Vapor Intrusion Management Plan
Lockheed Martin Middle River Complex

2323 Eastern Boulevard
Middle River, Maryland

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ACRONYMS

$\mu g/m^3$	microgram(s) per cubic meter
AF	attenuation factor
atm-m^3/mol	atmospheres per cubic meter/mole
ca	carcinogenic
DTSC	California Department of Toxic Substances Control
ESH	environment, safety, and health
eV	electron volt(s)
FID	flame ionization detectors
HQ	hazard quotient
HVAC	heating, ventilation, and air conditioning
IA	indoor air
IAQ	indoor air quality
Lockheed Martin	Lockheed Martin Corporation
MDE	Maryland Department of the Environment
MRC	Middle River Complex
MSDS	material safety data sheet
nc	noncarcinogenic
OSHA	(federal) Occupational Safety and Health Administration
PCE	tetrachloroethene
PID	photoionization detector
ppm	part(s) per million
SSD	sub-slab depressurization
SSDS	sub-slab depressurization system
STEL	short-term exposure limit
SV	sub-slab vapor
Tetra Tech	Tetra Tech, Inc.
TCE	trichloroethene
TWA	time-weighted average
USEPA	United States Environmental Protection Agency
VCP	Voluntary Cleanup Program
VI	vapor intrusion
VIMP	vapor intrusion management plan
VOC	volatile organic compound

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Section 1

Introduction

Vapor intrusion (VI) is the migration of volatile chemicals from the subsurface into the indoor air (IA) of buildings above a location of chemical contamination. This document was developed as a resource for personnel at the Lockheed Martin Middle River Complex (MRC) to help manage known VI pathways, and/or investigate yet unknown potential VI pathways at the site that may adversely affect facility indoor air quality (IAQ). Vapor intrusion should be evaluated as a potential human exposure pathway whenever volatile chemicals are in soil, soil gas, or groundwater underlying existing structures, or whenever these chemicals have the potential to underlie future buildings. The following sections will introduce the concepts of vapor intrusion, and provide a brief summary of vapor intrusion issues at the Middle River Complex.

1.1 CONCEPTS OF VAPOR INTRUSION

The physical properties of volatile chemicals can result in their migration through unsaturated soil into the indoor air of buildings near zones of subsurface contamination. The United States Environmental Protection Agency (USEPA) defines a chemical as volatile if its Henry's Law constant is 1×10^{-5} atmospheres times cubic meters per mole (atm-m^3/mol) or greater (USEPA, 2002). Henry's Law constants are calculated to characterize the equilibrium distribution of concentrations of volatile, soluble chemicals between gas and liquid phases (i.e., the solubility of a gas in a liquid at a particular temperature is proportional to the pressure of that gas above the liquid.)

The class of chemicals of greatest interest for this subsurface-to-indoor air pathway is volatile organic compounds (VOCs), including such common chemicals as petroleum hydrocarbons (e.g., benzene) and chlorinated solvents (e.g., trichloroethylene [TCE]). The U.S. Environmental Protection Agency has identified more than 100 chemicals with sufficient volatility and toxicity to pose a theoretical vapor intrusion hazard (USEPA, 2002). These chemicals should thus be included in any vapor intrusion investigation or program if they are known to have been used or released at a site, or if it might reasonably be assumed that they have been used or released at a site. Typically, the potential for vapor intrusion is evaluated during a site investigation.

The site-specific vapor intrusion risk assessment for the Middle River Complex indicates the potential for regulatorily unacceptable risks associated with vapor intrusion; appropriate response actions were implemented to mitigate these risks. Reasonable alternatives are considered when selecting response actions, including passive or active ventilation systems, floor sealants, or other mitigation measures. The potential for vapor intrusion in future structures should be addressed during design; any necessary measures to reduce vapor intrusion, including the associated construction costs for these measures, should also be included in the design. A typical approach for assessing potential risks posed by the vapor intrusion pathway, including its mitigation and remediation options, is summarized below:

Evaluate whether exposure to the vapors poses an acute (immediate) risk to building occupants: This can include both acute health risks and the risk of explosion. For acute risks, field instruments will be used, and results will be compared to federal Occupational Safety and Health Administration (OSHA) short-term and ceiling exposure levels (see Section 4.1). If acute risks from vapor intrusion are identified, the affected area may need to be evacuated until the risks are mitigated. If no acute risks are identified, a screening-level vapor intrusion evaluation may be conducted.

Conduct a screening level assessment of site contaminants: This evaluation typically involves comparing site soil gas or groundwater data to conservative (i.e. highly protective) risk-based screening values. If site concentrations are below screening levels, a low potential for vapor intrusion risk exists. If contaminant concentrations in affected media exceed risk-based screening values, then a site-specific vapor intrusion model may be evaluated.

Conduct a site-specific vapor intrusion pathway evaluation: Site-specific data are collected that may include sub-slab soil gas and/or indoor air samples. Multiple lines of evidence may be used to evaluate the magnitude and extent of vapor intrusion. Depending on the results of the investigation and comparison to site-specific trigger levels, further action (i.e., mitigation) may be warranted (if concentrations are above trigger levels) or be deemed unnecessary (if concentrations are below the trigger levels).

Evaluate mitigation/remediation options, if necessary: Mitigation involves techniques that prevent (or minimize) vapors associated with subsurface contamination from entering a building's indoor air. Common mitigation measures include installation of a passive venting system; sub-slab depressurization or pressurization devices; sealing cracks, sumps, and other potential preferential pathways; and installing vapor proof membranes. At active facilities, controls for land or building use may also be an option to control exposure. Remediation treats and removes chemicals from contaminated subsurface media, such as soil and groundwater. Common remediation options include soil removal, soil gas extraction, and groundwater treatment. Mitigation and remediation may be performed concurrently or separately, depending on site needs.

