



AFRL-SA-WP-TR-2025-0003

Missile Community Cancer Study Cancer and Health Risk Assessment for Malmstrom Air Force Base, Montana

**Lt Col Scott M. Boyd
Occupational & Environmental Health Department**

**Report Date
29 May 2025**



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**Date of Determination: 20 May 2025
Air Force Research Laboratory 711th Human Performance Wing
U.S. Air Force School of Aerospace Medicine
Occupational & Environmental Health
2510 Fifth Street, Bldg. 840
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The Missile Community Cancer Study Cancer and Health Risk Assessment for Malmstrom Air Force Base, Montana (Technical Report) study was designed to be in compliance with the U.S. Environmental Protection Agency (EPA), Health Effects Test Guidelines, Office of Prevention, Pesticides, and Toxic Substances (OPPTS) 870.2500, Acute Dermal Irritation published in August 1998 and the Organization for Economic Cooperation and Development (OECD) Guideline for Testing of Chemicals, Acute Dermal Irritation/Corrosion, Section 404, adopted on July 28th 2015. This study was performed in a Good Laboratory Practice (GLP) Standards certified laboratory at:

- A. Alliance Technical Group (Formerly Summit Environmental Technologies, Inc.), 3310 Win Street, Cuyahoga Falls, Ohio, 44223;
- B. Australian Laboratory Services, 301 Fulling Mill Road, Middletown, Pennsylvania, 17057;
- C. Bureau Veritas North America, 22345 Roethel Drive, Novi, Michigan, 48374;
- D. Defense Centers for Public Health – Aberdeen, 8252 Blackhawk Road, Aberdeen Proving Ground, Maryland, 21010.

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REPORT DOCUMENTATION PAGE

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14. ABSTRACT This report summarizes and analyzes the three rounds of environmental health surveillance conducted at Malmstrom Air Force Base (AFB), Montana. The three rounds at Malmstrom AFB were part of an overall missile community environmental sampling campaign that included F.E. Warren AFB, Wyoming; Minot AFB, North Dakota; Vandenberg Space Force Base (SFB), California; and Hill AFB, Utah. The purpose of these environmental health surveys was to assess the potential etiology of elevated non-Hodgkin Lymphoma (NHL) concerns within the Air Force missile community by characterizing and documenting exposures to potential environmental hazards in the Missile Alert Facilities (MAFS) and Missile Procedure Trainers (MPTs).					
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**DEPARTMENT OF THE AIR FORCE
711TH HUMAN PERFORMANCE WING (AFMC)
WRIGHT-PATTERSON AFB OHIO**

29 May 2025

MEMORANDUM FOR: AFGSC/SGPB

FROM: USAFSAM/OE
2510 Fifth Street, Building 840
WPAFB OH 45433-7913

SUBJECT: Consultative Letter, AFRL-SA-WP-TR-2025-0003, Missileer Cancer Study Cancer and Health Risk Assessment for Malmstrom Air Force Base, Montana

- References:
- (a) Air Force Manual 48-148, *Ionizing Radiation Protection* (Department of the United States Air Force, 2020)
 - (b) 40 Code of Federal Regulations Part 761, Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions (Washington, D.C.: USEPA, 2025)
 - (c) United States Environmental Protection Agency, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment (EPA-540-R-070-002)* (Washington, D.C.: USEPA, 2009)
 - (d) Agency for Toxic Substances & Disease Registry, *Cancer Classification Systems* (Atlanta: ATSDR, 2020)
 - (e) American Conference of Governmental Industrial Hygienists, *2024 TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices* (Cincinnati, 2024)
 - (f) Department of the Air Force, *Officer Career Briefs: Narrative Guidance, 13N – Nuclear & Missile Operations Career Development Guidance* (AF/A1. Washington, D.C.: 2023)
 - (g) United States Environmental Protection Agency, *Regional Guidance on Handling Chemical Concentration Data Near the Detection Limit in Risk Assessments* (Washington, D.C.: 2024)
 - (h) National Institute of Occupational Safety and Health, *Current Intelligence Bulletin 68: NIOSH Chemical Carcinogen Policy* (Washington, D.C.: NIOSH, 2017)

