Army Research Laboratory

An Investigation Into Ventilation and Dust Issues for the Joint Light Tactical Vehicle (JLTV)

by Sam E. Middlebrooks

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An Investigation Into Ventilation and Dust Issues for the Joint Light Tactical Vehicle (JLTV)

Sam E. Middlebrooks
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This report was prepared to investigate the occupational health hazard issues of indoor air quality and resulting human performance as it pertains to crew performance in enclosed military vehicles in general and the Joint Light Tactical Vehicle (JLTV) in particular. The JLTV is still in predevelopment testing, with the result that many of the details regarding specific vendor variants are competition sensitive in nature. This report has been prepared with this sensitivity in mind and has been verified for an unlimited distribution.

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Executive Summary

This report was prepared to investigate the occupational health hazard issues of indoor air quality and resulting human performance as it pertains to crew performance in enclosed military vehicles in general and the Joint Light Tactical Vehicle (JLTV) in particular. The JLTV is still in predevelopment testing with the result that many of the details regarding specific vendor variants are competition sensitive in nature. This report has been prepared with this sensitivity in mind and has been verified for an unlimited distribution declaration of "Approved for public release; distribution is unlimited" (Munya, 2011d).

ES.1 Requesting Activity

In August 2011, the U.S. Army Test and Evaluation Command, Army Evaluation Center (ATEC/AEC) requested assistance from the U.S. Army Research Laboratory, Human Research and Engineering Directorate (ARL/HRED) concerning recurring dust issues in military vehicles (Wojciechowski, 2011a). Specifically, they were interested in pursuing a previous study (Heuckeroth and Middlebrooks, 2011) further:

"Any additional thoughts and ideas for the MRAP ventilation work from last year? Ventilation-related issues continue to surface and additional attention is warranted for current and future programs."

Further (Wojciechowski, 2011b):

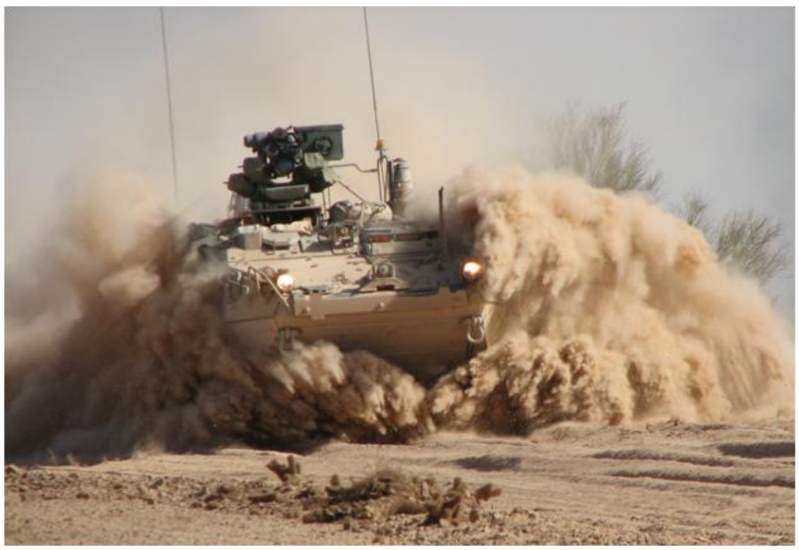
"I'm convinced ARL/HRED can help us understand and better define the mission impact of ventilation and dust to vehicle crews and their ability to perform their crew tasks. The Army provides armored vehicles to our soldiers to protect them from hazards. If poor ventilation causes them to open hatches or lack of available oxygen results in degraded mental and physical performance, we want to determine a way (or better way) to collect quantitative information (instrumentation) and use medically-approved thresholds to determine the effect to the crew. I'd like to follow the same approach for dust entering the vehicle and degrading the crew's vision and being a health hazard. Again, I'm looking for ways to quantitatively measure and report what's happening to the crew, both short- and long-term."

Following this request, ARL/HRED tasked the Fort Hood Field Element (Savage-Knepshield, 2011) to continue previous work in this area (Heuckeroth and Middlebrooks, 2011):

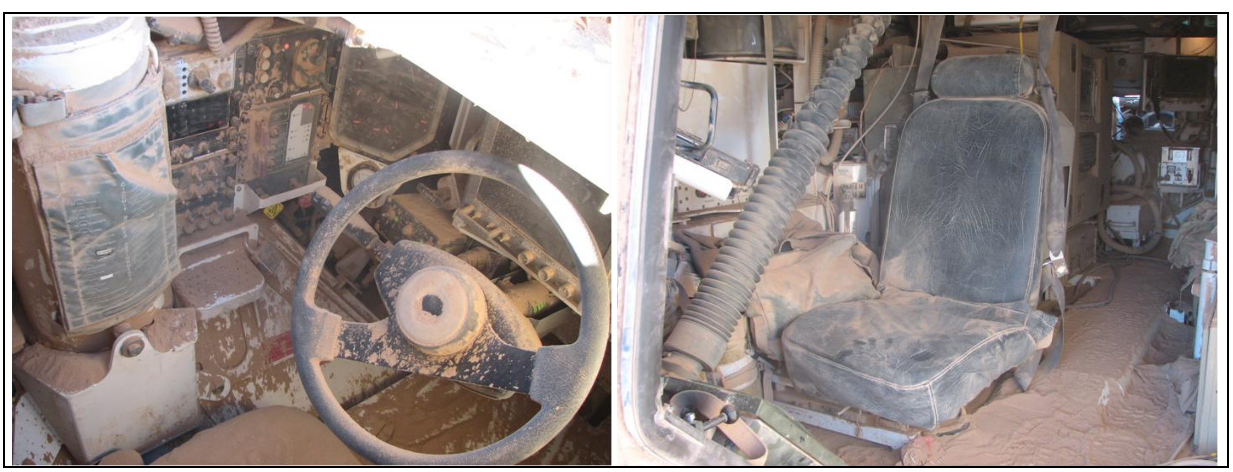
"Apparently, in testing at Yuma and other places, the JLTV is filling up with dust and people are having a difficult time seeing and breathing. Obviously, a bad thing and seems like a much larger problem than ventilation, unless the dust is getting in through the ventilation system. AEC would like to know what the standards are or what they should be so they have something to test against."

ES.2 Nature of the Problem

Initial development testing (DT) of three prototypes of the JLTV at Aberdeen Proving Ground (APG), MD (Dangerfield and Fredrickson, 2011a, 2011b) resulted in the generation of test incident reports (TIR) (Pakkala, 2010) which stated that the "… cab fills with excessive dust from rear of cab, breathing becomes difficult due to excessive amount of dust in cab" and that "dust settled on the front windshield and required cleaning approximately once per lap (test drive laps at APG)." Because of the competition sensitive nature of the current test results, specific pictures of examples of the dust buildup in and on the JLTV vehicles cannot be shown in this report. However, pictures from similar conditions experienced during testing of the Stryker vehicle are shown in figures ES-1–3 (Munya, 2011d).



ES-1. Exterior picture of the Stryker vehicle undergoing sand and dust exposure testing – hatches closed.



ES-2. Interior pictures of the Stryker vehicle undergoing sand and dust exposure testing – hatches closed.

ES-3. Oil mixed with sand and dust on one of the Stryker driver periscopes.

ES.3 BLUF- Bottom Line Up Front

Following the previous combat vehicle ventilation study (Heuckeroth and Middlebrooks, 2011), this study was conceived to investigate the overall effects of air quality and resulting human performance. The specific target audience was identified to be Soldiers in vehicle crew compartments in general where the crew members are dependent on the vehicle ventilation system for breathable air with a specific focus on the JLTV currently in development.

ES.3.1 Regulatory Requirements

This study identified the regulatory requirements for ventilation and air quality. These are:

- MIL-STD 1472: Outside fresh air shall be supplied at minimum rate of 0.57 m^3 (20 ft^3) /min/person (U.S. DOD, 1999), paragraph 5.12.6.2 – Ventilation. This parameter applies to spaces that are air conditioned. For spaces that are not air conditioned in hot climates the values are much greater at between 4.2 and 5.7 m^3 (150 and 200 ft^3)/min/person.

- 29 CFR 1910.1000 (OSHA Standard): Limit for total dust particulates - 15 mg/m^3, limit for Respirable fraction - 5 mg/m^3 (U.S. DOL, 2010), Particulates Not Otherwise Regulated (PNOR). (See appendix B for a complete listing of all contaminates in this standard.)

- American Conference of Governmental Industrial Hygienists (ACGIH): Limit of 3 mg/m^3 respirable particles, and 10 mg/m^3, inhalable particles (ACGIH, 2011), p. 74.

Official guidance from DOD (U.S. DOD, 1998) is that the "…DOD Components shall comply with the standards promulgated by OSHA under 29 U.S.C. 651 et seq. (reference (d)) in all nonmilitary-unique DOD operations and workplaces, regardless of whether work is performed by military or civilian personnel."

Noting that the ACGIH limits are more stringent than the OSHA standard (10 vs. 15 mg/m^3 inhalable particles and 3 vs. 5 mg/m^3 respirable particles, DA PAM 40-503 [2000]), paragraph 1-8.b states that "The DA mandates the use of ACGIH TLVs when they are more stringent that OSHA regulations…" Therefore, the recommended ventilation and air quality particulate standards are:

- 0.57 m^3 (20 ft^3)/min/person of fresh air.
- 3 mg/m^3 respirable particles limit.
- 10 mg/m^3 inhalable particles limit.

It is the opinion of the Public Health Command (Kluchinsky, 2011) that these 3 parameters are sufficient to evaluate the air quality of vehicle crew spaces as related to air flow rates and airborne particulates such as dust and smoke.

For conducting field measurements of airborne particulates ACGIH further recommends measurement of respirable particles using a 10-mm nylon cyclone at a flow rate of 1.7 L/min (ACGIH, 2011, p. 76–Particle Size Selective Sampling Criteria for Airborne Particulate Matter). For reference, a table from Engineering Toolbox (ET) listing particle sizes for various known airborne particles is included as appendix C.

Chemical air contaminants such as carbon monoxide (CO), carbon diode (CO^2), and ozone, (O^3), along with several hundred other contaminants (U.S. DOL, 2010), are in a different category and require other considerations. See appendix A for a table compiled by the U.S. Army Public Health Command (Braybrooke and Cambre, 2011a) comparing some of the most frequently occurring chemicals affecting air quality identified during weapons testing.

The term occupational exposure limit (OEL) is used by "…health professional(s) to help determine a worker's or population's health risk from exposure to a hazard. OEL is a generic term used to apply to all exposure limits, including but not limited to DOD standards, OSHA permissible exposure limits, DOD Component standards, military exposure guidelines… environmental health limits, American Conference of Governmental Industrial Hygienists TLVs… National Institute for Occupational Safety and Health recommended exposure limits, and other exposure limits reviewed for potential use" (U.S. DOD, 2008).

ES.3.2 Human Performance Effects

While the literature contains extensive references to air quality limits in the broad categories of airborne particulates and chemical contamination, the resulting effects on human performance, both physical and cognitive, are much more elusive to evaluate and quantify. The quantifiable effects of human performance resulting from reduced air quality is not well documented. There have been numerous studies reported in the medical literature, however, correlating their findings to actual and immediate effects on human performance, physical and cognitive, is not always forthcoming. Some of the pertinent findings from selected reports are:

a. Air Quality and Performance for Healthy Individuals (Pandolf, 1988):

- "Maximal exercise performance for healthy individuals seems to be altered by breathing ***carbon monoxide*** with the critical concentration being 4.3% carboxyhemoglobin (combination of O2 and CO in blood when CO is inhaled causing loss of blood's ability to combine with O2)."
- "The threshold level of sulfur dioxide which effects sub maximal exercise performance in healthy individuals is between 1.0 and 3.0 ppm."

b. Ventilation and Performance (LBNL, 2011): "Increases of 5% to 10% in aspects of human performance related to speed and accuracy may be associated with doubling the ventilation rate when rates are at or below minimum ventilation standards (15 cfm per person)."

c. Perceived Indoor Air Quality and Performance (LBNL, 2011): "Better perceived indoor air quality is correlated with improvements in office work tasks, with approximately a 1% increase in task performance per each 10% decrease in the percentage of occupants dissatisfied with indoor air quality."

d. Particulate Matter (McCafferty, 1981):

- "Currently, concern focuses on particulate matter serving as a transport mechanism for carrying toxic gases deeper into the respiratory tract that would otherwise, because of their solubility, not penetrate so far."
- "This and other criteria such as effects on visibility, materials, vegetation and sunlight resulted in the establishment of an air quality standard of 75 mg/m^3."
- "Most of the total suspended particulate is composed of dust, soot, organic matter and industrial-produced compounds containing sulfur, nitrogen, and metals."

e. Air Quality Guidelines (WHO, 2000), Carbon Monoxide:

- "In apparently healthy subjects, maximal exercise performance has decreased at CO levels as low as 5% (p. 76)."
- "The following guidelines are recommended to ensure that a CO level of 2.5% is not exceeded for a normal subject engaged in light or moderate exercise" (p. 77):
    - 100 mg/m^3 (90 ppm) for 15 min.
    - 60 mg/m^3 (50 ppm) for 30 min.
    - 30 mg/m^3 (25 ppm) for 1 hr.
    - 10 mg/m^3 (10 ppm) for 8 hr.

f. Air Quality Guidelines (WHO, 2000), Particulate Matter:

- "Recent studies suggest that short-term variations in particulate matter exposure are associated with health effects even at low levels of exposure (below 100 $\mu g/m^3$) (p. 186)."
- "Long-term exposure to low concentrations of particulate matter in air is associated with mortality and other chronic effects, such as increased rates of bronchitis and reduced lung function (p. 187)."
- "The weight of evidence from numerous epidemiological studies on short term responses points clearly and consistently to associations between concentrations of particulate matter and adverse effects on human health at low levels of exposure (p. 192)."