1.2 VAPOR INTRUSION AT THE MIDDLE RIVER COMPLEX

The Middle River Complex land parcels owned by LMC Properties, Inc., (LMCPI) are undergoing extensive site characterization studies to support remedial decisions under the Maryland Department of the Environment's (MDE) Voluntary Cleanup Program (VCP). Ongoing environmental characterization of the Middle River Complex has identified subsurface soil and groundwater contamination from VOCs under or near occupied workspaces (Tetra Tech, Inc. [Tetra Tech], 2006). Other, non-subsurface sources could also potentially affect indoor air contaminant concentrations, including indoor emissions from process chemicals, building materials, and other sources, as well as ambient (outdoor) air contributions (i.e., confounding sources).

In August 2006, Lockheed Martin Corporation (Lockheed Martin) sampled sub-slab vapor (SV) from beneath the Building A Basement and Plating Shop, and beneath the southern section of the Building C Basement (Tetra Tech, 2006). These locations were selected because contamination from volatile organic compounds had been observed in underlying groundwater. Analytical results from the sub-slab vapor sampling, as well as other site-specific information, were used as inputs for a human health risk assessment model (Johnson and Ettinger, 1991). The model estimated that these risks are at or below Maryland Department of the Environment and U.S. Environmental Protection Agency threshold values (Tetra Tech, 2006). However, because of uncertainties inherent in modeling, a supplemental indoor air quality investigation was proposed to observe whether volatile contaminants were in indoor air and, if so, whether they could be associated with subsurface volatile organic compound contamination.

Indoor air quality monitoring has been ongoing since 2006 for Middle River Complex Buildings A, B, and C. The results of the first monitoring round (in December 2006) for the vertical-launch system (VLS) facility indicated no need for additional sampling there, as no analyzed constituents had been detected in the facility above their applicable screening levels (Tetra Tech, 2007). Analytical results for Buildings A, B, and C indicated that some (but not all) chemicals of concern (COC) identified in the subsurface have also been detected in background and indoor air samples. Background (outdoor air) samples, collected at the four corners of the facility property, are used to measure on-site concentrations of chemicals that may be attributable to non-facility sources; they are also used to identify possible chemical contributions from site operations.

Indoor air quality data for the chemicals of concern were compared to risk-based screening levels derived using conservative U.S. Environmental Protection Agency default exposure assumptions and toxicity values. These analyses indicated that most of the volatile organic compounds detected in indoor air quality samples are probably *not* associated with sub-slab vapor intrusion. Migration of sub-slab vapor into indoor air may be occurring in limited locations. Trichloroethene in indoor air quality samples may be associated with sub-slab vapor migration at the Building A Plating Shop and in the Building C Basement, since it has co-occurred with a marker chemical (cis-1,2-dichloroethene) found only in sub-slab vapor samples. The chemical cis-1,2-dichloroethene is considered a marker of possible sub-slab vapor intrusion because it is not a manufactured chemical and is only found when other chlorinated compounds such as trichloroethylene break down.

The results of the first three rounds of monitoring led the project team to recommend mitigation for locations where chemicals in sub-slab vapor were known to be at concentrations above risk-based screening levels, indicating a potential for sub-slab vapor intrusion. The project team also recommended additional indoor air quality and sub-slab vapor sampling, to address areas of uncertainty identified during subsequent rounds of monitoring. In response to these recommendations, two sub-slab vapor mitigation systems were designed and installed: one beneath the Building A Plating Shop, and one beneath the south end of the Building C Basement, with full system startup on March 31, 2008. Periodic combined indoor air quality and sub-slab vapor monitoring rounds continue to investigate possible sources of sub-slab vapor, evaluate the performance of the sub-slab depressurization (SSD) systems, and provide ongoing protection of worker health and safety with respect to potential vapor intrusion.

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Section 2
Screening Levels, Trigger Levels, and Corresponding Actions

2.1 BACKGROUND

Vapor intrusion (VI) increases the potential that individuals may be exposed to sub-slab chemicals, thus increasing the potential risk of adverse health effects associated with this exposure. *Screening levels* are developed using risk assessment guidance from the U.S. Environmental Protection Agency (USEPA). They are risk-based concentrations derived from standardized equations combining exposure information assumptions with USEPA toxicity data. Screening levels are considered protective for humans over a lifetime. Screening levels are generic (i.e., they are calculated without site-specific information), so they are typically very conservative.

Both the USEPA and the Maryland Department of the Environment (MDE) recognize that chemical concentrations above published risk-based screening levels do not necessarily trigger a response action or identify a hazardous situation. However, exceeding a screening level does suggest that further evaluation of potential risks posed by site contaminants is appropriate.

