prevention
REL = recommended exposure level/limit
OSHA = Occupational Safety and Health Administration
PEL = permissible exposure limit.
resp = respirable
* [NYCDOH, 2002]

Other Substances that Were not Selected to be COPCs

The following summary is provided for substances that were investigated, but not included on the COPC list. A full discussion of the reasons is provided in Appendix A.

CITY_21MC100_002452160

NYC-WTC_000199589

NYC 9/11 Public Portal Document

Chemical	Reason
Benzene	Benzene is very volatile and dissipates into ambient air quickly. Grab samples that recorded high (above the OSHA PEL of 1 ppm) concentrations on the debris pile consistently dropped to below detection limits (20 ppb) at the site perimeter.
PCBs	In over 500 ambient air samples taken around the WTC work zone, none exceeded EPA's screening level of concern for ambient air (see Appendix B).
Chromium	All measurements (over 300 samples) of chromium in ambient air around the WTC work zone have been below EPA's screening level of concern for the ambient air (see Appendix B). Measurements in settled dust have been below EPA Removal Action Guidelines [EPA, 1997].
Cadmium	Cadmium was found in only two out of 300 air samples at levels greater than EPA's screening level for ambient air (Appendix B). Measurements in settled dust have been below EPA Removal Action Guidelines [EPA, 1997].
Manganese	Manganese was found in only four of over 300 air samples at levels that were greater than EPA's screening level for ambient air (Appendix B). Measurements in settled dust have been below EPA Removal Action Guidelines [EPA, 1997].
Mercury	Concern regarding mercury has been raised by a report of slightly elevated blood mercury levels in four Port Authority Police Officers at the WTC site (69 were screened). A NYC Department of Design and Construction report [Rottner, 2002] concluded that air and bulk data have not shown elevated Hg levels. The report also noted that routine urine screening of NYC firefighters assigned to the site did not indicate any sign of Hg exposure. A U.S. Geological Survey leachability study [USGS 2001] of indoor and outdoor WTC settled dust samples showed that it is unlikely that harmful levels of mercury could ever be released to the air. In addition, indoor air sampling using a Lumex Analyzer at numerous residential dwellings close to Ground Zero determined mercury vapor concentrations to be well below EPA's Reference Concentration (RfC) of .3 ug/m^3 [Johnson, 2002].
Particulate Matter (PM)	Ambient monitoring in the WTC area has shown that, since late October, levels of PM 10 and PM 2.5 (two commonly measured inhalable PM sizes) have been below EPA's level of concern for the ambient air (see Appendix B), indicating that there is no continuing source of PM entering homes and offices. EPA's Environmental Data Trend Report World Trade Center, 9/11/01 - 4/24/02 [EPA, 2002a] concluded that PM 2.5 and PM 10 appear to have returned to levels of a steady background state.

CITY_21MC100_002452161

NYC-WTC_000199590

NYC 9/11 Public Portal Document

Chemical	Reason
Refractory Ceramic Fibers (RCF)	Ceramic fiber-containing materials are not expected to be present in the WTC buildings, as they are mainly used in industrial high temperature applications. Limited sampling conducted by NYCDOH, 2002 did not indicate any ceramic fibers in four indoor air samples analyzed by scanning electron microscopy (SEM).
Mold	Mold was not directly associated with the WTC collapse. However, it may have resulted from the combination of water damage and inoperable HVAC systems. Guidelines for identifying and removing mold are provided through a NYCDOH website (see Appendix A).

Setting Benchmarks for the Contaminants of Potential Concern (COPCs)

A tiered approach was used to evaluate the health risks posed by contaminants that might be present in the indoor environment (air and settled dust). For each COPC, three levels were established:

Tier I — Level above which, after elimination of potential indoor sources (combustion by-products, stored chemicals, etc.), aggressive clean-up action should be taken expeditiously along with follow-up sampling to confirm attainment of Tier III level

Tier II — Range where diligent cleaning should continue, after elimination of potential indoor sources (combustion by-products, stored chemicals, etc.), with follow-up sampling to confirm attainment of Tier III level

Tier III — Level below which the risk is negligible or consistent with the New York City background level found in the aforementioned Background Study (see Introduction).