1. Introduction

This investigation consisted of 'collaborative brainstorming' between members of several organizations involved in the initial development and testing of the joint light tactical vehicle (JLTV) and literature searches of the social science and medical literature to determine what the known effects on human performance are from degraded air quality.

1.1 System Description of the JLTV

"The JLTV family of vehicles will consist of three payload categories—A (3500 lb), B (4000 lb for the U.S. Marine Corps and 4500 lb for the U.S. Army), and C (5100 lb)—each equipped with a companion trailer capable of carrying an equivalent payload. All configurations will be designed to maximize commonality while meeting the specific needs of the user. Payload categories will be further tailored with a set of mission-specific components (command, control, communications, computers, and intelligence; armor; and weapons) to achieve requirements of all sub configurations." Figure 1 shows the JLTVs from three vendors evaluated for this test (Dangerfield and Fredrickson, 2011b).

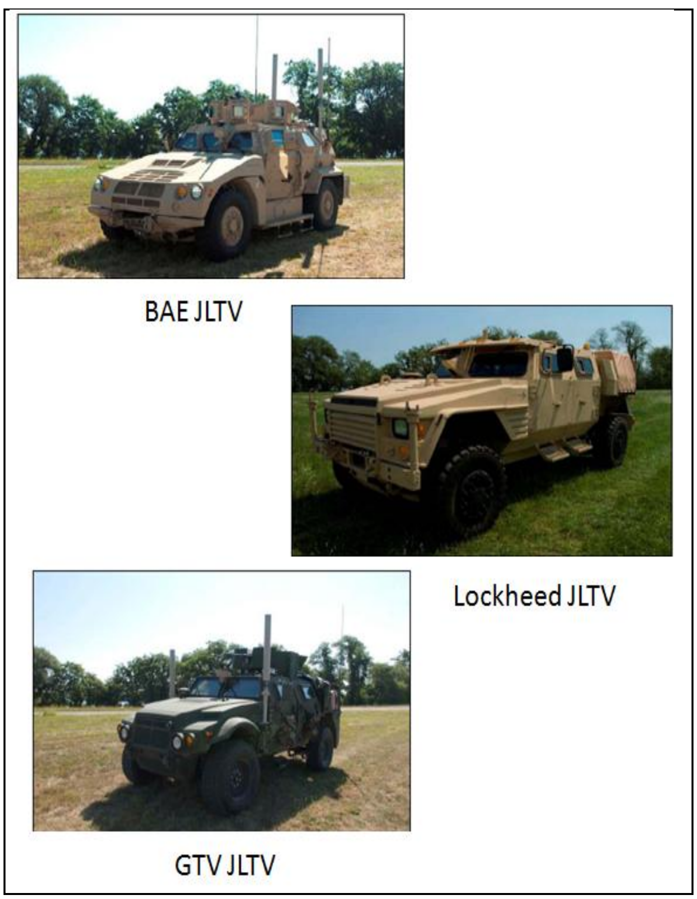


Figure 1. Three JLTV prototypes under current evaluation.

From Goodman (2011):

> "The Joint Light Tactical Vehicle (JLTV) is a major Army-Marine Corps acquisition program for a new-generation wheeled vehicle that would replace a portion of the services' High Mobility Multipurpose Wheeled Vehicle (HMMWV) fleet. The program's aim is to develop a new multi-mission light vehicle family with superior crew protection and performance compared to the HMMWVs. The JLTV family will balance critical weight and transportability constraints within performance, protection, and payload requirements."
>
> "The JLTV program is aligned with a joint program office under the management of the U.S. Army's Project Manager Joint Combat Support Systems, which falls under the leadership of the Program Executive Office Combat Support and Combat Service Support. In October 2008, the Army awarded three industry teams – BAE Systems, General Tactical Vehicles (GTV) (General Dynamics, AM General), and Lockheed Martin – technology development (TD) contracts to design and fabricate competitive prototypes for testing and evaluation."

From Stolarz (2011b):

> "The three vendors participating in this phase are BAE, GTV, and Lockheed Martin. Each vendor provided several vehicles in each of three payload categories: Cat A (3500-lb payload) general purpose, Cat B (4500-lb payload) infantry carrier (IC) and command and control on-the-move (C2OTM), Cat C (5100-lb payload) utility/shelter carrier. B-kit armor was also provided. The Joint Services have identified five capability gaps that must be addressed by the JLTV Family of Vehicles. (a) Gap 1: Move mounted combat forces: Six Passenger Combat Tactical Vehicle (CTV). (b) Gap 2: Move mounted combat support forces: 2- to 4-passenger configuration; ability to support multiple Combat Support mission tasks. (c) Gap 3: Move mounted combat service support forces: 2- to 4-passenger configuration; ability to support multiple Combat Service Support mission tasks. (d) Gap 4: Move light (airborne/air assault) forces; 2 crew plus 9 passengers or 2 crew with added shelter. (e) Gap 5: Move long-range reconnaissance forces; 4-passenger reconnaissance vehicle."

The features of the JLTV four-door general purpose (GP) vehicle currently envisioned are listed in table 1 (Glenn, 2011).

ES-1. Features of the JLTV four-door GP vehicle.

Technical Features	• 275–340 HP diesel engine (four or six cylinder) • Six-speed automatic transmission • Independent four-corner suspension (passive or semi-active) • Air-activated hydraulic anti-lock disc brake system with controlled trailer braking and traction control • Starter and alternator power train (15 kW on-board power generation) • Silent watch battery (2 h of silent watch) • Curb weight: 14,300 lb • GVW: 20,000 lb • GVWR: 21,500 lb
Safety Features	• 18–24-in ground clearance • Electronic stability control • Automatic fire extinguishing system [AFES] (engine and crew compartments) • Combat-locking doors • Central tire inflation system (CTIS) • Multiple occupant egress paths • Exterior provisions to accept EFP and RPG kits
Exterior Features	• Tubeless radial tires (365–395 mm wide, with 20–22.5-in rims) • 30–40 gal fuel tank • Pintle for towing JLTV trailer or legacy trailers (HMMWV/FMTV) • External NATO slave cable receptacles • LED headlights • Exterior lighting package (including blackout mode) • Fording to 30 in
Interior Features	• 3500 lb payload capacity with 60 ft^3 of additional stowage space for mission payload • Accommodates 5th–95th percentile combat-equipped occupants • Extreme climate condition HVAC controls • Noise-reducing crew compartment • Spall protection • Net-ready integrated C4I suite

The current ventilation requirements in the JLTV performance description (PD) documents make no mention of filtration or dust removal. They are (Munya, 2011a) as follows:

- PDFOV-920: The JLTV individual vents/ducts shall have hand moveable controls to adjust the amount of air output and position the air flow in a range from directly on crew to completely off crew.

- PDFOV-6989: The JLTV ventilation system shall comply with the ventilation system performance requirements in MIL-STD-1472F section 5.12.6.2, and have the capability to adjust the origin of air flow from 100% fresh air to nearly 100% recirculated air.
- PDFOV-8631: The JLTV shall include a mechanism to exhaust a minimum of 50% of the maximum inflowing airflow volume provided by the HVAC system at 1 in H2O interior pressure, with all doors and hatches closed.
- PDFOV-8632: The exhaust path location(s) shall be in a negative pressure area and secure from water, fume, dust, and debris intrusion.

1.2 Study Charter and Nature of the Problem

Data and information from ad hoc study group members, relevant literature, and initial test results were used during the course of this investigation.

1.2.1 Identification of the Problem

On August 12, 2011, following discussions with and requests from OTC, the chief of the ARL/HRED Human Factors Integration Division (HFID) (Savage-Knepshield, 2011) asked the ARL/HRED Fort Hood, TX, Field Element to investigate reports that unusual amounts of dust were accumulating in the crew compartments of JLTV prototypes during testing at Yuma Proving Ground (Lesko, 2011; Pakkala, 2010). This request followed similar requests from ATEC/AEC (Wojciechowski, 2011a) so that they could have a basis to make proposals to the WIPT and PMs for integration of air quality requirements into the overall T&E programs. Also, they were interested in getting ARL/HRED to help ‘understand and better define the mission impact of ventilation and dust to vehicle crews and their ability to perform their crew tasks’ (Wojciechowski, 2011b).

1.2.2 Ad Hoc Study Group Members

Following the request from ARL/HRED HFID division, the Fort Hood FE began to seek advice and comments from across ARL/HRED, ATEC, the PMs, and the system developers. The following individuals contributed to the dialog that resulted in the findings in this report.

1.2.2.1 From ATEC-AEC. Participating from the U.S. Army Test and Evaluation Command, Army Evaluation Center (ATEC/AEC at APG):

- Mr. Robert A. Wojciechowski, Jr. (Dir., ILSD), robert.a.wojciechowski.civ@mail.mil.
- Dr. Nigel R. Nicholson (Engineering Psychologist/AST MANPRINT), nigel.r.nicholson.civ@mail.mil.
- Mr. Richard L. Collins (Log Mgt Spec/AST ILS), richard.l.collins16.civ@mail.mil.
- Mr. William M. Halke (Log Mgt Spec), william.m.halke.civ@mail.mil.

- Mr. John J. Fuller (ORSA), john.j.fuller.civ@mail.mil.
- Mr. James P. Ables (Log Mgt Spec), james.p.ables.civ@mail.mil.
- Mr. Brian Stolarz (JLTV Lead Evaluator/AST Chair), brian.s.stolarz.civ@mail.mil.

1.2.2.2 From ATEC-OTC. Participating from the U.S. Army Test & Evaluation Command, Operational Test Command (ATEC/OTC at Ft. Hood):

- Mr. Craig S. Frederickson (JLTV ORSA), craig.frederickson@us.army.mil.

1.2.2.3 From ARL-HRED. Participating from the U.S. Army Research Laboratory, Human Research and Engineering Directorate (ARL/HRED):

- Dr. Sam Middlebrooks, (JLTV V&D Study Lead at Ft. Hood FE-OTC), sam.e.middlebrooks.civ@mail.mil.
- Dr. Pamela A. Savage-Knepshield (Dir., HFID at APG), pamela.a.savage-knepshield.civ@mail.mil.
- Dr. Bruce Sterling (Engineering Psychologist at Ft. Knox FE), bruce.sterling@us.army.mil.
- Ms. Cheryl Burns (Engineering Psychologist at Ft. Knox FE), cheryl.a.burns12.civ@mail.mil.
- Dr. Alan D. Davison (Chief, MMB at Ft. Leonard Wood FE), alan.d.davison@us.army.mil.
- Mr. Dave Harrah (Chief, ISB at APG), david.m.harrah.civ@mail.mil.
- Dr. Valerie Rice (Research Psychologist at Ft. Sam Houston FE-AMEDD), Valerie.Rice@amedd.army.mil.
- Dr. Raymond Bateman (Research Psychologist at Ft. Sam Houston FE-AMEDD), RBateman@arl.army.mil.
- Mr. Paul W. Munya (Research Psychologist at Warren, MI, FE-TACOM), paul.w.munya.civ@mail.mil.
- Ms. Belinda D. Lutas-Spencer (Research Psychologist at Warren MI, FE-TACOM), Belinda.lutas@us.army.mil.