A second set of benchmarks, the *trigger levels*, are discussed in this section where we address the development and application of site-specific, risk-based trigger levels. These trigger levels will be used to assess the potential for VI at the Middle River Complex (MRC), and will also be used to evaluate when mitigation may be needed or may be discontinued. The trigger levels are intended as a guide to determine:

- whether additional indoor air quality (IAQ) and sub-slab vapor (SV) monitoring are indicated

- whether mitigation is required
- whether or when an emergency response is indicated

2.2 DEVELOPMENT OF VI AND IAQ TRIGGER LEVELS

The default screening levels for industrial air (indoor air) set forth in USEPA's *Regional Screening Levels for Chemical Contaminants at Superfund Sites* (USEPA, 2011a) are currently used to evaluate the contaminants identified in the semi-annual SV and IAQ sampling events at the MRC; Table 2-1 presents a summary of these indoor air values. USEPA generates both carcinogenic (*ca*) and noncarcinogenic (*nc*) screening levels; the lowest of these is used to screen a given contaminant's detected concentration in SV after being divided by an attenuation factor of 0.03 to take into account the dilution that would occur in the indoor air. The attenuation factor represents the factor by which subsurface-vapor concentrations migrating into indoor air spaces are assumed to be reduced due to diffusive, advective, and/or other attenuating mechanisms. Simply stated, the soil gas is expected to get diluted on migration into indoor air; so the attenuation factor is the ratio of the indoor air concentration of a constituent to its subsurface vapor concentration under a conservative vapor intrusion scenario.

Although USEPA screening levels are calculated using a carcinogenic risk level of 1×10^{-6} (or one in one million), carcinogenic risk at the MRC is evaluated at the 1×10^{-5} (or one in 100,000) risk level, in accordance with MDE requirements.

From 2009 to August 2011, trichloroethene (TCE) was compared against a screening level of 25 micrograms per cubic meter ($\mu g/m^3$), which was MDE's screening level for TCE in industrial air. Only TCE was evaluated in this manner, as requested by MDE (MDE, 2009). However, on September 28, 2011, USEPA updated its toxicological review for TCE (USEPA, 2011b) and new toxicity criteria were subsequently published on USEPA's *Integrated Risk Information System* (IRIS), resulting in a new TCE screening value (8.8 $\mu g/m^3$) for industrial air. This value is the lowest of the carcinogenic/noncarcinogenic values for TCE, and is based on noncarcinogenic effects. This value is used to screen the IAQ results in anticipation of MDE adopting the updated USEPA guidance.

In November 2011, USEPA updated its toxicological review for methylene chloride (USEPA, 2011c), and new toxicity criteria were published on IRIS. A new screening value of

2,600 µg/m^3 was established for methylene chloride in industrial air. This is the lowest of the carcinogenic/noncarcinogenic values for methylene chloride, and is based on noncarcinogenic effects. This value is used to screen the IAQ results in anticipation of MDE adopting the updated USEPA guidance. The previous screening value had been 261 µg/m^3.

USEPA updated its toxicological review for tetrachloroethene (PCE) in February 2012 (USEPA, 2012a); as part of this document, new toxicity criteria were published on IRIS. The new criteria established a screening value of 175 µg/m^3 for PCE in industrial air (USEPA, 2012a). This is the lowest of the carcinogenic/noncarcinogenic values for PCE, and is based on noncarcinogenic effects. This value is used to screen the IAQ results in anticipation of MDE adopting the updated USEPA guidance. The previous screening value had been 20.8 µg/m^3. These updated screening levels reflect USEPA's review and incorporation of the most recent toxicity data for these compounds.

In the past, these default screening values were used to evaluate historical data collected as part of ongoing investigations at Block I. Concentrations of chemicals detected in SV were compared to their respective screening values, which were derived in accordance with methods discussed in Appendix D of USEPA's *Draft Guidance for Evaluating the VI to Indoor Air Pathway from Groundwater and Soils* (USEPA, 2002). SV screening values were calculated by dividing the default IAQ screening levels (shown in Table 2-1) by a conservative attenuation factor (AF) of 0.1. The attenuation factor used was obtained from the USEPA VI guidance (USEPA, 2002). An AF represents the factor by which subsurface vapor concentrations migrating into indoor air spaces are reduced due to diffusive, advective, and/or other attenuating mechanisms.

Exceedance of a screening level indicates that a potential VI risk exists, and that further evaluation is needed. In support of the ongoing revision of its 2002 vapor intrusion guidance, USEPA has published a study detailing the calculation of attenuation factors using USEPA's *Vapor Intrusion Database* (USEPA, 2012b). Since the release of the 2002 draft VI guidance, USEPA has collected data from vapor intrusion sites (primarily residential) to improve knowledge and understanding of vapor intrusion, and specifically the attenuation of vapors between the subsurface and indoor air. In the cited study, screening criteria were applied to create a subset of the overall database; this subset was subsequently used to calculate attenuation factors. USEPA's methodology ensured that subsurface concentrations of chlorinated VOCs, rather than ambient air (background) concentrations, were the primary data source used to calculate attenuation factors.

Attenuation factors were developed and compared for all residences, residences with basements, and residences with slab-on-grade. These comparisons indicated that the sub-slab attenuation factors for residences with basements are generally similar to those for residences with a slab-on-grade foundation. As expected, the median sub-slab soil-gas attenuation factors for commonly encountered chlorinated VOCs are quite similar, as are the 95th percentile values.

These observations are consistent with the conceptual model of vapor intrusion, which predicts that chemicals with similar fate and transport properties (such as chlorinated VOCs) would be expected to have similar attenuation factor values. This study suggests that USEPA will use an AF of 0.03 in its revised vapor intrusion guidance (USEPA, 2012b). There is greater confidence in this new value compared to the previously used default value of 0.1 because the new value is based on a large database that was specifically screened to remove confounding variables (e.g., background contributions). Accordingly, an AF of 0.03 will be used to calculate sub-slab screening and trigger levels.