The following hierarchal approach was employed for developing benchmark values: 1)Use of relevant and appropriate environmental standards/regulations; 2) Calculation of risk-based benchmarks using EPA risk assessment guidance; and, 3) Adaptation of occupational standards with additional safety factors. Accordingly, a review of environmental standards/regulations was conducted for each of the six COPCs. As a result of this exercise Tier I screening levels for lead in indoor air and settled dust were set using EPA's National Ambient Air Quality Standard (NAAQS) and the U.S. Housing and Urban Development's (HUD's) standard for floors, respectively. The clearance criteria established in the Asbestos Hazard Emergency Response Act (AHERA, 1986) of 70 structures/mm2 was utilized to evaluate asbestos samples from the ambient air monitoring effort. As detailed in Appendix B, the upper bound estimate for exposure duration to contaminants in the ambient air was one year. However, given the potential for extended exposure in residential dwellings, AHERA was deemed less appropriate to this setting.

CITY_21MC100_002452162

NYC-WTC_000199591

NYC 9/11 Public Portal Document

In cases where appropriate standards did not exist (e.g., asbestos), risk-based criteria were developed using established EPA risk assessment methods: for indoor air, methods described in EPA's "Risk Assessment Guidance for Superfund" [RAGS, 1989] were used; for settled dust, EPA Region III's "Wipe Sample Assessment" guidance was utilized with modifications (see Appendix D). The risk-based criteria reflect the most current toxicity criteria (Cancer Slope Factors and RfDs/RfCs) on EPA's Integrated Risk Information System (IRIS), which is a regularly updated (quarterly), online database that reports chemical toxicity reference values and information on human health effects that may result from exposure to chemicals in the environment.

For contaminants that lacked IRIS verified toxicity criteria, occupational standards were employed. Additional safety factors were added to account for higher exposure and greater sensitivity within the general population.

The clearance criteria paradigm described above is pathway and chemical specific. Accordingly, the benchmarks for each COPC do not account for multimedia and multiple chemical exposure.

Individual sampling results that exceed benchmark values should not be interpreted to represent the occurrence of an adverse health effect. Because benchmark levels assume continuous exposure for an extended duration, the average of the measured concentrations is more appropriate for evaluating risk than individual measurements. Consequently, isolated individual values above the benchmark level may not necessarily be indicative of a hazard.

Developing Risk-Based Criteria for Indoor Air

For carcinogenic compounds, the benchmarks were set so that a local resident's lifetime risk of developing cancer from exposure to WTC-related contaminants would not exceed a one-in-ten-thousand probability ($1x10^{-4}$) above the resident's background risk without this exposure. The amount of time that residents and office workers were exposed to WTC-related contaminants is unknown. To be conservative, the Tier I screening level was chosen to be protective of a resident who may have been exposed to WTC-related contaminants for one year. The Tier III clearance level was chosen to be protective of a resident who is exposed to WTC-related contaminants for 30 years, which is the upper-bound estimate for residency in one dwelling [EPA, 1989]. Cancer risk from less-than-lifetime inhalation exposure is given as:

$$\text{Risk} = \text{LAC} * \text{UR}$$

where LAC is the air concentration averaged over a lifetime, calculated as: AC * [EF*ED/LT], where AC is the average air concentration during the period of exposure ($\mu g/m^3$), EF is the exposure frequency (days/year), ED is the exposure duration (years), LT is lifetime (days), and UR is the unit risk factor, expressed in units of 1/concentration.

The following table lists the input parameters and numerical values (along with a brief explanation) used in this procedure. (See Appendix D for equations and a more detailed discussion).

CITY_21MC100_002452163

NYC-WTC_000199592

NYC 9/11 Public Portal Document

Table 2. Exposure parameters for calculating clearance criteria for air samples.