- (i) Agency for Toxic Substances & Disease Registry, *Guidance on Inhalation Exposures, Version 5* (Atlanta: ATSDR, 8 September 2021)
- (j) Agency for Toxic Substances & Disease Registry, *Guidance on Water Ingestion, Version 1* (Atlanta: ATSDR, 31 January 2023)
- (k) Agency for Toxic Substances & Disease Registry, *Exposure Dose Guidance for Dermal and Ingestion Exposure to Surface Water, Version 2* (Atlanta: ATSDR, 25 September 2018)
- (l) United States Environmental Protection Agency, *Regional Screening Levels (RSLs) – User’s Guide* (Washington, D.C.: 2024)
- (m) United States Environmental Protection Agency, *Exposure Factors Handbook (EFH)* (Washington, D.C.: 2025)
- (n) International Commission on Radiological Protection, *Lung Cancer Risk from Radon and Progeny and Statement on Radon* (New York, 1993)
- (o) United States Environmental Protection Agency, *Science Policy Council Handbook: Risk Characterization* (Washington, D.C.: 2000)
- (p) American Cancer Society, *Lifetime Risk of Developing or Dying From Cancer* (Atlanta, 2025)

1. EXECUTIVE SUMMARY

In response to concerns with perceived elevated Non-Hodgkin Lymphoma (NHL) rates among the Air Force Missile Community, the United States Air Force School of Aerospace Medicine Occupational and Environmental Health Department (USAFSAM/OE) performed three rounds of environmental exposure assessments at the fifteen (15) Missile Alert Facilities (MAFs) and two (2) Missile Procedure Trainers (MPTs) at Malmstrom Air Force Base (AFB), Montana. This environmental surveillance effort consisted of collecting over 2,700 environmental samples across inhalation, ingestion, and absorption exposure pathways assessing over 164 total chemicals. The determinations associated with this investigation include:

- A. Collecting environmental samples using calibrated equipment and methods endorsed by the United States Environmental Protection Agency (USEPA), National Institute of Occupational Safety and Health (NIOSH), and National Environmental Compliance Institute (NECi) using accredited laboratories;
- B. Assessing carcinogens by using protocols that exceed established methods endorsed by the Agency for Toxic Substances and Disease Registry (ATSDR);
- C. Conducting cancer risk, health risk, and target organ risk methodologies published by the USEPA; and
- D. Utilizing public health, environmental health, and statistical experts in NIOSH and the Air Force Institute of Technology (AFIT) Scientific Test and Analysis Techniques Center of Excellence (STATCOE) to advise and perform statistical analysis.

It is USAFSAM/OE's determination that the current environmental conditions within the Malmstrom AFB MAFs have the:

- A. Current potential to contribute to excess cancer risks ranging from a lower-bound estimate of less than one (1) excess cancer risk in ten thousand (10,000) assigned MAF personnel to a conservative, upper-bound estimate of twenty-three (23) excess cancer risks out of ten thousand (10,000) assigned MAF personnel. This potentially increases a male MAF workers' probability of developing cancer from 39.9% to 40.13% and a female MAF workers' probability of developing cancer from 39% to 39.23%, and;
- B. Current potential to contribute to a regulatory-based, non-cancer health risk which impacts the skin to a conservative, upper-bound non-cancer health risk which impacts the central nervous, cardiovascular, gastrointestinal, immune, respiratory, reproductive, and skin organ systems and blood, eyes, liver, and kidneys.

2. INTRODUCTION

This report summarizes and analyzes the three rounds of environmental exposure assessments conducted at Malmstrom AFB. Table 1 lists the interim reports that were published. The three rounds at Malmstrom AFB were part of an overall missile community environmental sampling campaign that included F.E. Warren AFB, Wyoming; Minot AFB, North Dakota; Vandenberg Space Force Base (SFB), California; and Hill AFB, Utah. The purpose of these environmental health surveys was to assess the potential etiology of elevated non-Hodgkin Lymphoma (NHL) concerns within the Air Force missile community by characterizing and documenting exposures to potential environmental hazards in the MAFs and MPTs. Rounds 1 through 3 of the environmental health survey occurred from:

- A. Round 1: 20 to 30 June 2023
- B. Round 2: 29 October to 9 November 2023
- C. Round 3: 8 to 15 April 2024

Radon surveillance occurred at the 15 MAFs beginning on 22 June 2023 and ending on 15 April 2024.

Interim reports were published for Rounds 1, 2 and 3 and are available on the Defense Technical Information Center (DTIC) website. Table 1 lists the Round 1-3 reports produced by USAFSAM/OE in support of the Missile Community Cancer Study (MCCS).