2.2.1 Indoor Air Trigger Level Calculations

The derivation of trigger levels for IA began with the risk-based screening levels currently used at the site. The use of modifying factors (i.e., multiplying, dividing) was examined. However, the project team concluded that the resulting trigger levels would either be so low that background concentrations might result in unnecessary action being taken, or so high that they would not be conservative/protective of human health. Site personnel are directly exposed to indoor air (i.e., no attenuation occurs), so the use of a higher trigger value might not allow intervention before a potential risk is present.

Current IAQ screening values, and the number of times they have been historically exceeded, indicates they could also serve as trigger levels for IA. They are low enough to protect site personnel even if exceeded, but not so high as to underestimate potential risks. Current practice is to further evaluate locations where the screening level is exceeded, which would be the first step taken when a trigger level is exceeded. Consequently, based on the similar response actions historically used at the MRC, and the objectives of applying the trigger levels, the current risk-based IAQ screening levels will also be used as the trigger levels for IA (see Table 2-2).

2.2.2 Sub-Slab Vapor Trigger Level Calculations

The intent of establishing the SV trigger levels is to identify contaminant concentrations when they are sufficiently low so that decisions regarding possible intervention can be made. SV trigger levels were developed by first dividing the IAQ trigger levels discussed in Section 2.2.1 by the default AF of 0.03, and then applying an additional multiplying factor of 3. This is considered protective of human health, as there is currently no known direct exposure of the working population to sub-slab vapors, even though actual SV levels in some cases have been more than one order of magnitude above the trigger level for TCE. In fact, there is no definitive evidence that SV levels correlate in any way to IAQ levels, despite multiple sampling events over the past six years.

Historical data indicate that the slab at the MRC has been effective in controlling or even preventing SV migration, since IAQ concentrations have typically been orders of magnitude less than corresponding SV concentrations. The MRC has demonstrated elevated concentrations of SV VOCs in the past; however, concentrations of SV contaminants in IA have rarely been above screening levels. As such, the use of a trigger value higher than the sub-slab screening value is considered appropriate given historical site-specific findings at the MRC (Table 2-2). VOC (mainly TCE) concentrations in SV are above trigger levels in certain areas. These areas are defined by multiple SV samples, and are located where mitigation has been conducted over the past five years, and in areas where additional mitigation is proposed in the near future. SV contribution to IA is not anticipated. However, monitoring and analysis will continue across the Block I buildings, and additional mitigation will be proposed in the future if determined necessary.

2.2.3 Application of Trigger Levels

As previously discussed, trigger levels provide site managers with a tool to evaluate the potential for VI risk before either SV or IA contaminant concentrations could possibly reach a level of concern. Figure 2-1 provides a decision matrix for using the trigger levels. When SV and/or IA concentrations exceed the trigger levels, steps should be taken to further evaluate whether a potentially complete VI pathway exists. Steps may be implemented, as appropriate, to reduce potential employee exposures.

The decision matrix in Figure 2-1 uses USEPA risk-based ranges to address potential scenarios associated with contamination in SV and IA. USEPA characterizes potential risk (i.e., the chance of a harmful effect) from chemical exposure as carcinogenic, non-carcinogenic, or both. The excess risk of cancer from exposure to a chemical is expressed as a probability, which is described by USEPA as the probability that an exposed individual will develop cancer (due to that exposure) by age 70. In general, USEPA considers excess cancer risks below one chance in a million (i.e., 1×10^{-6}) to be so small as to be negligible, and risks above one in 10,000 (i.e., 1×10^{-4}) sufficiently large that some sort of remediation may be indicated..

For most chemicals, the potential for noncarcinogenic effects is expressed as a ratio between a chemical's dose and its chemical-specific toxicity value; this ratio is the non-cancer hazard quotient (HQ). If the HQ for a chemical is less than or equal to one (1E+00), USEPA considers that chemical to have no appreciable noncarcinogenic risks (non-cancer health effects). If the HQ exceeds one, there is some possibility that non-cancer effects may occur; however, an HQ above 1E+00 does not indicate an effect will definitely occur. This is because of the margin of safety inherent in the derivation of the toxicity values. The larger the HQ value, the more likely that an adverse effect may occur. As can be seen in Figure 2-1, responses and activities are correlated to the degree of potential risk, ranging from no action at levels of low or no potential risk, to monitoring when risks fall within the USEPA risk range, to intervention when potential risks exceed the upper bounds of the risk range defined by USEPA.

After further evaluation, any identified areas of concern can be considered for mitigation measures, as discussed in Section 3. Lockheed Martin will receive the most recent data from the semiannual SV and IAQ sampling episodes, sub-slab depressurization (SSD) system monitoring, and any other SV or IAQ sampling at the MRC, with comparisons to the trigger levels included, so areas of potential concern may be identified and actions taken as necessary. When SV and IA concentrations fall below the trigger levels, decisions can be made regarding cessation of SSD or other modification of active and passive mitigation methods, because the trigger levels incorporate conservative safety factors.

2.3 SSD SYSTEM SHUTDOWN

When a SSD system (SSDS) has reduced SV contaminant concentrations below the previously discussed SV trigger levels, Lockheed Martin can evaluate SSDS shutdown. To be eligible for shutdown, a system should demonstrate consistent reduction of SV and IAQ contaminant concentrations within its radius of influence. SV contaminant concentrations must remain under the trigger levels for at least one year before the system can be shut down. Rebound testing will ensure that SV concentrations do not increase above trigger levels after system shutdown. Rebound testing monitors SV concentrations to see whether they increase to previously elevated levels (rebound) after a SSDS is shut down.