Input Parameter	Value	Explanation
Risk	1×10^{-4}	See Appendix C
AT-(Averaging Time - Carcinogens) of LT	25,550 days	See Appendix D
ED (Exposure Duration)	30 years	Upper-bound Estimate of Time in Residence [EPA, 1989]
EF (Exposure Frequency)	365 days/yr	Days in Residence [EPA, 1989]
IUR (Inhalation Unit Risk)	2.3 E -01 (asbestos) 2.86 E +5 (dioxin)* 7.3 E 0 (PAHs)*	IRIS, 2002 Dioxin Reassessment, EPA, 2001 IRIS, 2002

*IUR was calculated by route-to-route extrapolation of oral Slope Factor

The cancer risk level ($1x10^{-4}$) employed herein reflects the upper bound of the acceptable risk range (10^{-4} to 10^{-6}) established in EPA's Superfund regulation [Federal Register, 1990]. Practical Quantitation Limits (PQLs, the lowest level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating procedures [EPA, 1992]) and anticipated background levels [ATSDR, 1995] dictated the selection of the risk level at $1x10^{-4}$. A more detailed discussion of this subject can be found in Appendix C.

For non-carcinogenic compounds, airborne contaminant concentration is compared to the Reference Concentration (RfC). The RfC is an estimate of a chronic exposure concentration for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime [EPA, 1989]. That comparison (i.e, chronic exposure concentration (CEC) divided by the RfC) is called the Hazard Quotient (HQ).

$$HQ = CEC/RfC$$

where CEC is the daily averaged air concentration, calculated as: AC * [EF*ED/AT-NC], where AC is the average air concentration during the period of exposure ($\mu g/m^3$), EF is the exposure frequency (days), ED is exposure duration (years), AT-NC is the averaging time for non-carcinogens, and RfC is the reference concentration, expressed in units of 1/concentration.

According to EPA guidelines [EPA, 1989], if the HQ is greater than one, there may be concern for potential health effects. Therefore, for Tier III (clearance level), the benchmark screening level was set at an HQ of 1. For Tier I, which equates to a sub-chronic exposure scenario, an HQ of 10 was used, in accordance with EPA's Hazard Evaluation Handbook [EPA, 1997]. An HQ of 10 accounts for the fact that chronic toxicity criteria (RfDs/RfCs) are being applied to sub-chronic exposure scenarios (i.e., exposure not expected to exceed 6 months to one year in duration). Accordingly, an HQ of 10 was used for non-carcinogens to reflect a similar (i.e.,

CITY_21MC100_002452164

NYC-WTC_000199593

NYC 9/11 Public Portal Document

upper bound of 1 year) exposure duration. Note that contaminants (both non-carcinogens and carcinogens, alike) can exhibit acute effects from short-term, high-dose exposures. Because the Tier I benchmark levels are based on subchronic exposure (i.e., 1 year), acute effects from exposures that are below the benchmark levels would be unlikely. A review of EPA's draft Acute Exposure Guideline Levels [EPA, 2001a] and California EPA's (CAL-EPA) Acute Risk Levels demonstrates that the benchmark levels developed herein are categorically more stringent than the analogous US EPA and Cal-EPA acute levels.

Developing Risk-Based Criteria for Settled Dust

There is no established national guidance, and limited scientific literature, for assessing risk from interior surface wipe sampling (i.e., mass per unit area) data . The approach used in this report was adapted and modified from a methodology developed by the EPA Region III Superfund Program. It has been employed by the U.S. Army Corps of Engineers to develop risk-based clean-up goals for interior surfaces at the Claremont Polychemical Superfund site in Region II [Radian, 1999]. Additionally, the methodology is similar to an approach employed by the NYSDOH for evaluating a dioxin contaminated office building [NYSDOH, 1985] and one previously proposed by NJDEP for setting interior building surface clean-up goals [NJDEP, 1993].

A full discussion of the methodology employed for developing risk-based benchmarks based on contact with residues on indoor surfaces is presented in Appendix D. Briefly, this methodology provides an estimate of daily dose resulting from dermal absorption and ingestion associated with contacting contaminated surfaces and hand-to-mouth transfers. Dose is obtained by estimating the following: skin contact area and contact frequency with contaminated surfaces, transfer efficiency between surface and hand, transfer efficiency between hand and mouth, oral absorption of the contaminant and dermal absorption of residual contamination on skin. Consistent with the approach for indoor air, toxicity criteria were obtained from IRIS. The assessment procedure is described briefly below and in more detail in Appendix D.

For the purpose of developing risk-based clearance levels for interior surfaces, this approach is preferable to an approach that relies on measuring contaminant concentration on a mass per mass (ppm) basis (as might be done for an exterior soil assessment). After cleaning has occurred, it would be difficult to obtain the mass of dust necessary to perform a mass per mass measurement of contaminant concentration. In addition, literature on interior lead contamination demonstrates a strong correlation between lead load (mass per unit area) and blood lead concentration in children (Lanphear et. al., 1998).