1.2.2.4 From PHC. Participating from the U.S. Army Public Health Command (USA PHC) at APG:

- Dr. Timothy A. Kluchinsky (Industrial Hygienist), timothy.kluchinsky@us.army.mil.
- Mr. Robert G. Booze (Industrial Hygienist), robert.g.booze2@us.army.mil.

- Mr. Geoffrey Braybrooke (Industrial Hygienist), geoffrey.braybrooke@us.army.mil.
- Mr. John V. Cambre (Industrial Hygienist), john.v.cambre@us.army.mil.

1.2.2.5 From USAASC. Participating from the U.S. Army Acquisition Support Center at Warren, MI:

- Mr. Brett Johnson (JLTV Chief Engineer), brett.r.johnson8.civ@mail.mil.

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2. Discussion

The issue of air quality in enclosed spaces transcends any individual vehicle system such as the JLTV in that it applies to any crew space system where the occupants are dependent on the vehicle ventilation system for air of a quality sufficient to support physical and cognitive activities for a normal healthy person. Current U.S. Army systems in development that could benefit from this investigation include the MRAP and Ground Combat Vehicle (GCV) in addition to the JLTV.

2.1 Literature Review

In a previous study of combat vehicle ventilation requirements in general (Hueckeroth and Middlebrooks, 2011), the social science and psychology based literature was searched to determine what requirements existed for ventilation in closed vehicle spaces. This study provided insight into these requirements but more knowledge was needed to provide information needed to perform T&E evaluations for these systems. Specifically, what air quality standards apply to this situation and what the parameters are, and what the resulting effects are on human performance if these standards are not met? Therefore, for this study, a new literature search was initiated in the medical based literature with the search parameters “air quality” and “human performance.” The literature was replete with data concerning what the recommended air quality standards are, however, information providing quantitative effects on human performance, if the air quality standards are not met, was much more elusive to find.

2.1.1 Recommended Air Quality Standards

Air quality falls into two major categories. These are airborne particulate and chemical contaminants. Examples of particulate contaminants are dust and smoke and examples of chemical contaminants are carbon monoxide (CO), carbon dioxide (CO2), and ozone (O3).

Military Standard (MIL-STD) 1472F (U.S. DOD, 1999) in paragraph 5.12.6.2 titled Ventilation, gives its often repeated requirement of providing a minimum of 20 ft^3/min/person of fresh air. No mention is made of any contamination or filtration requirements. The complete wording from this paragraph is as follows:

> Outside fresh air shall be supplied at minimum rate of 0.57 m^3 (20 ft^3)/min/person. Air flow rates for hot-climate operation (temperatures above 32 °C [90 °F]) shall be maintained between 4.2 and 5.7 m^3 (150 and 200 ft^3)/min/person, unless air conditioning or individual (microclimate) cooling is provided. Air velocity at each person's head location shall be adjustable either continuously or with not less than three settings (OFF, LOW and HIGH) from near zero to at least 120 m (400 ft)/min.

OSHA provides a list of chemical contaminants in the U.S. Code of Federal Regulations, 29 CFR 1910.1000, table Z-1 Limits for Air Contaminants (U.S. DOL, 2010). A copy of this table is attached to this report at appendix B. Comments regarding airborne contaminants in this table are in the section titled ‘Particulates Not Otherwise Regulated (PNOR)’ and recommends the limit for total dust particulates to be 15 mg/m^3 and for Respirable fraction- 5 mg/m^3.

The American Conference of Governmental Industrial Hygienists (ACGIH) (ACGIH, 2011, appendix B; page 74) recommends that airborne particulate contaminants not exceed 3 mg/m^3 respirable particles, and 10 mg/m^3, inhalable particles.

Thus, the recommended limits for airborne particulate contaminants are stricter in the ACGIH standard than in the OSHA standard. For cases such as this, DA Pam 40-503 (U.S. Army, 2000) mandates use of ACGIH threshold limit values (TLVs) when they are more stringent than OSHA regulations. Therefore, recommended levels of ventilation and limits for airborne particulate contaminants for acceptable air quality from these references are (Middlebrooks, 2011):

- 0.57 m^3 (20 ft^3)/min/person of fresh air.
- 3 mg/m^3 respirable particles limit.
- 10 mg/m^3 inhalable particles limit.

It is the opinion of the U.S. Army Public Health Command (Kluchinsky, 2011) that these parameters can be used in testing and evaluation of air quality for ventilation and airborne particulates such as dust and smoke.

2.1.2 Effect on Human Performance if the Air Quality Standards Are Not Met

“Temperature, relative humidity, microbiological contaminants, particulates, and other aspects of indoor air quality should be considered in a total approach to defining and measuring air quality. Many chemically reactive irritants are known to be harmful to human health, causing a wide variety of chronic respiratory and carcinogenic problems with chronic exposure. Temperature, relative humidity, microbiological contaminants, particulates and other aspects of indoor air quality should be considered in a total approach to defining and measuring air quality” (Hollick and Sangiovanni, 2000).

“Indoor environmental qualities including lighting, ventilation and thermal comfort significantly impact human performance” (TRANE, 2011).

“The American Medical Association defines **air pollution** as ‘the excessive concentration of foreign matter in the air which adversely affects the well-being of the individual’. Many times a year the Shamal or north wind of Saudi Arabia comes whipping in at 25 kn, stirring up the fine sand which is breathed in for many hours at frequent times of the month. When you walk in such an atmosphere, your teeth feel the ‘gritting’ of fine sand, and your lungs will pay the price later. The most frequently encountered **air contaminants** are Halogens, Nitrogen compounds, Organic matter, Oxygen compounds, Radioactive substances, Solids, and Sulfur compounds” (Shaheen, 1974).

“Evidence continues to emerge showing that poor indoor air quality (IAQ) can cause illness(es) (such as) ‘…respiratory infections, (and) allergic diseases from biological contaminants…’ requiring absence from (work), and can cause acute health symptoms that decrease performance while (there). In addition, recent data suggest that poor IAQ may directly reduce a person’s ability to perform specific mental tasks requiring concentration, calculation, or memory” (EPA, 2003).

“Research has found lung damage in veterans who served in Iraq and Afghanistan. A 6-year study examining soldiers who reported exposure to smoke or polluted air while serving in Iraq or Afghanistan all had symptoms of shortness of breath. Of 80 soldiers examined, 49 received open lung biopsy. All 49 were abnormal and 38 of them demonstrated a condition known as **constrictive bronchiolitis**, a rare condition in otherwise healthy individuals that is generally untreatable” (Burns, 2011a; Yeldell, 2011). Reports of respiratory symptoms have been common among soldiers who have served in the Middle East, beginning in the 1990s and more recently in soldiers returning from Iraq and Afghanistan. Constrictive bronchiolitis is defined as an increase in wall thickness of more than 20%, as compared with normal thickness. The disorder is also associated with inhalational exposure to nitrogen dioxide, sulfur dioxide, inorganic dust, and fly ash. Studies suggest that there is a strong association between constrictive bronchiolitis and exercise limitation in a cohort of soldiers who served in the Middle East (King et al., 2011). Bronchiolitis obliterans (BO), also called obliterative bronchiolitis (OB) and constrictive bronchiolitis (CB), is a rare and life-threatening form of non-reversible obstructive lung disease in which the bronchioles (small airway branches) are compressed and narrowed by fibrosis (scar tissue) and/or inflammation. Bronchiolitis means inflammation of the bronchioles and obliterans refers to the fact that the inflammation or fibrosis of the bronchioles partially or completely obliterates the airways (Wikipedia, 2011).

The performance of workers is affected by indoor environmental conditions and by the features of buildings that influence indoor environmental conditions. Work performance may be improved from a few percent to possibly as much as 10% by providing superior indoor environmental quality (IEQ). The economic benefits of the work performance improvements will often far outweigh the costs of providing better IEQ (LBNL, 2011).

“Common complaints resulting from exposure to air pollution include eye irritation, nose and throat irritation, cough, inability to take a deep breath, and other symptoms indicative of a detrimental effect. The most common subjective response during **ozone** exposure is cough, substernal soreness, and dryness of the upper respiratory passages, caused by the initial irritation to the mucous membranes of the nose and throat. These symptoms occur after brief exposures to low concentrations of oxidant (0.05–0.10 ppm). Also, drowsiness, central nervous system depression, fatigue, nausea, and muscular incoordination are often cited as subjective responses to ozone exposure. The detrimental effect of **carbon monoxide** on physical work capacity has been confirmed. It has been observed that exposure to 50 ppm of carbon monoxide significantly decreases the length of time nonsmokers are able to continue to treadmill walk. A reduction in work time to exhaustion of 4.9% and 7.0% when COHb levels reached 3.3% and 4,3%, respectively has been noted. Inhalation of dust “caused an immediate and marked reduction in lung volumes in man,” as well as describing a rapid shallow respiration following exposure. Most of the total **suspended particulate** is composed of dust, soot, organic matter and industrial-produced compounds containing sulfur, nitrogen, and metals. **Carbon monoxide** exposures resulting in carboxyhemoglobin levels greater than 15% to 20% resulted in a linear relationship between the decrease in visual discrimination and increase in carboxyhemoglobin levels” (McCafferty, 1981).

“There is a demonstrated association and trend between bronchial obstruction and fine **particulate matter**” (Neuberger et al., 2004). “In studies of soil samples from Iraq (McDonald and Caldwell, 2004), the concentration of quartz in Iraqi dust and soil samples ranges from 35.4% to 89.8%. The average particle size of dust encountered in military operations in arid regions is much smaller than laboratory-generated quartz surrogate dust used in sand-and-dust chamber testing of weapons. Further, substantial amounts of soluble salt, carbonate, chlorides, and sulfates are present in nearly all of the samples.”

“Maximal exercise performance for healthy individuals seems to be altered by breathing **carbon monoxide** with the critical concentration being 4.3% carboxyhemoglobin. The threshold level of **sulfur dioxide** which effects submaximal exercise performance in healthy individuals is between 1.0 and 3.0 ppm. Total **Suspended Particulates** (TSP) for a 24 hr exposure at 150 mg/m^3 cause” (Pandolf, 1988):

- Aggravation of chronic lung disease and asthma.
- Aggravation of cardiorespiratory disease symptoms in elderly patients with heart or chronic lung disease.
- Increased cough, chest discomfort and restricted activity.

"Lowered indoor air quality (IAQ) can manifest itself as discomfort due to a combination of stimulation by odorants or irritants and unsatisfactory temperature or relative humidity levels. Lowered IAQ can also result in diminished human cognitive or neuromotor performance" (Wargocki, 2001).

"**Carbon Monoxide**: In apparently healthy subjects, maximal exercise performance has decreased at CO levels as low as 5%. The following guidelines are recommended to ensure that a CO level of 2.5% is not exceeded for a normal subject engaged in light or moderate exercise" (WHO, 2000) (p. 77):

- 100 mg/m^3 (90 ppm) for 15 min.
- 60 mg/m^3 (50 ppm) for 30 min.
- 30 mg/m^3 (25 ppm) for 1 hr.
- 10 mg/m^3 (10 ppm) for 8 hr.

"Laboratory testing of the effects of CO on humans reported the following findings" (Stewart et al., 1970):

- No untoward subjective symptoms or objective signs of illness were noted during or in the 24-hr period following the exposures to 25, 50, and 100 ppm of CO.
- Carbon Monoxide exposure of 200 ppm, for 1 to 4 hr: The three subjects exposed for 4 hr each reported that they had developed a "mild sinus" headache in the final hour. For one subject, this headache remained mild in intensity, subsiding completely in 2 hr. In the other two, headaches vanished during the first 30 min following exposure.
- Carbon Monoxide exposure of 500 ppm. During the first exposure to 500 ppm of CO, there were reports of light-headedness after only 20 min of exposure. There were also reports of a slight increase in reaction time 2 hr post-exposure but no impairment of time estimation ability.

"About 25 years ago, a question arose about ventilation requirements during silent watch with the turret completely closed up for an M1 Tank. We determined, in two separate evals, a quick one by my team, and one more detailed …, that if you turn off the ventilation while stationary, it takes at least 6 hr for CO2 levels to get to where it might be a problem and O2 levels (apparently) never became a serious problem …. . Considering that the Soldiers have to operate systems in Silent Watch and they drain the battery within an hour, it became a moot point because Soldiers have to start the engine up to recharge the batteries. So, may as well turn on the ventilation while the engine is running" (Harrah, 2011). From this study conducted in 1988 (Glumm, 1988), the exact findings were:

- **Oxygen** (O2) depletion for M1 tank indicates 9 hr for O2 depletion at 0.09 L/min to be a problem.