Measurement of SV while the mitigation system is operating may not adequately indicate what potential SV concentrations will be once the system is turned off. To evaluate the reduction of SV contamination, the semi-annual SV and IAQ data will be examined in conjunction with samples of SV collected from the SSDS influent. System influent measurements will provide a spatially averaged SV contaminant concentration (because the vapor is being drawn from all extraction points), and is less likely to be biased by a single sample with a highly elevated or highly depressed result. Once the results of the SSDS influent monitoring and SV/IAQ monitoring meet the trigger levels previously described, the system may be shut down to undergo rebound testing.

To perform a rebound test, the SSDS must be shut off for three to six months. The test will determine whether SV and IAQ contaminant concentrations increase (i.e., rebound) after the system is turned off. The actual length of time the system remains dormant depends on site-specific conditions that might reduce the flow of vapor. Thus, at locations with high clay content or tight soils, a longer dormant period may be needed.

At the beginning of the test, samples of SV are collected from the system influent (while the system is operating) and from the permanent vapor-monitoring points within the system radius of influence (at least 24 hours after the system has been turned off). These samples document baseline conditions. During the test period, samples of SV are periodically collected from the same locations.

If contaminant concentrations in SV and IAQ have not increased during the shutdown period and are still below trigger levels, then the decision may be made to remove the system. If the contaminant concentrations in SV show a clear increasing trend from baseline conditions, but are still below trigger levels, then the rebound test should continue; contaminant concentrations may continue to increase, or merely fluctuate with more time. If contaminant concentrations in SV and/or IA have increased and are above trigger levels, rebound has occurred, and the system will need to be reactivated. In that case, monitoring should continue, and the rebound test should be performed again after SV and/or IAQ monitoring results have produced concentrations below the trigger levels for a minimum of three consecutive months. The date of the new rebound test will be determined based on site-specific SV concentrations and trends.

Table 2-1

Indoor Air and Sub-Slab Vapor
Risk-Based Screening Levels for Indoor Workers
Lockheed Martin Middle River Complex
Middle River, Maryland

Chemical	Indoor Air Screening Level ($\mu g/m^3$)	Sub-Slab Screening Level ($\mu g/m^3$)	Source
Benzene	1.57E+01	5.23E+02	USEPA 2010, adjusted for 10^{-5} risk level
Carbon tetrachloride	2.04E+01	6.80E+02	USEPA 2010, adjusted for 10^{-5} risk level
Chlorodifluoromethane	2.19E+05	7.30E+06	USEPA 2010
Chloroform	5.33E+00	1.78E+02	USEPA 2010, adjusted for 10^{-5} risk level
Dichlorodifluoromethane	4.40E+02	1.47E+04	USEPA 2010
1,1-Dichloroethane	7.67E+01	2.56E+03	USEPA 2010, adjusted for 10^{-5} risk level
1,2-Dichloroethane	4.72E+00	1.57E+02	USEPA 2010, adjusted for 10^{-5} risk level
1,1-Dichloroethene	8.76E+02	2.92E+04	USEPA 2010
cis-1,2-Dichloroethene	2.63E+02	8.77E+03	trans-1,2-dichloroethene used as surrogate
trans-1,2-Dichloroethene	2.63E+02	8.77E+03	USEPA 2010
Ethylbenzene	4.91E+01	1.64E+03	USEPA 2010, adjusted for 10^{-5} risk level
Methyl tert-Butyl Ether	4.72E+02	1.57E+04	USEPA 2010, adjusted for 10^{-5} risk level
Methylene chloride	2.60E+03	8.67E+04	USEPA 2011
Naphthalene	3.61E+00	1.20E+02	USEPA 2010, adjusted for 10^{-5} risk level
Tetrachloroethene	1.75E+02	5.83E+03	USEPA 2012
Toluene	2.19E+04	7.30E+05	USEPA 2010
1,2,4-Trichlorobenzene	8.76E+00	2.92E+02	USEPA 2010
1,1,1-Trichloroethane	2.19E+04	7.30E+05	USEPA 2010
1,1,2-Trichloroethane	7.67E+00	2.56E+02	USEPA 2010, adjusted for 10^{-5} risk level
Trichloroethene	8.80E+00	2.93E+02	USEPA 2011
Vinyl chloride	2.79E+01	9.30E+02	USEPA 2010, adjusted for 10^{-5} risk level
Xylene, p-	3.07E+03	1.02E+05	USEPA 2010
Xylene, m-	3.07E+03	1.02E+05	USEPA 2010
Xylene, o-	3.07E+03	1.02E+05	USEPA 2010

Sub-Slab Screening Level = Indoor air screening level divided by an attenuation factor of 0.03

USEPA = United States Environmental Protection Agency

Table 2-2

Summary of Vapor Intrusion Trigger Levels
Lockheed Martin Middle River Complex
Middle River, Maryland

Chemical	Indoor Air Trigger Level ($\mu g/m^3$)	Sub-Slab Vapor Trigger Level ($\mu g/m^3$)
Benzene	1.57E+01	1.57E+03
Carbon tetrachloride	2.04E+01	2.04E+03
Chlorodifluoromethane	2.19E+05	2.19E+07
Chloroform	5.33E+00	5.33E+02
Dichlorodifluoromethane	4.40E+02	4.40E+04
1,1-Dichloroethane	7.67E+01	7.67E+03
1,1-Dichloroethene	4.72E+00	4.72E+02
1,2-Dichloroethane	8.76E+02	8.76E+04
cis-1,2-Dichloroethene	2.63E+02	2.63E+04
trans-1,2-Dichloroethene	2.63E+02	2.63E+04
Ethylbenzene	4.91E+01	4.91E+03
Methyl tert-Butyl Ether	4.72E+02	4.72E+04
Methylene chloride	2.60E+03	2.60E+05
Naphthalene	3.61E+00	3.61E+02
Tetrachloroethene	1.75E+02	1.75E+04
Toluene	2.19E+04	2.19E+06
1,2,4-Trichlorobenzene	8.76E+00	8.76E+02
1,1,1-Trichloroethane	2.19E+04	2.19E+06
1,1,2-Trichloroethane	7.67E+00	7.67E+02
Trichloroethene	8.80E+00	8.80E+02
Vinyl chloride	2.79E+01	2.79E+03
Xylenes, total	3.07E+03	3.07E+05