The following table lists the input parameters and numerical values (along with a brief explanation) used in this procedure. (See Appendix D for equations and a more detailed discussion.)

Table 3. Exposure parameters used to calculate clearance criteria for wipe samples.

CITY_21MC100_002452165

NYC-WTC_000199594

NYC 9/11 Public Portal Document

Input Parameter	Value	Explanation
SA (Skin Surface Area)	400 cm^2	Palm Side of Hands
CF (Contact Frequency)	16/day	See Appendix D
FTSS (Fraction Transferred from Surface to Skin)	0.05	See Appendix D
EF (Exposure Frequency)	365 days/yr	Days in Residence [EPA, 1989]
ED (Exposure Duration)	30 years	Upper-bound Estimate of Time in Residence [EPA, 1989]
ABSo (Oral Absorption Fraction)	1	See Appendix D
FTSM (Fraction Transferred from Skin to Mouth)	0.1	See Appendix D
ABSd (Dermal Absorption Fraction)	0.03 (dioxin) 0.13 (PAHs)	Chemical Specific [EPA, 2001b]
BW (Body Weight)	70 kg	Average Adult [EPA, 1989]
AT-NC (Averaging Time - Non Carcinogen)	–	
AT-C (Averaging Time - Carcinogen)	25,550 days	See Appendix D
CSF (Cancer slope factor -dermal and oral)	1.0 E+6 (dioxin) 7.3 E 0 (PAHs)	Dioxin Reassessment: EPA, 2001 IRIS, 2002

In light of the limited data for many of the input parameters used to estimate dose from exposure to residues on surfaces, conservative exposure estimates were employed. Still, there may be a concern for highly exposed sub-populations. Infants and young children constitute such a group due to age-specific activities such as crawling and mouthing and increased surface-area to body-weight ratios. In cases where non-carcinogenic effects are driving clearance levels, the difference in dose on a mg/kg/day basis between an adult and a young child could be considerable. However, in this document the two compounds (dioxin, PAHs) for which the surface contact methodology has been used to develop clearance levels are carcinogens, so it is this effect that drives the clearance levels. As such, the Tier III clearance level is strongly influenced by overall exposure duration, which in this assessment has been set at 30 years. Consequently, weighted over 30 years, the impact of a high-exposure period (i.e., early childhood) is diluted. It is acknowledged that Tier I (one year exposure duration) screening levels for carcinogens may underestimate cancer risk for children, but Tier I contaminant levels are not expected to persist, therefore the magnitude of any associated uncertainty would be small. If a contaminant was to be added to the COPC list that had its clearance level based on a non-

CITY_21MC100_002452166

NYC-WTC_000199595

NYC 9/11 Public Portal Document

carcinogenic endpoint, a separate wipe assessment analysis should be performed taking into account childhood exposure parameters. A more complete discussion of the uncertainties associated with the methodology for surface contact assessment is presented in Appendix D.

With the exception of asbestos, the extremely limited air sampling data for specific building constituents in indoor air dictated that an assessment approach had to be based on historical data relating the concentration of fibers in air (fibers per cubic centimeters or f/cc) to the load in settled dust (fibers per square centimeters or f/cm^2) [Millette and Hays 1994]. Although the empirical relationships (called K factors) are not rigorous enough to rely on for a firm health decision, they are used in this report to define what might constitute elevated building material counts that would need to be addressed on a near-term basis. This approach may overestimate potential exposures but, as such, is protective.

Developing Benchmark Levels Based on Occupational Health Standards

For fibrous glass and silica, risk-based methods were not available for indoor air due to lack of established environmental toxicity criteria. Therefore, benchmark levels were set based on occupational health standards established by the American Conference of Governmental Industrial Hygienists [ACGIH] (called "threshold limit values" or TLVs) and the Occupational Safety and Health Administration [OSHA] (called "permissible exposure limits" or PELs). TLVs/PELs are established to protect employees who might have been exposed to substances during an eight-hour day, for five days a week. For Tier I levels, TLVs/PELs were divided by ten to be more protective of residents who might be exposed to substances twenty-four hours a day, seven days a week. In addition, the TLVs/PELs were established to protect a healthy worker. For Tier III levels, TLVs or PELs were divided by 100 to be protective of a more diverse population that includes sensitive individuals such as children, older adults, and the infirm.