- **Carbon Dioxide** (CO_2) buildup for M1 tank indicates 5 hr for CO_2 buildup at 0.3 L/min to be a problem.

2.1.3 Historical Review of Air Quality Issues on Selected Past U.S. Army Vehicles

The ventilation systems in the **Ml/MlAl** battle tank, M60 battle tank, and the **M2A2-M2A3** fighting vehicle were evaluated to determine their effectiveness as compared to ventilation requirements stated in MIL-STD-1472C (Allen et al., 1992):

- M1A1: ventilation system is only capable of meeting ventilator requirements of MIL-STD-1472F for ambient temperature of <90 °F with the 200 ft^3/min (CFM) bulk dump employed or when in motion with hatches open; over 90°, M1A1 cannot operate under any ventilation configuration to meet increased ventilator requirements.
- M1A1 and M1: adequate ventilation may be unachievable or may result from unacceptable overpressure if the leakage rate is reduced to 100 CFM at 1.5-in water gauge.

Problem area in the High Mobility Multipurpose Wheeled Vehicle-Heavy Variant (**HMMWV-HV**): Accumulating dust conditions and poor door seals. Description: Large quantities of dust enter the rear of the ambulances through the ventilation system and numerous vehicle gaskets and seals. Dust enters through ineffective seals at the rear door gaskets and the retractable stair gaskets. Dust comes in through the ventilation system when used to obtain outside fresh air (Krohn and Spiegel, 1990).

Problem area in the **Stryker** Infantry Carrier Vehicle (ICV) and seven configurations (Singapore, 2004):

- Data collected during the developmental test indicates that ventilation airflow is below the recommended guidelines of MIL-STD-1472F.
- Breathing Toxic Fumes: With the vehicle moving, engine fumes are directed at commander, when standing in the cupola. Breathing toxic fumes could be potential health hazard which would result in cognitive decrement without having other health symptoms.
- Chemical substance exposures to engine/APU exhaust.
- Chemical substance exposure resulting from TOW Missile motor propellant combustion products while firing from inside the MC-B.
- Inadequate ventilation for operation in high ambient temperature.

Problem area in the Heavy Equipment Transport System (**HETS**) (M1000 Semi-trailer and M1070 Truck Tractor) (Akens, 1993): Results indicate that when ambient temperatures exceed 90 °F, temperature inside HETS M1070 Cab exceeds 100 °F—markedly higher than recommended by MIL-STD-1472F.

Problem area in the **M1A2 Abrams Tank** (Singapore, 1994):

- The average temperature in M1A1 crew compartment was 102.4 °F (a possible ventilation issue) which is way above the effective temperature of 85 °F (96 °F ambient) maximum limit for reliable human performance.
- If condition is allowed to continue without providing increased cooling to the crew compartment, the crew will suffer from dehydration and performance decrements in the following tasks:
  - Tasks which require attention to detail (map plotting, coding or decoding, target identification).
  - Tasks which require arm-hand steadiness (aiming, tracking, shooting).
  - Tasks with sudden or sustained demands for physical or cognitive actions.

Command and Control Vehicle (C2V) (McMahon, 1996): In several instances during testing the mission module (MM) quickly filled with smoke when an electronic device failed. Smoke quickly rose to the ceiling and engulfed the breathing zones of all the MM crew. The hazard is the amount of CO, CO_2, and toxic byproducts from electrical installations.

Problem area in the **XM707 Fire Support Vehicle** (Singapore, 1998): There is a critical concern for heat stress to the crew (possible ventilation issue).

Problem area in the **Armored Security Vehicle (ASV)** (Singapore, 1999):

- Inadequate heating, ventilation and air-conditioning systems.
- Presence of toxic gases in the crew compartment from weapons firing and air intrusion from the engine compartment.
- Presence of diesel engine exhaust and weapon ammo combustion products in the crew compartment.
- Insufficient ventilation air supply for crew (oxygen deficiency).

Problem area in the **Bradley Fighting Vehicle Systems** A3 (BFVS A3) (Singapore, 2001):

- Heat stress and heat related performance degradation including reduced crew mental and physical fatigue (possible ventilation issue).
- The ventilation system on BFVS has a problem with removing combustion products from the crew spaces.

Problem area in the Stryker Nuclear, Biological, and Chemical Reconnaissance Vehicle (**NBCRV**) (Singapore, 2007): Exposure to oxygen deficiency (ventilation air). Test data indicates a total fresh air supply provided by the over-pressure system (OPS) of approximately

60 CFM; the MIL-STD-1472F requires 20CFM/person (total of 80 CFM for a four person crew) of fresh air.

Problem area in the Stryker Mobile Gun System (**MGS**) (Singapore, 2008): High interior vehicle temperature while operating in the buttoned-up condition (possible ventilation issue).

Problem area in the Joint Service Nuclear, Biological, and Chemical Reconnaissance System (**JSLNBCRS**) high-mobility multipurpose wheeled vehicle (HMMWV) variant (Webster et al., 2006): Improve the ECU reliability to operate in appropriate environmental conditions (such as high temperature, blowing sand, and rain).

2.2 Opinion of the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM).

The CHPPM conducted a health hazard assessment report (HHAR) in support of a Concept Decision Review (CDR) for the JLTV in 2007 (Gross, 2007). The purpose of this HHAR was " … intended to identify potential health hazards associated with JLTVs and recommend exposure controls to eliminate or control the hazards during System Development and Demonstration (SDD) with emphasis on elimination by design." Findings and recommendations pertaining to air quality and crew space ventilation included:

- Oxygen deficiency – ventilation (crew/passenger spaces): Paragraph 3.e.(1). "Ensure the design/operation of JLTV FOV cab/shelter ventilation system/environmental control units provides the required rate of fresh and recirculated air to cab/shelter occupants when operating in a buttoned-up mode IAW MIL-STD-1472F, paragraphs 5.8.1.2 and 5.12.6.2." Further, in paragraph 6.e.(1).a, "The JLTV FOVs crew/passenger compartments and occupied vehicle-mounted shelters will likely be operated buttoned up with the ventilation system operating to provide fresh and recirculated air for adequate breathing air, the elimination of toxic chemicals, and equipment cooling. General ventilation of occupied spaces also contributes to the comfort and efficiency of personnel and improved worker health since adequate ventilation helps to control odors, extreme temperature and humidity conditions, carbon dioxide buildup, and the spread of communicable diseases via contamination of airborne dust and droplets. Ventilation system performance/design criteria for mobile enclosures (e.g., shelters and buttoned up vehicle cabs) and traditional vehicles (e.g., roll up/down windows) are provided in MIL-STD-1472F, paragraph 5.8.1.2 and paragraph 5.12.6.2, respectively."
- Temperature extremes (operation in hot and cold climate conditions): Paragraph 3.g.(1). "Design the JLTV FOV (family of vehicles) mobile personnel enclosures/shelters and vehicle cab heating and air-conditioning systems to meet/exceed the performance /design criteria requirements contained in MIL-STD-1472F, paragraphs 5.8.1 and 5.12.6, respectively." Further, in paragraph 6.g.(1).a "Since the JLTV FOV will deploy worldwide anywhere Joint forces deploy to a variety of climatic conditions, it is very likely that

Soldiers will operate the vehicles and vehicle-mounted shelters in cold and hot climate temperature extremes. Army system specifications routinely require operation in basic and hot climatic design types (–25 degrees (°) Fahrenheit (F) to +120 °F) defined IAW AR 70-38. Recent experience has shown that Soldiers and their equipment are exposed to even lower and higher temperature extremes during deployments. Soldier exposures to excessive levels and duration of either heat or cold stress may cause vigilance and performance decrements, temporary or permanent injury, and death."

2.3 Opinion of the U.S. Army Public Health Command (PHC)

Considering the differences between the OSHA standard (U.S. DOL, 2010) and the ACGIH standard (ACGIH, 2011) '…the ACGIH recommendation would be preferable' (Braybrooke and Cambre, 2011b). This opinion also meets the requirements as stated in DA Pam 40-503 (U.S. Army, 2000) (Paragraph 1-8.b), which states that "The DA mandates the use of ACGIH TLVs when they are more stringent than OSHA regulations..." Thus, the ACGIH recommendation that "…airborne concentrations should be kept below 3 mg/m^3 respirable particles, and 10 mg/m^3 inhalable particles, until such time as a TLV is set for a particle substance." Therefore the following limits define the requirements for ventilation and airborne dust contaminants:

- 0.57 m^3 (20 ft^3)/min/person of fresh air.
- 3 mg/m^3 respirable particles limit.
- 10 mg/m^3 inhalable particles limit.

"For air quality concerns you need to provide a means to filter the air to eliminate potential toxic gases and particulate from entering the occupied space. The filtration systems, to be selected, will determine the size of the ventilation systems fan needed to meet the design and performance criteria recommended in MIL-STD-1472F para. 5.12.6.2" (Braybrooke and Cambre, 2011b; Kluchinsky, 2011).

In addition, "…exposures to … (airborne contaminants) in the workplace may cause serious and sometimes disabling effects. Further, good industrial hygiene and public health practice require that workplace exposures to particulates be maintained below the level associated with physical irritation, accidents, and respiratory effects." Further, "…OSHA finds that good industrial hygiene practice demands, and prudent public health policy supports, effective workplace control over exposure to all particulates. The effects associated with overexposure to particulates in the workplace constitute material impairments of health and functional capacity and include upper respiratory tract irritation, skin injury, eye irritation, and other forms of physical irritation."

"In the final rule, OSHA establishes an 8-hr TWA limit of 15 mg/m(3), measured as total particulate, and retains the 5-mg/m(3) limit for respirable particulates for all particulates not otherwise regulated. The Agency concludes <u>that these limits will protect workers against the</u>

significant safety and health risks associated with exposure to excessive concentrations of these substances, which include ***reduced visibility, deposits in the eyes, ears, and nasal passages, throat and eye irritation, upper-respiratory-tract problems, skin injury, and other forms of physical irritation***. The change in terminology from nuisance dusts to particulates not otherwise regulated clarifies OSHA's intent and also more accurately reflects the fact that exposure to all particulates at levels higher than those being established in this final rule causes material impairment of health and functional capacity in workers experiencing these exposures" (Braybrooke and Cambre, 2011b).

Additional comments:

"ACGIH (particulates not otherwise specified) has moved towards size-selective sampling for airborne particulate matter. This move is to help define the particle sizes most closely associated with health effects of concern. There is also considerable evidence to suggest that "total dust" sampling by conventional means underestimates the concentrations of "inhalable particles," or those particles that may be hazardous when deposited anywhere in the respiratory tract. Inhalable particles are also measured by specialized equipment, different from the "total dust" measurements."

"The ACGIH believes that even biologically inert, insoluble, or poorly soluble particles may have adverse effects and recommends that airborne concentrations of dusts be controlled to 10 mg/m^3 (inhalable fraction) and respirable particles (ACGIH/ISO/European Standard Committee defined as particles less than 4 micron in size) be kept below 3 mg/m^3. The ACGIH suggests that these limits be carefully applied to particles that do not have an applicable TLV, are insoluble or poorly soluble in water (or aqueous lung fluid) and have low toxicity (i.e., are not toxic to cells, not damaging to DNA, or otherwise chemically reactive with lung tissue, do not emit ionizing radiation, cause immune sensitization, or cause toxic effects either than by inflammation or the mechanism of "lung overload")" (Braybrooke and Cambre, 2011b).

3. Summary

The Department of Defense Instruction 6055.1 (U.S. DOD, 1998), paragraph E3.4.2.1, states that "The DOD Components shall apply OSHA and other non-DOD regulatory safety and health standards to military-unique equipment, systems, operations, or workplaces, in whole or in part, insofar as practicable." While DODI 6055.01 will replace DODI 6055.1 in the near future, it is in draft and the comments in current 6055.1 found in Enclosure 3 E3.4.2.1 still apply (Booze, 2011).

A current news item (McGarry and Capaccio, 2011) has reported that "A U.S. Senate panel decided today to end a potential $54 billion Joint Light Tactical Vehicles program for the Army and Marine Corps, citing "'excessive cost growth'." This report was echoed in consecutive *Defense News* reports (Brannen, 2011; Hoffman, 2011). Whether or not the JLTV program continues, the air quality and human performance considerations investigated in this report should be considered in the design of any military vehicle where conditions can exist where the crew is totally dependent on the vehicle ventilation system for adequate air quality.

Summarizing the findings in this report (Middlebrooks, 2011), the recommended regulatory requirements for allowable air quality as pertains to ventilation and airborne particulates are:

- 0.57 m^3 (20 ft^3)/min/person of fresh air.
- 3 mg/m^3 respirable particles limit.
- 10 mg/m^3 inhalable particles limit.