FIGURE 2-1
TRIGGER LEVEL DECISION MATRIX
LOCKHEED MARTIN MIDDLE RIVER COMPLEX
MIDDLE RIVER, MARYLAND

Indoor Air Sampling Results		**Sub-Slab Vapor Sampling Results**	**Response**	**Activities**
Concentrations below screening/trigger levels: Carcinogenic risk $< 10^{-6}$ Hazard quotient <1	**AND**	Concentrations below screening levels: Carcinogenic risk $< 10^{-5}$ Hazard quotient <1	None [1]	Determine sub-slab vapor plume is stable
Concentrations at or slightly above screening/trigger levels: Carcinogenic risk $\geq 10^{-6}$ but $< 10^{-5}$ Hazard quotient ≥ 1 but < 3	**OR**	Concentrations at or slightly above trigger levels: Carcinogenic risk $\geq 10^{-5}$ but $< 10^{-4}$ Hazard quotient ≥ 1	Semi-annual monitoring	Collect additional data: sub-slab vapor, indoor air samples
Concentrations much higher than screening/trigger levels: Carcinogenic risk $>10^{-5}$ Hazard quotient >3	**OR**	Concentrations much higher than trigger levels: Carcinogenic risk $>10^{-4}$ Hazard quotient >3	Communicate with tenants; evaluate possible mitigation[2]	Institute engineering controls and continue monitoring

[1] Based on two consecutive semi-annual rounds with all results below screening levels. Screening levels are the same as trigger levels for indoor air. Trigger levels are three times screening levels for sub-slab vapor.

[2] Because a correlation of sub-slab vapor to indoor air results has not been established, active sub-slab mitigation would typically be based on the sub-slab vapor sampling results. Other engineering controls would typically be used for indoor air above trigger levels.

Section 3

Management of Potential Vapor-Intrusion Risks

If regulatorily unacceptable risk from vapor intrusion (VI) is identified, it must be appropriately managed. Early planning will assist in making informed site management decisions. In managing potential VI risk, the results of indoor air and sub-slab investigations are integrated with other considerations, such as economic or legal concerns, to identify the need for mitigation, remedial action, or other risk-reduction activities. Additional factors, such as regulatory requirements, technical implementability, and employee/tenant acceptance, must also be considered when making risk management decisions.

An important distinction needs to be made between *remediation* and *mitigation*. *Remediation* refers to the treatment, removal, and reduction in the amount of contaminants at a site. *Mitigation* means taking measures to minimize or reduce exposure to the conditions as they currently exist. Mitigation, by itself, usually does not have a direct effect on the contaminant source area.

3.1 MANAGEMENT OF POTENTIAL ACUTE RISKS

Acute risks are those that may result in immediate harmful effects. At the Middle River Complex (MRC), the potential for acute risks from VI may be increased through a number of possible scenarios, including the intentional breaching of the facility slab in areas of sub-slab contamination or through incidental cracking. Under such circumstances, the VI manager should contact environment, safety, and health (ESH) personnel to determine the best course of action.

By its nature, management of acute risk from VI requires a rapid response. Possible responses for acute risk include vacating the premises to eliminate exposure, and/or providing additional localized ventilation. Immediate action is especially important when potentially explosive gases, such as petroleum hydrocarbons, are present. Where the possibility of explosive hazards exists, facility security, facility firefighting, the local fire department, and/or appropriate regulators should be alerted.

Monitoring programs to manage potential acute risks will rely on direct reading instruments such as photoionization detectors (PIDs) and/or flame ionization detectors (FIDs). (If a PID is used, a lamp of appropriate photon energy for the sub-slab vapor and indoor air chemicals of concern should be selected.) The direct reading instruments cited have varying degrees of response to different chemicals, so trigger levels must be developed accordingly based on instrument response.

Table 3-1 contains the trigger levels to be used during acute events. These levels are based on federal Occupational Safety and Health Administration (OSHA) short-term exposure limits (STELs) and eight-hour time-weighted averages (TWAs). These values are for short-term exposures, and are more appropriate for screening acute exposures than the United States Environmental Protection Agency's (USEPA's) screening levels, which are based on chronic (long-term) exposure scenarios. (Note that the units in Table 3-1 are in parts per million [ppm], and not in micrograms per cubic meter [$\mu g/m^3$] as shown in earlier tables, because ppm is the concentration unit most commonly used in field instruments. Concentrations in ppm can be converted to $\mu g/m^3$ using a compound–specific conversion factor that includes the compound's molecular weight:

Conc in µg/m3 = [Conc in ppm] * [molecular weight] / 24,450.)

Any location(s) where the slab has been compromised should be monitored to identify whether sub-slab contamination is migrating into the occupied space. The occupied space should also be monitored to assess airborne (breathing zone) concentrations of SV contaminants. If trigger levels are exceeded, then the area will need to be vacated until mitigation measures (e.g., localized ventilation) are implemented.