The following tables show the benchmark levels developed for each contaminant of potential concern. Each table is accompanied by risk equations, toxicity criteria and a summary of any contaminant-specific assumptions that were made in developing the benchmark values.

CITY_21MC100_002452167

NYC-WTC_000199596

NYC 9/11 Public Portal Document

Table 4. Lead

Tier	Action	Lead (settled dust)		Lead (indoor air)	
		Level	Basis	Level	Basis
I	Aggressive cleaning. If levels persist, take additional action to reduce exposure.	>40 ug/ft^2	1) HUD standard for floors 2) Residential Lead Hazard Standard (TSCA Section 403)	>1.5 ug/m^3	NAAQS (intended to keep 99.5% of children below 30 ug/dl)
II	Maintain recommended cleaning methods. Consider additional monitoring.	40 ug/ft^2 to 25 ug/ft^2 (or background)	25 ug/ft^2 is HUD screening level for floors	1.5 ug/m^3 to 1 ug/m^3 (or background)	1 ug/m^3 is the calculated value using EPA's IEUBK Lead Model for Children*
III	No further action	<25 ug/ft^2 (or background)	Level could also be set at that found in background, or unaffected, areas, so that no increase in risk due to lead would be expected.	1 ug/m^3 (or background)	Level could also be set at that found in background, or unaffected, areas, so that no increase in risk due to lead would be expected.

* EPA developed the Integrated Exposure Uptake Biokinetic (IEUBK) Lead Model [EPA, 1994] to evaluate multimedia lead exposure to children in residential settings. EPA established a goal of attaining a 95% probability that blood lead levels in children be less than 10 ug/dl [EPA 1994a]. Setting the indoor air lead concentration at 1 ug/m^3 (and using background concentrations for lead in water, diet, soil and dust) the IEUBK Lead Model estimates that 96% of the blood lead probability distribution falls below 10 ug/dl. See Appendix E for model run data files and graph of blood lead probability distribution.

CITY_21MC100_002452168

NYC-WTC_000199597

NYC 9/11 Public Portal Document

Table 5. Polycyclic Aromatic Hydrocarbons (PAHs)

Tier	Action	PAHs (settled dust)		PAHs (indoor air)	
		Level	Basis	Level	Basis
I	Aggressive cleaning. If levels persist, take additional action to reduce exposure.	>9 mg/m^2	9 mg/m^2 represents a $1x10^{-4}$ risk estimate for a 1 year exposure	>6 ug/m^3	6 ug/m^3 represents a $1x10^{-4}$ risk estimate for a 1 year exposure
II	Maintain recommended cleaning methods. Consider additional monitoring	9 mg/m^2 to 0.3 mg/m^2 (or background)	0.3 mg/m^2 represents a $1x10^{-4}$ risk estimate for a 30 year exposure	6 ug/m^3 to 0.2 ug/m^3 (or background)	0.2 ug/m^3 represents a $1x10^{-4}$ risk estimate for a 30 year exposure
III	No further action	<0.3 mg/m^2 (or background)	Level could also be set at that found in background, or unaffected, areas, so that no increase in risk due to PAHs would be expected.	<0.2 ug/m^3 (or background)	Level could also be set at that found in background, or unaffected, areas, so that no increase in risk due to PAHs would be expected.

Toxicity criteria for benzo(a)pyrene:

Oral Slope Factor = 7.3 E 00 $(mg/kg/day)^{-1}$ (IRIS, 2002)

(Inhalation cancer risk was calculated by route-to- route extrapolation of oral Slope Factor)

The following carcinogenic PAHs are evaluated as benzo(a)pyrene-equivalents [EPA, 1993]:

Compound	Relative Potency
Benzo(a)pyrene	1
Benz(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.01
Chrysene	0.001
Dibenzo(a,h)anthracene	1
Indeno(1,2,3-c,d)pyrene	0.1