Despite this documented need, "… Currently there is no requirement for crew compartment air filtration (in the JLTV) because of a lack of CDD linkage. There is no requirement for allowable air quality or particulate composition for the same reason. In the course of the PD reviews-the argument advanced for incorporating an air filtration system in the crew compartment was rejected" (Munya, 2011b). This further rejected the proposal of the JLTV system safety engineer for a ventilation system in this vehicle (Munya, 2011c). In addition, the point was made that "…contractually from the PM viewpoint the only standards that have to be met are what went into the RFP" (Burns, 2011b). Also, "…they (the PMs) view the 'requirements' as being only those specifications in the Requirements Documents" (Fuller, 2011a). To summarize, "…PMs are still financially motivated NOT to pay for anything that costs money - if it is not mandatory" (Fuller, 2011b).

The JLTV Lead Evaluator notes that "…For JLTV, the potential short-term hazard is the effect on driver/crew visibility if there is sufficient dust on the INSIDE of the windshield/transparent armor that prevents them from seeing where they are going or being able to see areas around the vehicle' impacting their situational awareness. The potential long-term hazard (respirable dust particles) is much harder to quantify, but may be the more significant issue, and may have cumulative effects" (Stolarz, 2011a).

The JLTV Chief Engineer agrees that dust passing into the crew compartment through the ventilation system is a problem. His comments are: "…the HVAC passing dust into the crew cabin is a concern. Seems we should have a filtration requirement with a particle size per volume of air specified…" (Johnson, 2011). OSHA agrees that there are specific health risks associated with exposure to excessive concentrations of airborne contaminants which include "…reduced visibility, deposits in the eyes, ears, and nasal passages, throat and eye irritation, upper-respiratory-tract problems, skin injury, and other forms of physical irritation" (Braybrooke and Cambre, 2011b).

The ventilation and air quality issues described in this study may become moot regarding the JLTV program as the media (Bloomberg, DefenseNews) is reporting that “...the Senate Appropriations subcommittee on defense is recommending terminating the Joint Light Tactical Vehicle (JLTV)...” (Brannen, 2011; Hoffman, 2011; McGarry and Capaccio, 2011). However, regardless of the fate of the JLTV program, this issue is one that ATEC will be grappling with for some time. The JLTV may be terminated but the problem remains for other vehicles with similar situations of crew spaces that are totally enclosed for blast effects protection such as the MRAP and ground combat vehicle, so this study and resultant findings are very much in keeping with design considerations that should be considered in future vehicle development programs.

From a human factors standpoint the concerns raised in this study are a “ … safety (lack of visibility) as well as health issue…” (Sterling, 2011). The fundamental question thus comes down to “…whether Soldiers can function fully in lesser air quality and for what period of time (before performance degradation begins) and whether there may be implications for short or long term health issues” (Rice, 2011).

4. Preparing Activity

The Human Research and Engineering Directorate of the U.S. Army Research Laboratory conducted this study. The point of contact is Dr. Sam E. Middlebrooks, ARL-HRED Fort Hood Field Element, Fort Hood, TX, DSN 738-9379, commercial (254) 288-9379, or e-mail sam.e.middlebrooks.civ@mail.mil.

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Appendix A. Some of the Most Frequent Chemicals Seen During Weapons Testing

This appendix appears in its original form, without editorial change.

Comparison of Some of the Most Frequent Chemicals
Affecting Air Quality Seen During Weapons Testing
at the U.S. Army Public Health Command

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September 22, 2011

This table (Braybrooke and Cambre, 2011a) was compiled by the U.S. Army Public Health Command to provide an insight to airborne chemical contaminants that could be encountered on the battlefield.

Table 1- Frequently Occurring Chemicals Seen During Weapons Testing

Acknowledged by the Army as "Standard Criteria"					Non-Standard Criteria"
Compound	**OSHA PEL (ppm)**	**ACGIH TLV * (ppm)**	**Recommended Army Occ. Exp. Limits (ppm) [most conservative]**		**NIOSH-IDLH (ppm)**
Ammonia (NH_3)	PEL = 50	TWA = 25 STEL = 35	TWA = 25 STEL = 35		**IDLH = 300
Carbon Dioxide (CO_2) (above atmospheric)	PEL = 5000	TWA = 5000 STEL = 30,000	TWA = 5000 STEL = 30,000		**IDLH = 40,000
Carbon Monoxide (CO)	PEL = 50	TWA = 25 EL = 75	TWA = 25 EL = 75		**IDLH = 1200 ****Ceiling = 200
Nitric Oxide (NO)	PEL = 25	TWA = 25 *EL = 75	TWA = 25 *EL = 75		**IDLH = 100
Nitrogen Dioxide (NO_2)	Ceiling = 5	***TWA = 3 ***STEL = 5	***TWA = 3 ***STEL = 5		**IDLH = 20
Hydrogen Cyanide (HCN)	PEL = 10	TLV = NA STEL = NA Ceiling = 4.7	PEL = 10 Ceiling = 4.7		**IDLH = 50
Methane (CH_4)	PEL = NA	TWA = 1000	TWA = 1000		**IDLH = NA
Compound	**OSHA PEL Milligrams per cubic meter (mg/m^3)**	**ACGIH TLV * (mg/m^3)**	**Recommended Army Occ. Exp. Limits (mg/m^3) [most conservative]**		**NIOSH-/IDLH (mg/m^3)**
Lead (Pb) (particulate)	AL = 0.03 mg/m^3 PEL = 0.05 mg/m^3	TLV = 0.05 mg/m^3 *EL =0.15 mg/m^3	TLV = 0.05 mg/m^3 *EL =0.15 mg/m^3 **IDLH =100 mg/m^3		**IDLH =100 mg/m^3
Tungsten (W) (particulate)	PEL = NA	TLV = 5 mg/m^3 STEL = 10 mg/m^3	TLV = 5 mg/m^3 STEL = 10 mg/m^3		**IDLH = NA

Footnotes:
* Excursion Limit (EL)–Is used when no STEL is published. The ACGIH guidance states that the Excursion Limit "may exceed 3 times the TLV for no more than a total of 30 minutes during a work-day, and under no circumstance should they exceed 5 times the TLV, provided that the TLV is not exceeded"
**The NIOSH-IDLH are not acknowledged by the Army as "standard criteria" but listed here to indicate life threatening concentrations
***Notice of Intent change by ACGIH
**** From NIOSH
N/A – Not Applicable
OEL – occupational exposure limit
OSHA – Occupational and Safety Health Administration
ACGIH – American Council of Government Industrial Hygienists
NIOSH – National Institute of Occupational Safety and Health
PEL – Permissible Exposure Limit (OSHA-standard)
TWA – Time-Weighted Average (ACGIH-standard)
STEL – Short-Term Exposure Limit (ACGIH-standard)
EL – Excursion Limit
IDLH – Immediately Dangerous to Life and Health (NIOSH-standard)
AL – OSHA TWA Action Limit (OSHA-standard)

Appendix B. Table Z-1 From 29CFR2910.1000: Limits for Air Contaminants

This appendix appears in its original form, without editorial change.

This table (U.S.DOL, 2010) from the web site:

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

DOL OSHA

Regulations (Standards - 29 CFR) - Table of Contents

- Part Number: 1910
- Part Title: Occupational Safety and Health Standards
- Subpart: Z
- Subpart Title: Toxic and Hazardous Substances
- Standard Number: 1910.1000 TABLE Z-1
- Title: TABLE Z-1 Limits for Air Contaminants.

TABLE Z-1 LIMITS FOR AIR CONTAMINANTS

NOTE: Because of the length of the table, explanatory Footnotes applicable to all substances are given below as well as at the end of the table. Footnotes specific only to a limited number of substances are also shown within the table.

Footnote(1) The PELs are 8-hour TWAs unless otherwise noted; a (C) designation denotes a ceiling limit. They are to be determined from breathing-zone air samples.

Footnote(a) Parts of vapor or gas per million parts of contaminated air by volume at 25 degrees C and 760 torr.

Footnote(b) Milligrams of substance per cubic meter of air. When entry is in this column only, the value is exact; when listed with a ppm entry, it is approximate.

Footnote(c) The CAS number is for information only. Enforcement is based on the substance name. For an entry covering more than one metal compound measured as the metal, the CAS number for the metal is given - not CAS numbers for the individual compounds.

Footnote(d) The final benzene standard in 1910.1028 applies to all occupational exposures to benzene except in some circumstances the distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing, and the percentage exclusion for liquid mixtures; for the excepted subsegments, the benzene limits in Table Z-2 apply. See 1910.1028 for specific circumstances.

Footnote(e) This 8-hour TWA applies to respirable dust as measured by a vertical elutriator cotton dust sampler or equivalent instrument. The time-weighted average applies to the cotton waste processing operations of waste recycling (sorting, blending, cleaning and willowing) and garnetting. See also 1910.1043 for cotton dust limits applicable to other sectors.

Footnote(f) All inert or nuisance dusts, whether mineral, inorganic, or organic, not listed specifically by substance name are covered by the Particulates Not Otherwise Regulated (PNOR) limit which is the same as the inert or nuisance dust limit of Table Z-3.

Footnote(2) See Table Z-2.

Footnote(3) See Table Z-3.

Footnote(4) Varies with compound.

Footnote(5) See Table Z-2 for the exposure limits for any operations or sectors where the exposure limits in 1910.1026 are stayed or are otherwise not in effect.

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Acetaldehyde...........	75-07-0	200	360	
Acetic acid............	64-19-7	10	25	
Acetic anhydride.......	108-24-7	5	20	
Acetone................	67-64-1	1000	2400	
Acetonitrile...........	75-05-8	40	70	
2-Acetylaminofluorene; see 1910.1014........	53-96-3			
Acetylene dichloride; see 1,2-Dichloroethylene.				
Acetylene tetrabromide.	79-27-6	1	14	
Acrolein...............	107-02-8	0.1	0.25	
Acrylamide.............	79-06-1	....	0.3	X
Acrylonitrile; see 1910.1045........	107-13-1			
Aldrin.................	309-00-2	....	0.25	X
Allyl alcohol..........	107-18-6	2	5	X
Allyl chloride.........	107-05-1	1	3	
Allyl glycidyl ether... (AGE)................	106-92-3	(C)10	(C)45	
Allyl propyl disulfide.	2179-59-1	2	12	
alpha-Alumina..........	1344-28-1			
Total dust...........		....	15	
Respirable fraction..		....	5	
Aluminum Metal (as Al).	7429-90-5			
Total dust...........		....	15	
Respirable fraction..		....	5	
4-Aminodiphenyl; see 1910.1011........	92-67-1			
2-Aminoethanol; see Ethanolamine.....				
2-Aminopyridine........	504-29-0	0.5	2	
Ammonia................	7664-41-7	50	35	
Ammonium sulfamate.....	7773-06-0			
Total dust...........		....	15	
Respirable fraction..		....	5	
n-Amyl acetate.........	628-63-7	100	525	
sec-Amyl acetate.......	626-38-0	125	650	
Aniline and homologs...	62-53-3	5	19	X
Anisidine (o-,p-isomers).......	29191-52-4	....	0.5	X
Antimony and compounds				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
(as Sb).............	7440-36-0	....	0.5	
ANTU (alpha Naphthylthiourea)....	86-88-4	....	0.3	
Arsenic, inorganic compounds (as As); see 1910.1018........	7440-38-2			
Arsenic, organic compounds (as As)....	7440-38-2	....	0.5	
Arsine.................	7784-42-1	0.05	0.2	
Asbestos; see 1910.1001........	(4)			
Azinphos-methyl........	86-50-0	....	0.2	X
Barium, soluble compounds (as Ba)....	7440-39-3	....	0.5	
Barium sulfate.........	7727-43-7			
Total dust...........		....	15	
Respirable fraction..		....	5	
Benomyl................	17804-35-2			
Total dust...........		....	15	
Respirable fraction..		....	5	
Benzene; See 1910.1028. See Table Z-2 for the limits applicable in the operations or sectors excluded in 1910.1028(d)	71-43-2			
Benzidine; See 1910.1010........	92-87-5			
p-Benzoquinone; see Quinone.				
Benzo(a)pyrene; see Coal tar pitch volatiles............				
Benzoyl peroxide.......	94-36-0	....	5	
Benzyl chloride........	100-44-7	1	5	
Beryllium and beryllium compounds (as Be).............	7440-41-7		(2)	
Biphenyl; see Diphenyl.				
Bismuth telluride, Undoped.............	1304-82-1			