3.2 MANAGEMENT OF POTENTIAL CHRONIC RISKS

If the results of SV and/or IAQ monitoring indicate that potential chronic risks are regulatorily unacceptable, steps will be taken as part of a risk management strategy to address these potential risks. The steps may range from addressing building parameters to remediation of groundwater and soil contamination. Several options exist for mitigating potential chronic risks, including:

- ***Sealing cracks/annular spaces around utilities, the floor/wall intersection, and/or cracks in basement floor:*** This uses epoxy-based sealants that are impenetrable to vapors. Although this approach may help reduce the flux rate at specific locations, it may be inadequate to eliminate vapor intrusion over a large slab.

- ***Sealing and venting groundwater sumps:*** Many buildings with basements have sumps intended to capture any unexpected water release (flooding, burst hose, etc.). These sumps are dug into the ground below the rest of the foundation and may serve as an easy access point for vapors. Sealing and venting them maintains their function while preventing VI.

- ***Placing vapor barriers beneath the building:*** Vapor barriers can be plastic or geotextile sheeting, or perhaps a sealant, applied directly to the foundation and/or basement wall. Barriers are more easily installed during building construction than during a retrofit. This technique is often used in conjunction with active mitigation systems at sites with known contamination. Damage to even a small portion of the barrier during installation can result in significant leakage across the barrier.

- ***Reducing basement depressurization by ducting in outside air for furnace combustion:*** For furnaces in basements, bringing outside air into the furnace decreases the pressure differential across the slab. Lowering the pressure differential in a basement lessens the pull on subsurface vapors ***Over-pressurization of the building using air/air heat exchangers:*** This technique creates a positive pressure in the building by supplying more outdoor air to the inside than the amount of air exhausted. To work effectively, buildings should be tightly sealed and have a ventilation system capable of producing the output needed to maintain the pressure differential. This may only be viable for limited portions of Block I at the MRC due to the high use of natural ventilation through open doors and bays.

- ***Passive or active sub-slab depressurization systems:*** This technique creates a relatively low pressure beneath the building foundation; this low pressure is greater in strength than the pressure differential that exists between the building and the soil, thus intercepting vapor and preventing it from migrating into the structure. Passive and active systems are very similar in design; the only real difference is inclusion of a powered fan to create a low-pressure zone for the active system. A passive depressurization system may not be particularly effective, because it lacks any means of actively moving vapors, relying instead on natural thermal and wind effects to move the soil gas from the collection zone to the external vent.

Mitigation techniques may be used individually or they may be used in combination as part of an overall plan.

Monitoring programs to assess potential chronic risks from VI are similar to the current semiannual sampling and analysis of SV and IAQ. The existing program can be expanded to address any newly identified areas of concern. Should mitigation steps not meet the goal of reducing sub-slab and indoor air contaminant concentrations to regulatorily acceptable levels, remediation of affected media will be required.

Removing the source of vapors is often the preferred remediation strategy at VI sites. Greater short-term effects may be seen with soil removal and soil-vapor extraction, as they either eliminate or reduce the source of contamination, or intercept the contaminated soil gas, thereby reducing potential exposure. Groundwater remediation is a long-term option that may require an unacceptably extended time until cleanup goals are met.

Implementing both a remediation and a mitigation strategy at the site may be necessary. For example, if potential risks are high enough in currently occupied spaces, then some kind of mitigation measure will be needed to immediately reduce exposure. However, since mitigation does not affect the source concentration, a remediation strategy may also be needed so that the source mass and long-term risks can be reduced.

The possible effects the remedial alternatives may have on VI should also be considered. Certain groundwater remedies may change the chemical conditions of the subsurface, which may in turn increase the possibility of VI. Degradation products that have more stringent screening levels than their parent compounds may be produced. These possibilities should be considered as part of risk management project planning.

In addition to mitigation and remediation, other risk management strategies, including land use and building use controls, may be implemented. If possible, areas of high potential risk should be vacated and personnel should be moved to locations where potential risks are lower. Similarly, property located over a contaminant plume should not be developed unless mitigation measures are included to address potential future risks from VI.

Land use controls and institutional controls are common tools for limiting access and/or development. Institutional controls may be applied at undeveloped sites or sites where land use may change in the future. Institutional controls may be necessary to ensure that the VI pathway is effectively addressed in the future. Institutional controls may include requirements to install engineering controls on buildings to mitigate potential VI pathways. Institutional controls might also limit certain kinds of land use (such as residential) that might be associated with regulatorily unacceptable health risks. Furthermore, engineering controls implemented as a part of institutional controls will require operations and maintenance to retain their effectiveness.

3.3 EXIT STRATEGY

An exit strategy is an important component of the VI management plan. An exit strategy is a plan for reducing potential risk from VI to a level where no further remedial action or mitigation is needed. Monitoring may continue to verify that response actions were effective in reducing potential risks to regulatorily acceptable levels. When this status is achieved, the site will no longer require active management.

The exit strategy will incorporate the previously discussed trigger levels to clearly identify that the site no longer poses a regulatorily unacceptable VI risk. An exit strategy should be developed early in a VI project so site management and regulators can agree as to when potential risks at a site have been adequately mitigated. Factors to be considered in an exit strategy include mitigation and/or remediation techniques, final cleanup goals, land use, and possible future building construction and/or land use. While the vapor management program is currently in early phases of investigation, followed by mitigation as determined useful, with evaluation of results, the program's goal will be to develop appropriate plans and agreement with regulators to finalize a future exit strategy.