CITY_21MC100_002452169

NYC-WTC_000199598

NYC 9/11 Public Portal Document

Table 6. Dioxin

Tier	Action	Dioxin (settled dust)		Dioxin (indoor air)	
		Level	Basis	Level	Basis
I	Aggressive cleaning. If levels persist, take additional action to reduce exposure.	>120 ng/m^2	120 ng/m^2 represents a 1x10^{-4} risk estimate for a 1 year exposure	>0.03 ng/m^3	0.03 ng/m^3 represents a 1x10^{-4} risk estimate for a 1 year exposure
II	Maintain recommended cleaning methods. Consider additional monitoring	120 ng/m^2 to 4 ng/m^2 (or background)	4 ng/m^2 represents a 1x10^{-4} risk estimate for a 30 year exposure	0.03 ng/m^3 to 0.001 ng/m^3 (or background)	0.001 ng/m^3 represents a 1x10^{-4} risk estimate for a 30 year exposure
III	No further action	<4 ng/m^2 (or background)	Level could also be set at that found in background, or unaffected, areas, so that no increase in risk due to dioxin would be expected.	<0.001 ng/m^3 (or background)	Level could also be set at that found in background, or unaffected, areas, so that no increase in risk due to dioxin would be expected.

Toxicity criteria for dioxin:

Oral Slope Factor = 1.0 E 06 (mg/kg/day)$^{-1}$ [EPA, 2001]

(Inhalation cancer risk was calculated by route-to- route extrapolation of oral Slope Factor)

The table above reflects the proposed cancer Slope Factor for 2,3,7,8 TCDD and the toxicity equivalence (TEQ) paradigm for carcinogenic dioxin/furan congeners present in EPA's draft dioxin reassessment [EPA, 2001]. An equivalent table reflecting the previous IRIS-verified cancer Slope Factor for 2,3,7,8 TCDD would be represented by multiplying all listed values by a factor of six.

The methodology for estimating dose from wipe sampling data (see Appendix D) is consistent with the approach NYSDOH used in assessing office buildings in Binghamton, with modifications made to input parameters to reflect residential rather than occupational exposure. In addition, the Tier III benchmark equates to a lifetime exposure level which is approximately one tenth of that which results from current dietary intake of dioxin (65 pg/d). It is thus

CITY_21MC100_002452170

NYC-WTC_000199599

NYC 9/11 Public Portal Document

reasonable to assume that any lower level of exposure would result in an inconsequential reduction in the current risk levels experienced by the general U.S. population.

Information regarding NYC background levels also would be an important consideration in determining the appropriate longer-term value. This report proposes selecting the longer-term value on the basis of a $1x10^{-4}$ risk level or NYC background, as determined by the WTC-directed Background Study.

NYC-WTC_000199600

NYC 9/11 Public Portal Document

Table 7. Asbestos

Tier	Action	Asbestos (Settled Dust)		Asbestos (indoor air)	
		Level	Basis	Level	Basis
I	Aggressive cleaning. If levels persist, take additional action to reduce exposure. Evaluate conditions in the area, including representativeness of air samples, asbestos settled dust levels, and loading.	> 30,000 f/cm^2	Millette's K factor to estimate airborne levels for different activities (see narrative below).	>0.028 f/cc (PCME*)	0.028 f/cc represents a 1x10^{-4} risk estimate for a 1 year exposure
II	Maintain recommended cleaning methods. Consider additional monitoring. Evaluate conditions in the area including representativeness of air samples, fibrous glass settled dust levels and loading.	30,000 f/cm^2 to background	---	0.028 f/cc 0.0009 f/cc (or background)	0.0009 f/cc represents a 1x10^{-4} risk estimate for a 30 year exposure
III	No further action required.	Background	Level is set at that found in background, or unaffected, areas, so that no increase in risk due to the asbestos fibers would be expected.	0.0009 f/cc (PCME*) (or background)	Level is set at that found in background, or unaffected, areas. In this way, no increase in risk due to the asbestos fibers would be expected.

* PCME - fibers greater than 5 micrometers long (aspect ratio >3:1). Analysis by TEM.