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Total dust...........		....	15	
Respirable fraction..		....	5	
Boron oxide............	1303-86-2			
Total dust...........		....	15	
Boron trifluoride......	7637-07-2	(C)1	(C)3	
Bromine................	7726-95-6	0.1	0.7	
Bromoform..............	75-25-2	0.5	5	X
Butadiene (1,3-Butadiene); See 29 CFR 1910.1051; 29 CFR 1910.19(1)....	106-99-0	1 ppm/5 ppm STEL		
Butanethiol; see Butyl mercaptan.				
2-Butanone (Methyl ethyl ketone)	78-93-3	200	590	
2-Butoxyethanol........	111-76-2	50	240	X
n-Butyl-acetate........	123-86-4	150	710	
sec-Butyl acetate......	105-46-4	200	950	
tert-Butyl-acetate.....	540-88-5	200	950	
n-Butyl alcohol........	71-36-3	100	300	
sec-Butyl alcohol......	78-92-2	150	450	
tert-Butyl alcohol.....	75-65-0	100	300	
Butylamine.............	109-73-9	(C)5	(C)15	X
tert-Butyl chromate (as CrO(3))......... see 1910.1026	1189-85-1			
n-Butyl glycidyl ether (BGE)................	2426-08-6	50	270	
Butyl mercaptan........	109-79-5	10	35	
p-tert-Butyltoluene....	98-51-1	10	60	
Cadmium (as Cd); see 1910.1027........	7440-43-9			
Calcium Carbonate......	1317-65-3			
Total dust...........		....	15	
Respirable fraction..		....	5	
Calcium hydroxide......	1305-62-0			
Total dust...........		....	15	
Respirable fraction..		....	5	
Calcium oxide..........	1305-78-8	....	5	
Calcium silicate.......	1344-95-2			
Total dust...........		....	15	
Respirable fraction..		....	5	

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Calcium sulfate........	7778-18-9			
Total dust...........		....	15	
Respirable fraction..		....	5	
Camphor, synthetic.....	76-22-2	....	2	
Carbaryl (Sevin).......	63-25-2	....	5	
Carbon black...........	1333-86-4	....	3.5	
Carbon dioxide.........	124-38-9	5000	9000	
Carbon disulfide.......	75-15-0		(2)	
Carbon monoxide........	630-08-0	50	55	
Carbon tetrachloride...	56-23-5		(2)	
Cellulose..............	9004-34-6			
Total dust...........		....	15	
Respirable fraction..		....	5	
Chlordane..............	57-74-9	....	0.5	X
Chlorinated camphene...	8001-35-2	....	0.5	X
Chlorinated diphenyl oxide................	55720-99-5	....	0.5	
Chlorine...............	7782-50-5	(C)1	(C)3	
Chlorine dioxide.......	10049-04-4	0.1	0.3	
Chlorine trifluoride...	7790-91-2	(C)0.1	(C)0.4	
Chloroacetaldehyde.....	107-20-0	(C)1	(C)3	
a-Chloroacetophenone (Phenacyl chloride)..	532-27-4	0.05	0.3	
Chlorobenzene..........	108-90-7	75	350	
o-Chlorobenzylidene malononitrile........	2698-41-1	0.05	0.4	
Chlorobromomethane.....	74-97-5	200	1050	
2-Chloro-1,3-butadiene; See beta-Chloroprene.				
Chlorodiphenyl (42% Chlorine)(PCB)..	53469-21-9	....	1	X
Chlorodiphenyl (54% Chlorine)(PCB)..	11097-69-1	....	0.5	X
1-Chloro-2, 3-epoxypropane; See Epichlorohydrin.				
2-Chloroethanol; See Ethylene chlorohydrin				
Chloroethylene; See Vinyl chloride.				
Chloroform (Trichloromethane)...	67-66-3	(C)50	(C)240	

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
bis(Chloromethyl) ether; see 1910.1008.	542-88-1			
Chloromethyl methyl ether; see 1910.1006.	107-30-2			
1-Chloro-1-nitropropane	600-25-9	20	100	
Chloropicrin...........	76-06-2	0.1	0.7	
beta-Chloroprene.......	126-99-8	25	90	X
2-Chloro-6 (trichloromethyl) pyridine............	1929-82-4			
Total dust...........		....	15	
Respirable fraction..		....	5	
Chromic acid and chromates (as CrO(3))	(4)		(2)	
Chromium (II) compounds (as Cr).............	7440-47-3	....	0.5	
Chromium (III) compounds (as Cr)....	7440-47-3	....	0.5	
Chromium (VI) compounds See 1910.1026(5)				
Chromium metal and insol. salts (as Cr).	7440-47-3	....	1	
Chrysene; see Coal tar pitch volatiles......				
Clopidol..............	2971-90-6			
Total dust...........		....	15	
Respirable fraction..		....	5	
Coal dust (less than 5% SiO(2)), respirable fraction..			(3)	
Coal dust (greater than or equal to 5% SiO(2)), respirable fraction............			(3)	
Coal tar pitch volatiles (benzene soluble fraction), anthracene, BaP, phenanthrene, acridine, chrysene, pyrene..............	65966-93-2	....	0.2	
Cobalt metal, dust,				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
and fume (as Co).....	7440-48-4	....	0.1	
Coke oven emissions; see 1910.1029........				
Copper.................	7440-50-8			
Fume (as Cu).........		....	0.1	
Dusts and mists (as Cu).............		....	1	
Cotton dust (e), see 1910.1043........		....	1	
Crag herbicide (Sesone)	136-78-7			
Total dust...........		....	15	
Respirable fraction..		....	5	
Cresol, all isomers....	1319-77-3	5	22	X
Crotonaldehyde.........	123-73-9	2	6	
	4170-30-3			
Cumene.................	98-82-8	50	245	X
Cyanides (as CN).....	(4)	....	5	X
Cyclohexane............	110-82-7	300	1050	
Cyclohexanol...........	108-93-0	50	200	
Cyclohexanone..........	108-94-1	50	200	
Cyclohexene............	110-83-8	300	1015	
Cyclopentadiene........	542-92-7	75	200	
2,4-D (Dichlorophen- oxyacetic acid)......	94-75-7	....	10	
Decaborane.............	17702-41-9	0.05	0.3	X
Demeton (Systox).......	8065-48-3	....	0.1	X
Diacetone alcohol (4-Hydroxy-4-methyl- 2-pentanone).........	123-42-2	50	240	
1,2-Diaminoethane; see Ethylenediamine..				
Diazomethane...........	334-88-3	0.2	0.4	
Diborane...............	19287-45-7	0.1	0.1	
1,2-Dibromo-3- chloropropane (DBCP); see 1910.1044........	96-12-8			
1,2-Dibromoethane; see Ethylene dibromide...				
Dibutyl phosphate......	107-66-4	1	5	
Dibutyl phthalate......	84-74-2	....	5	
o-Dichlorobenzene......	95-50-1	(C)50	(C)300	
p-Dichlorobenzene......	106-46-7	75	450	

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
3,3'-Dichlorobenzidine; see 1910.1007........	91-94-1			
Dichlorodifluoromethane	75-71-8	1000	4950	
1,3-Dichloro-5, 5-dimethyl hydantoin.	118-52-5	....	0.2	
Dichlorodiphenyltri- chloroethane (DDT)...	50-29-3	....	1	X
1,1-Dichloroethane.....	75-34-3	100	400	
1,2-Dichloroethane; see Ethylene dichloride..				
1,2-Dichloroethylene...	540-59-0	200	790	
Dichloroethyl ether....	111-44-4	(C)15	(C)90	X
Dichloromethane; see Methylene chloride...				
Dichloromonofluoro- methane.............	75-43-4	1000	4200	
1,1-Dichloro-1- nitroethane..........	594-72-9	(C)10	(C)60	
1,2-Dichloropropane; see Propylene dichloride.				
Dichlorotetrafluoro- ethane..............	76-14-2	1000	7000	
Dichlorvos (DDVP)......	62-73-7	....	1	X
Dicyclopentadienyl iron	102-54-5			
Total dust...........		....	15	
Respirable fraction..		....	5	
Dieldrin...............	60-57-1	....	0.25	X
Diethylamine...........	109-89-7	25	75	
2-Diethylaminoethanol..	100-37-8	10	50	X
Diethyl ether; see Ethyl ether......				
Difluorodibromomethane.	75-61-6	100	860	
Diglycidyl ether (DGE).	2238-07-5	(C)0.5	(C)2.8	
Dihydroxybenzene; see Hydroquinone.....				
Diisobutyl ketone......	108-83-8	50	290	
Diisopropylamine.......	108-18-9	5	20	X
4-Dimethylaminoazo- benzene; see 1910.1015........	60-11-7			
Dimethoxymethane;				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
see Methylal.........				
Dimethyl acetamide.....	127-19-5	10	35	X
Dimethylamine..........	124-40-3	10	18	
Dimethylaminobenzene; see Xylidine.........				
Dimethylaniline (N,N-Dimethylaniline)	121-69-7	5	25	X
Dimethylbenzene; see Xylene...........				
Dimethyl-1,2-dibromo-2, 2-dichloroethyl phosphate............	300-76-5	....	3	
Dimethylformamide......	68-12-2	10	30	X
2,6-Dimethyl-4-heptanone; see Diisobutyl ketone....				
1,1-Dimethylhydrazine..	57-14-7	0.5	1	X
Dimethylphthalate......	131-11-3	....	5	
Dimethyl sulfate.......	77-78-1	1	5	X
Dinitrobenzene				
(all isomers)........			1	X
(ortho)..............	528-29-0			
(meta)...............	99-65-0			
(para)...............	100-25-4			
Dinitro-o-cresol.......	534-52-1	....	0.2	X
Dinitrotoluene.........	25321-14-6	....	1.5	X
Dioxane (Diethylene dioxide).	123-91-1	100	360	X
Diphenyl (Biphenyl)....	92-52-4	0.2	1	
Diphenylmethane diisocyanate; see Methylene bisphenyl isocyanate...........				
Dipropylene glycol methyl ether.........	34590-94-8	100	600	X
Di-sec octyl phthalate (Di-(2-ethylhexyl) phthalate)...........	117-81-7	....	5	
Emery..................	12415-34-8			
Total dust...........		....	15	
Respirable fraction..		....	5	
Endrin.................	72-20-8	....	0.1	X