Table 1: MCCS Reports Published for F.E. Warren, Malmstrom, and Minot AFBs

	F.E. Warren AFB	Malmstrom AFB	Minot AFB	Consolidated Radon
Round 1	AFRL-SA-WP- TR-2023-0012	AFRL-SA-WP- TR-2023-0010	AFRL-SA-WP- TR-2023-0009	AFRL-SA-WP- TR-2023-0014
Round 2	AFRL-SA-WP- OT-2024-0001	AFRL-SA-WP- TR-2024-0003	AFRL-SA-WP- TR-2024-0001	AFRL-SA-WP- TR-2024-0002
Round 3	AFRL-SA-WP- TR-2024-0010	AFRL-SA-WP- TR-2024-0009	AFRL-SA-WP- TR-2024-0008	AFRL-SA-WP- TR-2024-0012

Additionally, USAFSAM/OE conducted surveillance at Vandenberg SFB and Hill AFB. Vandenberg SFB is the assigned base of the 377th Test and Evaluation Group (TEG) and the 532nd Training Squadron (TRS). The 377th TEG oversees testing, planning, execution, analysis, and reporting of all Minuteman III intercontinental ballistic missile (ICBM) tests. The 532nd TRS delivers Air Force Specialty Code training to 450 Nuclear and Missile Operations Officers (13Ns) and Missile and Space Systems Maintenance Specialists (2M0) each year. The Strategic Missile Integration Complex at Hill AFB is the Department of Defense's (DoD) sole test environment for system integration and operational testing of modifications and upgrades to ICBM weapon systems. MCCS reports for these installations are also available on the DTIC website.

Table 2 lists historical reports produced by USAFSAM/OE in support of Vandenberg SFB and Hill AFB which can be found on DTIC.

Table 2: MCCS Reports for Vandenberg SFB and Hill AFB

	Vandenberg SFB	Hill AFB
Environmental Surveillance	AFRL-SA-WP-TR-2024-0009	AFRL-SA-WP-TR-2024-0011
Radon Surveillance	AFRL-SA-WP-TR-2024-0007	AFRL-SA-WP-CL-2024-0001

3. MALMSTROM AFB ENVIRONMENTAL SURVEILLANCE RESULTS SUMMARY

Six types of samples (air-chemical and chemical mixture agents, air-radiological agent, drinking water-chemical chemical mixture agents, surface swipe-chemical mixture agent, soil-chemical agent and moisture, and direct read indoor air-quality parameters) were collected. The sampling encompassed over 160 individual chemical and radiological agents. Eighteen (18) agents had one or more detected concentrations above the laboratory or direct-reading equipment limit of detection (LOD)/limit of quantification (LOQ) as follows:

- A. Air-Chemical: 1,2-Dichloroethane, P+M Xylene, Styrene, Benzene, Toluene, and Trans-1,2-Dichloroethylene;
- B. Air-Radiological: Radon;
- C. Drinking Water: Di(2-ethylhexyl)phthalate, 2-3-7-8-Tetrachlorodibenzo-p-dioxin, and Total Nitrate/Nitrite;
- D. Surface Swipe: Aroclor 1254 and Aroclor 1260;
- E. Direct Read: Carbon monoxide, carbon dioxide, ozone in indoor air and potential of hydrogen (pH), total chlorine, and free chlorine in drinking water.

Considering these chemicals/mixtures were detected at Malmstrom AFB, these chemicals/mixtures were not detected:

- A. At every MAF;
- B. Every round; and
- C. In both the TopSide Support Buildings and the LCCs.

3.1. Air-Chemical: Environmental air sampling was conducted to assess inhalation exposure. Samples were collected in each of the fifteen (15) MAF Topside Support Buildings and Launch Control Centers (LCCs) and analyzed for volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), and organophosphates. Sampling for VOCs and organophosphates occurred during Rounds 1, 2, and 3 and sampling for PCBs occurred during Rounds 1 and 2 (see Table 1). Of the sixty-nine (69) chemical agents assessed in each of the fifteen (15) MAFs, six (6) chemical agents (1,2-Dichloroethane, p+m Xylene, Styrene, Benzene, Toluene, and Trans-1,2-Dichloroethylene) had one or more detected concentration above the laboratory or direct-reading equipment LOD/LOQ. Chemicals/mixtures where were below the laboratory LOD/LOQ are addressed in paragraph 4.7.