CITY_21MC100_002452172

NYC-WTC_000199601

NYC 9/11 Public Portal Document

Toxicity criteria for asbestos:

Inhalation Unit Risk = 2.3 E-01 $(f/cc)^{-1}$ [IRIS, 2002]

Risk-based criteria were used to develop the Tiered benchmark levels for asbestos in air. Conservative assumptions of continuous exposure to a constant level of airborne fibers for either 1 year (Tier I) or 30 years (Tier III) were combined with the IRIS Slope Factor to establish benchmarks representative of a 1x 10-4 estimate of excess lifetime cancer risk for each scenario. This approach makes several assumptions, chief among those is the quantification of asbestos fibers in air based on the PCM definition of a fiber (greater than 5um in length with an aspect ratio of 3:1 or greater) and the use of the IRIS Slope Factor which was designed to apply to fibers so defined. Although there is some concern regarding shorter fibers, the approach used here represents the current consensus by the US EPA for quantifying risk of airborne asbestos fibers. It should be noted there is ongoing debate regarding the nature of health effects which may be attributed to shorter asbestos fibers. Both EPA and ATSDR are currently pursuing meetings to discuss and further refine these issues. However for the purposes of this response, addressing PCM equivalent fibers is considered protective.

The Tier I level for asbestos in settled dust was based on K factors [Millette and Hays, 1994], which are empirical relationships between concentrations of asbestos fibers in settled dust and indoor air. Millette developed the K factors by studying matched air and settled dust samples taken from various homes, at varying levels of activity in the home. The Tier I level was based on the K factor for a worst case scenario of a high level of activity. Although K factors are not rigorous enough to rely upon for a firm health decision, they are used here only to define what might constitute elevated fiber counts, that would need to be addressed as a near-term concern. This approach may overestimate potential exposures, but as such, is protective.

It should be noted that the airborne Tier I level of 0.028 f/cc PCM equivalents roughly equates to the AHERA TEM standard of 70 f/mm^2 (0.022 f/cc) in total fiber counts. Based on empirical information from the WTC ambient air monitoring program [EPA, 2002c] that recorded less than 20% of total AHERA TEM fiber counts to be >5 um in length, the AHERA TEM standard of 70 f/mm^2 (0.022 f/cc) and the alternate AHERA PCM standard of 0.01 f/cc both meet the risk-based criteria established for the Tier I screening level.

CITY_21MC100_002452173

NYC-WTC_000199602

NYC 9/11 Public Portal Document

Table 8. Fibrous Glass

Tier	Action	Fibrous Glass (settled dust)		Fibrous Glass (indoor air)	
		Level	Basis	Level	Basis
I	Aggressive cleaning. If levels persist, take additional action to reduce exposure. Evaluate conditions in the area including representativeness of air samples, fibrous glass settled dust levels and loading.	> 100,000 f/cm^2	Millette's K factor to estimate airborne levels for different activities (see narrative below).	> 0.1 f/cc	ACGIH TLV of 1 f/cc (see narrative below).
II	Maintain recommended cleaning methods. Consider additional monitoring. Evaluate conditions in the area including representativeness of air samples, fibrous glass settled dust levels and loading.	100,000 f/cm^2 to background	---	0.01 to 0.1 f/cc	---
III	No further action required	background	Level is set at that found in background, or unaffected, areas. In this way, no increase in risk due to the fibers would be expected.	< 0.01 f/cc	ACGIH TLV of 1 f/cc (see narrative below)

* Fibers with length > 5μm with an aspect ratio > 3:1, as defined in the ACGIH TLV.
Air concentrations measured by PCM, NIOSH 7400, confirmed by SEM.

The benchmarks for airborne fibrous glass were set based on the consideration that low level exposures to fibrous glass would not pose the potential for significant long-term health effects given the expected low biopersistence of these materials [ATSDR, 2002]. The current occupational exposure standards for fibrous glass (glass and mineral wools) is established to prevent the upper respiratory tract and skin irritant effects. In order to apply this standard to a general population and accounting for a longer daily exposure than seen in the occupation

CITY_21MC100_002452174

NYC-WTC_000199603

NYC 9/11 Public Portal Document

setting, uncertainty factors were used to reduce the allowable airborne levels for the Tiered bench marks. The Tier I benchmark is set at one tenth of the TLV and the Tier III level is set at 1 hundredth of the TLV. It is believed these levels will prevent conditions which may cause irritant health effects for most individual.