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Epichlorohydrin........	106-89-8	5	19	X
EPN....................	2104-64-5	....	0.5	X
1,2-Epoxypropane; see Propylene oxide......				
2,3-Epoxy-1-propanol; see Glycidol.........				
Ethanethiol; see Ethyl mercaptan......				
Ethanolamine...........	141-43-5	3	6	
2-Ethoxyethanol (Cellosolve).........	110-80-5	200	740	X
2-Ethoxyethyl acetate (Cellosolve acetate).	111-15-9	100	540	X
Ethyl acetate..........	141-78-6	400	1400	
Ethyl acrylate.........	140-88-5	25	100	X
Ethyl alcohol (Ethanol)	64-17-5	1000	1900	
Ethylamine.............	75-04-7	10	18	
Ethyl amyl ketone (5-Methyl-3-heptanone)...........	541-85-5	25	130	
Ethyl benzene..........	100-41-4	100	435	
Ethyl bromide..........	74-96-4	200	890	
Ethyl butyl ketone (3-Heptanone)........	106-35-4	50	230	
Ethyl chloride.........	75-00-3	1000	2600	
Ethyl ether............	60-29-7	400	1200	
Ethyl formate..........	109-94-4	100	300	
Ethyl mercaptan........	75-08-1	(C)10	(C)25	
Ethyl silicate.........	78-10-4	100	850	
Ethylene chlorohydrin..	107-07-3	5	16	X
Ethylenediamine........	107-15-3	10	25	
Ethylene dibromide.....	106-93-4		(2)	
Ethylene dichloride (1,2-Dichloroethane).	107-06-2		(2)	
Ethylene glycol dinitrate............	628-96-6	(C)0.2	(C)1	X
Ethylene glycol methyl acetate; see Methyl cellosolve acetate...				
Ethyleneimine; see 1910.1012........	151-56-4			
Ethylene oxide;				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
see 1910.1047........	75-21-8			
Ethylidene chloride;				
see 1,1-Dichlorethane				
N-Ethylmorpholine......	100-74-3	20	94	X
Ferbam.................	14484-64-1			
Total dust...........		....	15	
Ferrovanadium dust.....	12604-58-9	....	1	
Fluorides (as F).......	(4)	....	2.5	
Fluorine...............	7782-41-4	0.1	0.2	
Fluorotrichloromethane				
(Trichloro-				
fluoromethane).......	75-69-4	1000	5600	
Formaldehyde;				
see 1910.1048........	50-00-0			
Formic acid............	64-18-6	5	9	
Furfural...............	98-01-1	5	20	X
Furfuryl alcohol.......	98-00-0	50	200	
Grain dust (oat, wheat				
barley)..............	....	....	10	
Glycerin (mist)........	56-81-5			
Total dust...........		....	15	
Respirable fraction..		....	5	
Glycidol...............	556-52-5	50	150	
Glycol monoethyl ether;				
see 2-Ethoxyethanol..				
Graphite, natural				
respirable dust......	7782-42-5		(3)	
Graphite, synthetic....				
Total dust...........		....	15	
Respirable Fraction..		....	5	
Guthion;				
see Azinphos methyl..				
Gypsum.................	13397-24-5			
Total dust...........		....	15	
Respirable fraction..		....	5	
Hafnium................	7440-58-6	....	0.5	
Heptachlor.............	76-44-8	....	0.5	X
Heptane (n-Heptane)....	142-82-5	500	2000	
Hexachloroethane.......	67-72-1	1	10	X
Hexachloronaphthalene..	1335-87-1	....	0.2	X
n-Hexane...............	110-54-3	500	1800	
2-Hexanone (Methyl				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
n-butyl ketone)......	591-78-6	100	410	
Hexone (Methyl isobutyl ketone).....	108-10-1	100	410	
sec-Hexyl acetate......	108-84-9	50	300	
Hydrazine.............	302-01-2	1	1.3	X
Hydrogen bromide.......	10035-10-6	3	10	
Hydrogen chloride......	7647-01-0	(C)5	(C)7	
Hydrogen cyanide.......	74-90-8	10	11	X
Hydrogen fluoride (as F)...............	7664-39-3		(2)	
Hydrogen peroxide......	7722-84-1	1	1.4	
Hydrogen selenide (as Se)..............	7783-07-5	0.05	0.2	
Hydrogen sulfide.......	7783-06-4		(2)	
Hydroquinone...........	123-31-9	....	2	
Iodine.................	7553-56-2	(C)0.1	(C)1	
Iron oxide fume........	1309-37-1	....	10	
Isomyl acetate.........	123-92-2	100	525	
Isomyl alcohol (primary and secondary)...........	123-51-3	100	360	
Isobutyl acetate.......	110-19-0	150	700	
Isobutyl alcohol.......	78-83-1	100	300	
Isophorone.............	78-59-1	25	140	
Isopropyl acetate......	108-21-4	250	950	
Isopropyl alcohol......	67-63-0	400	980	
Isopropylamine.........	75-31-0	5	12	
Isopropyl ether........	108-20-3	500	2100	
Isopropyl glycidyl ether (IGE)..........	4016-14-2	50	240	
Kaolin.................	1332-58-7			
Total dust...........		....	15	
Respirable fraction..		....	5	
Ketene.................	463-51-4	0.5	0.9	
Lead inorganic (as Pb); see 1910.1025........	7439-92-1			
Limestone..............	1317-65-3			
Total dust...........		....	15	
Respirable fraction..		....	5	
Lindane................	58-89-9	....	0.5	X
Lithium hydride........	7580-67-8	....	0.025	
L.P.G. (Liquified				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
petroleum gas).......	68476-85-7	1000	1800	
Magnesite.............	546-93-0			
Total dust...........		....	15	
Respirable fraction..		....	5	
Magnesium oxide fume...	1309-48-4			
Total Particulate....		....	15	
Malathion.............	121-75-5			
Total dust...........		....	15	X
Maleic anhydride.......	108-31-6	0.25	1	
Manganese compounds (as Mn).............	7439-96-5	....	(C)5	
Manganese fume (as Mn)..	7439-96-5	....	(C)5	
Marble.................	1317-65-3			
Total dust...........		....	15	
Respirable fraction..		....	5	
Mercury (aryl and inorganic)(as Hg)....	7439-97-6		(2)	
Mercury (organo) alkyl compounds (as Hg)....	7439-97-6		(2)	
Mercury (vapor) (as Hg)	7439-97-6		(2)	
Mesityl oxide..........	141-79-7	25	100	
Methanethiol; see Methyl mercaptan.				
Methoxychlor...........	72-43-5			
Total dust...........		....	15	
2-Methoxyethanol; (Methyl cellosolve)..	109-86-4	25	80	X
2-Methoxyethyl acetate (Methyl cellosolve acetate)............	110-49-6	25	120	X
Methyl acetate.........	79-20-9	200	610	
Methyl acetylene (Propyne)............	74-99-7	1000	1650	
Methyl acetylene propadiene mixture (MAPP)..............		1000	1800	
Methyl acrylate........	96-33-3	10	35	X
Methylal (Dimethoxy-methane)..	109-87-5	1000	3100	
Methyl alcohol.........	67-56-1	200	260	
Methylamine............	74-89-5	10	12	
Methyl amyl alcohol;				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
see Methyl Isobutyl carbinol............				
Methyl n-amyl ketone...	110-43-0	100	465	
Methyl bromide.........	74-83-9	(C)20	(C)80	X
Methyl butyl ketone; see 2-Hexanone.......				
Methyl cellosolve; see 2-Methoxyethanol.				
Methyl cellosolve acetate; see 2-Methoxyethyl acetate..............				
Methyl chloride........	74-87-3		(2)	
Methyl chloroform (1,1,1-Trichloro-ethane)..............	71-55-6	350	1900	
Methylcyclohexane......	108-87-2	500	2000	
Methylcyclohexanol.....	25639-42-3	100	470	
o-Methylcyclohexanone..	583-60-8	100	460	X
Methylene chloride.....	75-09-2		(2)	
Methyl ethyl ketone (MEK); see 2-Butanone				
Methyl formate.........	107-31-3	100	250	
Methyl hydrazine (Monomethyl hydrazine)...........	60-34-4	(C)0.2	(C)0.35	X
Methyl iodide..........	74-88-4	5	28	X
Methyl isoamyl ketone..	110-12-3	100	475	
Methyl isobutyl carbinol............	108-11-2	25	100	X
Methyl isobutyl ketone; see Hexone...........				
Methyl isocyanate......	624-83-9	0.02	0.05	X
Methyl mercaptan.......	74-93-1	(C)10	(C)20	
Methyl methacrylate....	80-62-6	100	410	
Methyl propyl ketone; see 2-Pentanone......				
alpha-Methyl styrene...	98-83-9	(C)100	(C)480	
Methylene bisphenyl isocyanate (MDI).....	101-68-8	(C)0.02	(C)0.2	
Mica; see Silicates....				
Molybdenum (as Mo).....	7439-98-7			

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Soluble compounds....		....	5	
Insoluble Compounds				
Total dust.........		....	15	
Monomethyl aniline.....	100-61-8	2	9	X
Monomethyl hydrazine; see Methyl hydrazine.				
Morpholine............	110-91-8	20	70	X
Naphtha (Coal tar).....	8030-30-6	100	400	
Naphthalene...........	91-20-3	10	50	
alpha-Naphthylamine; see 1910.1004........	134-32-7			
beta-Naphthylamine; see 1910.1009........	91-59-8			
Nickel carbonyl (as Ni)	13463-39-3	0.001	0.007	
Nickel, metal and insoluble compounds (as Ni).............	7440-02-0	....	1	
Nickel, soluble compounds (as Ni)....	7440-02-0	....	1	
Nicotine..............	54-11-5	....	0.5	X
Nitric acid...........	7697-37-2	2	5	
Nitric oxide..........	10102-43-9	25	30	
p-Nitroaniline........	100-01-6	1	6	X
Nitrobenzene..........	98-95-3	1	5	X
p-Nitrochlorobenzene...	100-00-5	....	1	X
4-Nitrodiphenyl; see 1910.1003........	92-93-3			
Nitroethane...........	79-24-3	100	310	
Nitrogen dioxide.......	10102-44-0	(C)5	(C)9	
Nitrogen trifluoride...	7783-54-2	10	29	
Nitroglycerin.........	55-63-0	(C)0.2	(C)2	X
Nitromethane..........	75-52-5	100	250	
1-Nitropropane.........	108-03-2	25	90	
2-Nitropropane.........	79-46-9	25	90	
N-Nitrosodimethylamine; see 1910.1016				
Nitrotoluene (all isomers)........		5	30	X
o-isomer............	88-72-2			
m-isomer............	99-08-1			
p-isomer............	99-99-0			
Nitrotrichloromethane;				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
see Chloropicrin.....				
Octachloronaphthalene..	2234-13-1	....	0.1	X
Octane.................	111-65-9	500	2350	
Oil mist, mineral......	8012-95-1	....	5	
Osmium tetroxide (as Os).............	20816-12-0	....	0.002	
Oxalic acid............	144-62-7	....	1	
Oxygen difluoride......	7783-41-7	0.05	0.1	
Ozone..................	10028-15-6	0.1	0.2	
Paraquat, respirable dust.................	4685-14-7	....	0.5	X
	1910-42-5			
	2074-50-2			
Parathion..............	56-38-2	....	0.1	X
Particulates not otherwise regulated (PNOR)(f)............				
Total dust...........		....	15	
Respirable fraction..		....	5	
PCB; see Chlorodiphenyl (42% and 54% chlorine)............				
Pentaborane............	19624-22-7	0.005	0.01	
Pentachloronaphthalene.	1321-64-8	....	0.5	X
Pentachlorophenol......	87-86-5	....	0.5	X
Pentaerythritol........	115-77-5			
Total dust...........		....	15	
Respirable fraction..		....	5	
Pentane................	109-66-0	1000	2950	
2-Pentanone (Methyl propyl ketone).......	107-87-9	200	700	
Perchloroethylene (Tetrachloroethylene)	127-18-4		(2)	
Perchloromethyl mercaptan............	594-42-3	0.1	0.8	
Perchloryl fluoride....	7616-94-6	3	13.5	
Petroleum distillates (Naphtha)(Rubber Solvent)............		500	2000	
Phenol.................	108-95-2	5	19	X
p-Phenylene diamine....	106-50-3	....	0.1	X
Phenyl ether, vapor....	101-84-8	1	7	

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Phenyl ether-biphenyl mixture, vapor.......		1	7	
Phenylethylene; see Styrene..........				
Phenyl glycidyl ether (PGE)................	122-60-1	10	60	
Phenylhydrazine........	100-63-0	5	22	X
Phosdrin (Mevinphos)...	7786-34-7	....	0.1	X
Phosgene (Carbonyl chloride)............	75-44-5	0.1	0.4	
Phosphine.............	7803-51-2	0.3	0.4	
Phosphoric acid........	7664-38-2	....	1	
Phosphorus (yellow)....	7723-14-0	....	0.1	
Phosphorus pentachloride........	10026-13-8	....	1	
Phosphorus pentasulfide	1314-80-3	....	1	
Phosphorus trichloride.	7719-12-2	0.5	3	
Phthalic anhydride.....	85-44-9	2	12	
Picloram..............	1918-02-1			
Total dust...........		....	15	
Respirable fraction..		....	5	
Picric acid...........	88-89-1	....	0.1	X
Pindone (2-Pivalyl-1, 3-indandione)........	83-26-1	....	0.1	
Plaster of paris.......	26499-65-0			
Total dust...........		....	15	
Respirable fraction..		....	5	
Platinum (as Pt).......	7440-06-4			
Metal................		....	....	
Soluble Salts........		....	0.002	
Portland cement........	65997-15-1			
Total dust...........		....	15	
Respirable fraction..		....	5	
Propane................	74-98-6	1000	1800	
beta-Propriolactone; see 1910.1013........	57-57-8			
n-Propyl acetate.......	109-60-4	200	840	
n-Propyl alcohol.......	71-23-8	200	500	
n-Propyl nitrate.......	627-13-4	25	110	
Propylene dichloride...	78-87-5	75	350	
Propylene imine........	75-55-8	2	5	X
Propylene oxide........	75-56-9	100	240	