3.1.1. Volatile Organic Compound (VOC) Sampling: Ninety (90) VOC air samples were collected, each assessing fifty-one (51) individual VOCs, equating to four-thousand five hundred and ninety (4,590) total data points. Of the fifty-one (51) VOCs assessed, six (6) chemicals (1,2-Dichloroethane, p+m Xylene, Styrene, Benzene, Toluene, and Trans-1,2-Dichloroethylene) had one or more detected concentrations greater than the sampling and analytical method LOD/LOQ.

3.1.2. Polychlorinated Biphenyl (PCB): A total of thirty-two (32) PCB air samples were collected in the MAFs, LCCs and MPTs. Seven (7) unique PCB isomers were analyzed for, equating to two hundred twenty-four (224) data total points. All PCB air sample concentrations were less than the sampling and analytical method LOD/LOQ.

3.1.3. Organophosphates: A total of ninety (90) organophosphate air samples were collected, each assessing ten (10) individual organophosphates, equating to nine hundred (900) total data points. All organophosphate air sample concentrations were less than the sampling and analytical method LOD/LOQ.

3.2. Air-Radiological: Environmental air sampling to assess inhalation exposure to radon was conducted from 22 June 2023 to 15 April 2024. Inhalation exposure to radon in each location within each MAF that were sampled was less than four (4) Working Level Months per year (WLM/yr), which is the published annual exposure limit in Air Force Manual (AFMAN) 48-148, *Ionizing Radiation Protection* (20 July 2020).

3.3. Drinking Water: Drinking water sampling to assess ingestion exposure occurred during Rounds 1, 2, and 3 (see Table 1). Samples were collected from each of the fifteen (15) MAF Topside Support Building kitchen sinks and LCC bathroom sinks and analyzed for semi-volatile organic compounds (SVOCs), organophosphates, PCBs, diquat, paraquat, total nitrate/nitrite and dioxin. Of the seventy-nine (79) chemical agents analyzed for in each of the fifteen (15) MAFs, three (3) chemicals (Di(2-ethylhexyl)phthalate, 2-3-7-8-Tetrachlorodibenzo-p-dioxin, and Total Nitrate/Nitrite) had one or more detected concentrations greater than the sampling and analytical method LOD/LOQ.

3.3.1. Semi-Volatile Organic Compounds (SVOCs) & Organophosphates: Ninety (90) SVOC/organophosphate water samples were collected, each assessing the concentrations of fifty-two (52) chemicals equating to four thousand six hundred eighty (4,680) total data points. Of the fifty-two (52) SVOCs & organophosphates assessed in drinking water, one chemical (Di(2-ethylhexyl)phthalate) had one or more detected concentration above the sampling and analytical method LOD/LOQ.

3.3.2. Polychlorinated Biphenyl (PCB): A total of eighty-eight (88) PCB water samples were collected, each assessing the concentrations of seven (7) individual PCB isomers, Total PCBs, Toxaphene, and Technical Chlordane which equate to eight hundred eighty (880) total data

points. Of these ten (10) chemicals/mixtures assessed in drinking water, all concentrations of PCBs in drinking water were less than the sampling and analytical method LOD/LOQ.

3.3.3. Diquat and Paraquat: A total of ninety (90) water samples were collected assessing the concentration of diquat and paraquat equating to one hundred eighty (180) total data points. All concentrations of diquat/paraquat in drinking water were less than the sampling and analytical method LOD/LOQ.

3.3.4. Dioxin: A total of ninety (90) water samples were collected assessing the concentration of 2-3-7-8-Tetrachlorodibenzo-p-dioxin equating to ninety (90) data points. Of the ninety dioxin samples collected, detected concentrations of 2-3-7-8-Tetrachlorodibenzo-p-dioxin were found in two (2) samples.

3.3.5. Total Nitrate/Nitrite: A total of ninety (90) Total Nitrate/Nitrite samples were collected. Of the ninety samples collected, detected concentrations of Total Nitrate/Nitrite were found in thirty (30) samples.

3.4. Dermal Absorption – PCB Swipe Sampling: On 4 August 2023, USAFSAM published the Malmstrom Air Force Base PCB Initial Environmental Air and Swipe Sample Results, which documented the presence of PCBs on surfaces in the MAFs. Twenty (20) surfaces within each of the fifteen (15) MAFs were collected for a total of 300 samples. An additional thirty-six (36) surface swipe samples were collected in the MPTs. PCBs were detected in:

- A. Five (5) LCCs where concentrations were less than the USEPA surface contamination mitigation thresholds mandated by 40 Code of Federal Regulations (CFR) 761, and
- B. Two (2) LCCs where concentrations were greater than the USEPA surface contamination mitigation thresholds mandated by 40 CFR 761.