Although fibrous glass in settled dust is known to be a contact irritant, little data exist to provide a threshold relating to what fiber loading may result in skin irritation, or airborne levels of concern. However, as with asbestos it was deemed preferable to have a Tier I benchmark available so that there was some upper bound to settled dust loadings that may trigger action. Here again Millet's K factors were used to correlate dust loading levels to the air benchmarks. The Tier I level for fibrous glass in settled dust was based on Millette's K factors, which are empirical relationships between concentrations of asbestos fibers in settled dust and indoor air. Millette developed the K factors by studying matched air and settled dust samples taken from various homes, at varying levels of activity in the home. The Tier I level was based on the K factor for a worst case scenario of a high level of activity. Although K factors are based on activity data for asbestos, they are believed to be protective for fibrous glass, which is larger and less airborne. In addition, although K factors are not rigorous enough to rely upon for a firm health decision, they are used here only to define what might constitute elevated fiber counts, that would need to be addressed as a near-term concern. This approach may overestimate potential exposures, but as such, is protective.

The Tier I level for fibrous glass in indoor air was based on the American Conference of Governmental Industrial Hygienists' (ACGIH) threshold limit value (TLV) of 1 f/cc. That TLV is based on limiting irritant effects of fibrous glass on workers. The TLV was divided by a factor of ten to account for the different exposure durations between ACGIH's workers and the WTC area's residents.

The Tier III level for fibrous glass in indoor air was based on the ACGIH TLV of 1 f/cc, divided by a factor of 100 to account for greater exposure and the different sensitivities between ACGIH's healthy works and the WTC area's more varied population.

CITY_21MC100_002452175

NYC-WTC_000199604

NYC 9/11 Public Portal Document

Table 9. Crystalline silica - respirable fraction of alpha-quartz

Tier	Action	Crystalline Silica (settled dust)		Crystalline Silica (indoor air)	
		Level	Basis	Level	Basis
I	Aggressive cleaning. If levels persist, take additional action to reduce exposure. Evaluate conditions in the area including representativeness of air samples, asbestos settled dust levels and loading.	---	---	10.0 $\mu g/m^3$ *	OSHA PEL of 100 $\mu g/m^3$ (see narrative below).
II	Maintain recommended cleaning methods. Consider additional monitoring. Evaluate conditions in the area including representativeness of air samples, fibrous glass settled dust levels and loading.	above background		10.0 $\mu g/m^3$ to 1 $\mu g/m^3$ (or background) *	
III	No further action required.	background	Level is set at that found in background, or unaffected, areas. In this way, no increase in risk due to the silica in settled dust would be expected.	1 $\mu g/m^3$ or background	OSHA PEL of 100 $\mu g/m^3$ (see narrative below).

* Silica measured in airborne respirable dust, by NIOSH 7500.

The benchmarks for silica in indoor air were derived from the Occupational Safety and Health Administration's (OSHA) permissible exposure limit (PEL) for dust containing 100% respirable silica in air of 100 $\mu g/m^3$ (0.1mg/m^3)as a time weighted average for an 8 hour exposure.

Silica exposure poses risk of both cancer and non-cancer respiratory health effects. Although no

CITY_21MC100_002452176

NYC-WTC_000199605

NYC 9/11 Public Portal Document

Reference Concentration (RfC) or IRIS Slope Factor exists, there are methodologies for examining risks of non-occupational exposures, on which to draw upon for a risk based approach to set benchmark levels. The approach taken here is a dual approach, where in the face of uncertainties the quantification of the benchmarks was based on the current occupational standards. Broader risk-based discussion of other methodologies provides support for the chosen benchmark levels although not quantitatively employed here to derive the benchmarks.

The Tier I benchmark is set at one tenth of the OSHA PEL. A single year of exposure at this benchmark ($10ug/m^3$) would provide a cumulative silica loading to the lungs less than the $1mg/m^3$ work-year loading which is believed to be the departure point for adverse health effects. Additionally this level is also the effective National Ambient Air Quality Standard for silica, where PM_{10} at 50 ug/m^3 contains no more than 10% crystalline silica. A recent review by supports the finding that this level would be protective of long-term non-cancer health effects [EPA, 1996]. The Tier III benchmark is set at one hundredth of the OSHA PEL. A 30 year continuous exposure at this level would not result in a cumulative silica loading to the lungs greater than the $1mg/m^3$ year loading which is believed to be the departure point for adverse health effects.

CITY_21MC100_002452177

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