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Propyne; see Methyl acetylene...........				
Pyrethrum.............	8003-34-7	....	5	
Pyridine..............	110-86-1	5	15	
Quinone...............	106-51-4	0.1	0.4	
RDX: see Cyclonite.....				
Rhodium (as Rh), metal fume and insoluble compounds...........	7440-16-6	....	0.1	
Rhodium (as Rh), soluble compounds....	7440-16-6	....	0.001	
Ronnel................	299-84-3	....	15	
Rotenone..............	83-79-4	....	5	
Rouge.................				
Total dust...........		....	15	
Respirable fraction..		....	5	
Selenium compounds (as Se).............	7782-49-2	....	0.2	
Selenium hexafluoride (as Se).............	7783-79-1	0.05	0.4	
Silica, amorphous, precipitated and gel.	112926-00-8		(3)	
Silica, amorphous, diatomaceous earth, containing less than 1% crystalline silica	61790-53-2		(3)	
Silica, crystalline cristobalite, respirable dust......	14464-46-1		(3)	
Silica, crystalline quartz, respirable dust.................	14808-60-7		(3)	
Silica, crystalline tripoli (as quartz), respirable dust......	1317-95-9		(3)	
Silica, crystalline tridymite, respirable dust......	15468-32-3		(3)	
Silica, fused, respirable dust......	60676-86-0		(3)	
Silicates (less than 1% crystalline silica)				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Mica (respirable dust)................	12001-26-2		(3)	
Soapstone, total dust	....		(3)	
Soapstone, respirable dust.................	....		(3)	
Talc (containing asbestos): use asbestos limit: see 29 CFR 1910.1001.....			(3)	
Talc (containing no asbestos), respirable dust......	14807-96-6		(3)	
Tremolite, asbestiform; see 1910.1001...........				
Silicon................	7440-21-3			
Total dust...........		....	15	
Respirable fraction..		....	5	
Silicon carbide........	409-21-2			
Total dust...........		....	15	
Respirable fraction..		....	5	
Silver, metal and soluble compounds (as Ag).............	7440-22-4	....	0.01	
Soapstone; see Silicates........				
Sodium fluoroacetate...	62-74-8	....	0.05	X
Sodium hydroxide.......	1310-73-2	....	2	
Starch.................	9005-25-8			
Total dust...........		....	15	
Respirable fraction..		....	5	
Stibine................	7803-52-3	0.1	0.5	
Stoddard solvent.......	8052-41-3	500	2900	
Strychnine.............	57-24-9	....	0.15	
Styrene................	100-42-5		(2)	
Sucrose................	57-50-1			
Total dust...........		....	15	
Respirable fraction..		....	5	
Sulfur dioxide.........	7446-09-5	5	13	
Sulfur hexafluoride....	2551-62-4	1000	6000	
Sulfuric acid..........	7664-93-9	....	1	
Sulfur monochloride....	10025-67-9	1	6	

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
Sulfur pentafluoride...	5714-22-7	0.025	0.25	
Sulfuryl fluoride......	2699-79-8	5	20	
Systox; see Demeton...				
2,4,5-T (2,4,5-trichlorophenoxyacetic acid)...............	93-76-5	....	10	
Talc; see Silicates...				
Tantalum, metal and oxide dust...........	7440-25-7	....	5	
TEDP (Sulfotep)........	3689-24-5	....	0.2	X
Tellurium and compounds (as Te)....	13494-80-9	....	0.1	
Tellurium hexafluoride (as Te).............	7783-80-4	0.02	0.2	
Temephos...............	3383-96-8			
Total dust...........		....	15	
Respirable fraction..		....	5	
TEPP (Tetraethyl pyrophosphaate)......	107-49-3	....	0.05	X
Terphenylis............	26140-60-3	(C)1	(C)9	
1,1,1,2-Tetrachloro-2, 2-difluoroethane.....	76-11-9	500	4170	
1,1,2,2-Tetrachloro-1, 2-difluoroethane.....	76-12-0	500	4170	
1,1,2,2-Tetrachloro-ethane..............	79-34-5	5	35	X
Tetrachoroethylene; see Perchloroethylene				
Tetrachloromethane; see Carbon tetrachloride.				
Tetrachloronaphthalene.	1335-88-2	....	2	X
Tetraethyl lead (as Pb)	78-00-2	....	0.075	X
Tetrahydrofuran........	109-99-9	200	590	
Tetramethyl lead, (as Pb).............	75-74-1	....	0.075	X
Tetramethyl succinonitrile.......	3333-52-6	0.5	3	X
Tetranitromethane......	509-14-8	1	8	
Tetryl (2,4,6-Trinitro-phenylmethyl-nitramine)...........	479-45-8	....	1.5	X
Thallium, soluble				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
compounds (as Tl)....	7440-28-0	....	0.1	X
4,4'-Thiobis(6-tert, Butyl-m-cresol)......	96-69-5			
Total dust...........		....	15	
Respirable fraction..		....	5	
Thiram................	137-26-8	....	5	
Tin, inorganic compounds (except oxides) (as Sn)......	7440-31-5	....	2	
Tin, organic compounds (as Sn).............	7440-31-5	....	0.1	
Titanium dioxide.......	13463-67-7			
Total dust...........		....	15	
Toluene................	108-88-3		(2)	
Toluene-2, 4-diisocyanate (TDI).	584-84-9	(C)0.02	(C)0.14	
o-Toluidine............	95-53-4	5	22	X
Toxaphene; see Chlorinated camphene.				
Tremolite; see Silicates........				
Tributyl phosphate.....	126-73-8	....	5	
1,1,1-Trichloroethane; see Methyl chloroform				
1,1,2-Trichloroethane..	79-00-5	10	45	X
Trichloroethylene......	79-01-6		(2)	
Trichloromethane; see Chloroform				
Trichloronaphthalene...	1321-65-9	....	5	X
1,2,3-Trichloropropane.	96-18-4	50	300	
1,1,2-Trichloro-1,2, 2-trifluoroethane....	76-13-1	1000	7600	
Triethylamine..........	121-44-8	25	100	
Trifluorobromomethane..	75-63-8	1000	6100	
2,4,6-Trinitrophenol; see Picric acid......				
2,4,6-Trinitrophenyl- methyl nitramine; see Tetryl..........				
2,4,6-Trinitrotoluene (TNT)...............	118-96-7	....	1.5	X
Triorthocresyl				

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS (continued)

Substance	CAS No. (c)	ppm (a)(1)	mg/m(3) (b)(1)	Skin designation
phosphate............	78-30-8	....	0.1	
Triphenyl phosphate....	115-86-6	....	3	
Turpentine.............	8006-64-2	100	560	
Uranium (as U).........	7440-61-1			
Soluble compounds....		....	0.05	
Insoluble compounds..		....	0.25	
Vanadium...............	1314-62-1			
Respirable dust				
(as V2O5))...........		....	(C)0.5	
Fume (as V2O5).......		....	(C)0.1	
Vegetable oil mist.....				
Total dust...........		....	15	
Respirable fraction..		....	5	
Vinyl benzene;				
see Styrene..........				
Vinyl chloride;				
see 1910.1017........	75-01-4			
Vinyl cyanide;				
see Acrylonitrile				
Vinyl toluene..........	25013-15-4	100	480	
Warfarin...............	81-81-2	....	0.1	
Xylenes				
(o-, m-, p-isomers)..	1330-20-7	100	435	
Xylidine...............	1300-73-8	5	25	X
Yttrium................	7440-65-5	....	1	
Zinc chloride fume.....	7646-85-7	....	1	
Zinc oxide fume........	1314-13-2	....	5	
Zinc oxide.............	1314-13-2			
Total dust...........		....	15	
Respirable fraction..		....	5	
Zinc stearate..........	557-05-1			
Total dust...........		....	15	
Respirable fraction..		....	5	
Zirconium compounds				
(as Zr)..............	7440-67-7	....	5	

* Footnote(1) The PELs are 8-hour TWAs unless otherwise noted; a (C) designation denotes a ceiling limit. They are to be determined from breathing-zone air samples.

Footnote(a) Parts of vapor or gas per million parts of contaminated air by volume at 25 degrees C and 760 torr.

Footnote(b) Milligrams of substance per cubic meter of air. When entry is in this column only, the value is exact; when listed with a ppm entry, it is approximate.

Footnote(c) The CAS number is for information only. Enforcement is based on the substance name. For an entry covering more than one metal compound measured as the metal, the CAS number for the metal is given - not CAS numbers for the individual compounds.

Footnote(d) The final benzene standard in 1910.1028 applies to all occupational exposures to benzene except in some circumstances the distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing, and the percentage exclusion for liquid mixtures; for the excepted subsegments, the benzene limits in Table Z-2 apply. See 1910.1028 for specific circumstances.

Footnote(e) This 8-hour TWA applies to respirable dust as measured by a vertical elutriator cotton dust sampler or equivalent instrument. The time-weighted average applies to the cotton waste processing operations of waste recycling (sorting, blending, cleaning and willowing) and garnetting. See also 1910.1043 for cotton dust limits applicable to other sectors.

Footnote(f) All inert or nuisance dusts, whether mineral, inorganic, or organic, not listed specifically by substance name are covered by the Particulates Not Otherwise Regulated (PNOR) limit which is the same as the inert or nuisance dust limit of Table Z-3.

Footnote(2) See Table Z-2.

Footnote(3) See Table Z-3

Footnote(4) Varies with compound.

Footnote(5) See Table Z-2 for the exposure limits for any operations or sectors where the exposure limits in 1910.1026 are stayed or are otherwise not in effect.

[54 FR 36767, Sept. 5, 1989; 54 FR 41244, Oct. 6, 1989; 55 FR 3724, Feb. 5, 1990; 55 FR 12819, Apr 6, 1990; 55 FR 19259, May 9, 1990; 55 FR 46950, Nov. 8, 1990; 57 FR 29204, July 1, 1992; 57 FR 42388, Sept. 14, 1992; 58 FR 35340, June 30, 1993; 61 FR 56746, Nov. 4, 1996; 62 FR 42018, August 4, 1997; 71 FR 10373, Feb. 28, 2006]

Appendix C. Sizes of Airborne Particles as Dust

This appendix appears in its original form, without editorial change.

This table (ET, 2011), lists “Sizes of airborne particle as dust, pollen bacteria, virus and many more.”

Particle	Particle Size (microns)
one inch	25400
dot (.)	615
Eye of a Needle	1230
Glass Wool	1000
Spanish Moss Pollen	150 - 750
Beach Sand	100 - 10000
Mist	70 - 350
Fertilizer	10 - 1000
Pollens	10 - 1000
Cayenne Pepper	15 - 1000
Textile Fibers	10 - 1000
Fiberglass Insulation	1 - 1000
Grain Dusts	5 - 1000
Human Hair	40 - 300
Human Hair	60 - 600
Dust Mites	100 - 300
Saw Dust	30 - 600
Ground Limestone	10 - 1000
Tea Dust	8 - 300
Coffee	5 - 400
Bone Dust	3 - 300
Hair	5 - 200
Cement Dust	3 - 100
Ginger	25 - 40
Mold Spores	10 - 30
Starches	3 - 100
Red Blood Cells	5 - 10
Mold	3 - 12
Mustard	6 - 10
Antiperspirant	6 - 10
Textile Dust	6 - 20
Gelatin	5 - 90
Spider web	2 - 3
Spores	3 - 40
Combustion-related – motor vehicles, wood burning, open burning, industrial processes	up to 2.5
Fly Ash	1 - 1000
Milled Flour, Milled Corn	1 - 100
Coal Dust	1 – 100
Iron Dust	4 - 20
Smoke from Synthetic Materials	1 - 50
Lead Dust	2
Face Powder	0.1 - 30
Talcum Dust	0.5 - 50
Asbestos	0.7 - 90
Calcium Zinc Dust	0.7 - 20
Paint Pigments	0.1 - 5
Auto and Car Emission	1 - 150
Metallurgical Dust	0.1 - 1000
Metallurgical Fumes	0.1 - 1000

Particle	Particle Size (microns)
Clay	0.1 - 50
Humidifier	0.9 - 3
Copier Toner	0.5 - 15
Liquid Droplets	0.5 - 5
Insecticide Dusts	0.5 - 10
Anthrax	1 - 5
Yeast Cells	1 - 50
Carbon Black Dust	0.2 - 10
Atmospheric Dust	0.001 - 40
Smoldering or Flaming Cooking Oil	0.03 - 0.9
Corn Starch	0.1 - 0.8
Sea Salt	0.035 - 0.5
Bacteria	0.3 - 60
Bromine	0.1 - 0.7
Lead	0.1 - 0.7
Radioactive Fallout	0.1 - 10
Rosin Smoke	0.01 - 1
Combustion	0.01 - 0.1
Smoke from Natural Materials	0.01 - 0.1
Burning Wood	0.2 - 3
Coal Flue Gas	0.08 - 0.2
Oil Smoke	0.03 - 1
Tobacco Smoke	0.01 - 4
Viruses	0.005 - 0.3
Typical Atmospheric Dust	0.001 to 30
Sugars	0.0008 - 0.005
Pesticides & Herbicides	0.001
Carbon Dioxide	0.00065
Oxygen	0.0005

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