3.4 COMMUNICATION OF POTENTIAL RISK

A critical aspect of VI projects/management is to communicate information regarding potential risks with building occupants, as well as with management and regulatory agencies. VI is a relatively new and unfamiliar concept, with considerable potential to raise concerns among site occupants. Factors associated with VI, such as the unfamiliarity of the pathway and potential risks, an assumed lack of control over the potential risk, and potential harm from the exposure, contribute to the likelihood that workers will perceive a high level of risk no matter what investigations and monitoring may find.

Sampling for VI and remedial actions can be disruptive to building occupants because it can involve excavating or drilling through floors and the presence of obtrusive equipment. This could potentially alarm building occupants, and may raise health concerns. VI issues occur indoors, where people work, so workers' input, understanding, and cooperation can significantly affect assessment and mitigation activities.

Risk communication practices and principles should be followed at every step throughout a project, from planning to follow-up communication after the project concludes. Effective risk communication is based on building, maintaining, and/or repairing relationships with potentially affected individuals; this can influence program success. Early involvement of workers and tenants is critical.

Too often, risk communication is seen as something that takes place after the fact, when all the important decisions have already been made. This approach often produces negative outcomes, because affected individuals feel that they were not informed and involved early on, and can create unnecessary difficulties in completing assessments and implementing solutions. If tenants and employees are not informed of the steps leading to conclusions, they are very likely to regard study conclusions skeptically, and trust and credibility will be lost.

Such a scenario may lead to protracted disagreement about what was done at the site, what the results mean, and the correct path forward. Corporate or outside communication staff shall be consulted before any meeting or presentation to facility employees or tenants. Educational materials that incorporate risk management principles may be generated by communications personnel to assist in delivering a consistent message and providing clear, effective responses to questions from interested parties.

TABLE 3-1

ACTION LEVELS FOR ACUTE EXPOSURE
LOCKHEED MARTIN MIDDLE RIVER COMPLEX
MIDDLE RIVER, MARYLAND

Chemical	CAS #	Occupational Exposure Limit (OEL)	OEL Reference	Can this chemical be monitored by a FID?	Can this chemical be monitored by a PID (RAE)?	Lamp strength for PID (eV)	# of Exposures allowed in any one work day	Time per Exposure (mins)	PID ACTION LEVEL/ INSTRUMENT READING (ppm)	FID ACTION LEVEL/ INSTRUMENT READING (ppm)
1,1,1-Trichloroethane	71-55-6	450	ACGIH 15 min STEL	yes	yes	11.7	1	3	2250	350
1,1-Dichloroethane	75-34-3	100	OSHA TWA8	yes	no	NA	1	3	NA	3750
1,1-Dichloroethene	75-35-4	5	ACGIH TWA8	yes	yes	10.6	1	3	650	45
1,2-Dichloroethane	107-06-2	100	OSHA Ceiling	yes	yes	11.7	1	any	60	80
1,2-Dichloroethene - cis	156-59-2	200	OSHA TWA8	yes	yes	10.6	1	3	22000	2400
1,2-Dichloroethene - trans	156-60-5	200	OSHA TWA8	yes	yes	10.6	1	3	14000	2400
Benzene	71-43-2	2.5	ACGIH STEL	yes	yes	10.6	1	3	6.5	2.75
Carbon Tetrachloride	56-23-5	25	OSHA Ceiling	yes	yes	11.7	1	any	42	2.5
Chlorodifluoromethane	75-45-6	1000	ACGIH TWA8	yes	no	NA	1	3	NA	64000
Chloroform	67-66-3	50	OSHA Ceiling	yes	yes	11.7	1	3	175	32
Dichlorodifluoromethane	75-71-8	1000	OSHA TWA8	yes	no	NA	1	3	NA	24000
Ethylbenzene	100-41-4	125	ACGIH STEL	yes	yes	10.6	1	3	325	625
Methyl tert-Butyl Ether (MTBE)	1634-04-4	40	ACGIH TWA8	no	yes	10.6	1	3	5575	NA
Methylene Chloride	75-09-2	125	OSHA 15 minute STEL	yes	yes	11.7	1	3	445	90
Naphthalene	91-20-3	100	OSHA TWA8	no	yes	10.6	1	3	6500	N/A
Tetrachloroethylene	127-18-4	200	OSHA Ceiling	yes	yes	10.6	1	any	114	140
Toluene	108-88-3	300	OSHA Ceiling	yes	yes	10.6	1	any	150	330
Trichlorobenzene, 1,2,4-	120-82-1	5	ACGIH Ceiling	no	yes	10.6	1	any	2.3	NA
Trichloroethane, 1,1,2-	79-00-5	10	OSHA TWA8	yes	yes	11.7	1	3	1400	1300
Trichloroethene	79-01-6	200	OSHA Ceiling	yes	yes	10.6	1	any	108	140
Vinyl Chloride	75-01-4	5	OSHA 15 minute Ceiling	yes	yes	10.6	1	3	50	1.25
Xylene	106-42-3	150	OSHA 15 minute STEL	yes	yes	10.6	1	3	290	120

ACGIH - American Conference of Governmental Industrial Hygienists
15 min STEL - 15 Minute Short Term Exposure Limit
OSHA Occupational Safety and Health Adminstration Eight Hour Time Weighted Average
TWA 8 -Eight Hour Time Weighted Average
Ceiling - Ceiling Limit
FID - flame ionization detector
PID - photo ionization detector
any - instantaneous exposure requiring immediate exit

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Section 4

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