As documented in Appendix 1 (Malmstrom AFB Consolidated Surface Contamination Exposures), two (Aroclor 1254 and Aroclor 1260) of the seven PCB isomers were detected in the 336 swipes collected at Malmstrom AFB.

3.5. Soil: Soil sampling for organophosphates occurred during Rounds 1, 2 and 3 (see Table 1). A total of two hundred sixty four (264) soil samples were collected at locations surrounding each MAF, each assessing the concentrations of ten (10) organophosphates equating to two thousand six hundred forty (2,640) data points. All concentrations of organophosphates in the two hundred sixty four (264) soil samples were less than the sampling and analytical method LOD/LOQ.

3.6. Direct Read Parameters: Direct reading instruments were used to directly measure several indoor air quality and water quality parameters.

3.6.1 Indoor Air Quality: Direct reading instruments were used to directly measure instantaneous indoor air concentrations of carbon monoxide, carbon dioxide, percent relative humidity, ozone, and cubic feet per minute of exhaust air flow.

- A. Carbon monoxide (CO) concentrations ranged from less than 0.1 parts per million (ppm) to 4.1 ppm. These concentrations fall below the American Conference of Governmental Industrial Hygienists (ACGIH) 8-hour Threshold Limit Value (TLV) of 25 ppm.
- B. Carbon dioxide (CO₂) concentrations ranged from 477 ppm to 810 ppm, which were less than current recommended levels for indoor air environments (1000 ppm) established by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

C. Ozone concentrations ranged from less than 0.01 ppm to 0.05 ppm. ACGIH has an eight (8) hour TLV of 0.05 ppm for heavy work, 0.08 ppm for moderate work, and 0.10 ppm for light work.

D. Percent relative humidity (RH) ranged from 31.4% RH to 62.4% RH. Systems with dehumidification capability should maintain RH to less than 65% per ASHRAE.

E. Air temperature ranged from 66.5 degrees Fahrenheit (°F) to 76.2°F. The ASHRAE guidelines recommend 68°F to 74°F in the winter and 72°F to 80°F in the summer.

3.6.2 Drinking Water Quality: Direct reading instruments were used to directly measure several instantaneous drinking water quality parameters.

A. Potential of hydrogen (pH) ranged from 7.4 to 8.4 and indicated the water was slightly basic in pH. The USEPA established a secondary, unenforceable maximum contaminant level (MCL) for pH ranging from 6.5 to 8.5.

B. Total chlorine ranged from less than the instrument detection limit to 1.52 ppm and is the sum of combined chlorine and free chlorine.

C. Free chlorine ranged from less than the instrument detection limit to 1.44 ppm and is the chlorine available to eliminate harmful microbes and neutralize contaminants. For chlorine, the USEPA has an MCL of four (4) ppm.

4. HEALTH RISK ASSESSMENT METHODOLOGY

USAFSAM/OE conducted the health risk assessment in accordance with Chapter 8 of the USEPA *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual* (Part F, Supplemental Guidance for Inhalation Risk Assessment) {Version January 2009, Document # EPA-540-R-070-002}. In accordance with EPA-540-R-070-002 (USEPA, 2009), USAFSAM/OE performed a:

- A. Total Estimated Cancer Risk Determination (TECRD);
- B. Non-Cancer Estimated Health Risk Determination (NCEHRD);
- C. Target Organ Risk Determination (TORD)

These assessments assume health is impacted by simultaneous exposure to multiple chemicals (USEPA, 2009). AFIT STATCOE performed statistical analysis for each chemical, which will be discussed in Section 4.6.

4.1. CARCINOGEN BACKGROUND

Cancer classification systems maintained by several agencies were consulted. Per ATSDR, three United States agencies and one international agency have cancer classification systems for carcinogens (ATSDR, 2020). These agencies are:

- A. National Toxicology Program (NTP) within the United States Department of Health and Human Services (DHHS);
- B. USEPA;
- C. International Agency for Research on Cancer (IARC); and
- D. NIOSH within the DHHS.

Although not specifically identified as one of the three United States agencies for cancer classification, USAFSAM included carcinogen classifications determined by ACGIH. By using the ACGIH carcinogen classification, four additional drinking water chemicals (Atrazine, Bromacil, Cyanazine, and Simazine) would have been included in the TECRD, if any of these chemicals had been detected above the laboratory LOD/LOQ. Appendix 2 (Malmstrom AFB MAF Carcinogen Listing) documents the cancer determination for each chemical included in the TECRD.

4.1.1. NTP

The NTP publishes the Report on Carcinogens (RoC), which is a congressionally mandated listing of chemicals that are *Known to be a Human Carcinogen* or *Reasonably Anticipated to be a Human Carcinogen* (ATSDR, 2020). The NTP classifies a chemical as:

A. **Known to be a Human Carcinogen when** there is sufficient evidence of carcinogenicity from studies in humans which indicates a causal relationship between exposure to the agent and human cancer (ATSDR, 2020).

B. **Reasonably Anticipated to be a Human Carcinogen when:**

(1) There is limited evidence of carcinogenicity from studies in humans, which indicates that causal interpretation is credible, but that alternative explanations, such as chance, bias, or confounding factors, could not adequately be excluded (ATSDR, 2020).

(2) There is sufficient evidence of carcinogenicity from studies in experimental animals, which indicates there is an increased incidence of malignant and/or a combination of malignant and benign tumors (ATSDR, 2020).

(3) There is less than sufficient evidence of carcinogenicity in humans or laboratory animals, but the agent, substance, or mixture belongs to a well-defined, structurally related class of substances whose members are listed in a previous RoC as either known to be a human carcinogen or reasonably anticipated to be a human carcinogen, or there is convincing relevant information that the agent acts through mechanisms indicating it would likely cause cancer in humans (ATSDR, 2020).

4.1.2. USEPA

The USEPA Integrated Risk Information System (IRIS) conducts hazard analysis and quantitative risk assessments to assess cancer risks posed by chemicals (ATSDR, 2020). The USEPA IRIS utilizes the following carcinogen classifications:

A. **Group A/Carcinogenic to Humans** when there is adequate human data to demonstrate the causal association of the agent with human cancer (ATSDR, 2020)

B. **Group B/Probably Carcinogenic to Humans** when there is sufficient evidence from animal bioassay data but with either:

(1) **Group B1** when there is limited human evidence that is indicative of a possible causal relationship, but not exclusive of alternative explanations (ATSDR, 2020).

(2) **Group B2** when there is little or no human data (ATSDR, 2020).

C. **Group C/Possibly Carcinogenic to Humans** when there is limited animal evidence and little or no human data (ATSDR, 2020).

D. **Group D/Not Classifiable as to Human Carcinogenicity** when there is not adequate data either to support or refute human carcinogenicity (ATSDR, 2020).

E. **Group E/Evidence of Non-Carcinogenicity for Humans** when there is no evidence for carcinogenicity in at least two adequate animal tests in different species or in both adequate epidemiologic and animal studies (ATSDR, 2020).

4.1.3. IARC

IARC is an organization within the World Health Organization (WHO). According to their mission statement, “The objective of IARC is to promote international collaboration in cancer research. The Agency is interdisciplinary, bringing together skills in epidemiology, laboratory sciences, and biostatistics to identify the causes of cancer so that preventive measures may be adopted and the burden of disease and associated suffering reduced”. The agency produces “Monographs on the Evaluation of Carcinogenic Risks to Humans”, which utilize the following classification system (ATSDR, 2020):

A. **Group 1/Carcinogenic to Humans** when there is sufficient evidence in humans; or if there is both strong evidence in exposed humans that the agent exhibits key characteristics of carcinogens and sufficient evidence of carcinogenicity in experimental animals (ATSDR, 2020).

B. **Group 2A/Probably Carcinogenic to Humans** when there is at least two of the following evaluations, including at least one that involves either exposed humans or human cells or tissues (ATSDR, 2020):

- (1) Limited evidence of carcinogenicity in humans (ATSDR, 2020).
- (2) Sufficient evidence of carcinogenicity in experimental animals (ATSDR, 2020).
- (3) Strong evidence that the agent exhibits key characteristics of carcinogens (ATSDR, 2020).
- (4) If there is inadequate evidence regarding carcinogenicity in humans, there should be strong evidence in human cells or tissues that the agent exhibits key characteristics of carcinogens (ATSDR, 2020).

C. **Group 2B/Possibly Carcinogenic to Humans** when one of the following evaluations have been made (ATSDR, 2020):

- (1) Limited evidence of carcinogenicity in humans (ATSDR, 2020).
- (2) Sufficient evidence of carcinogenicity in experimental animals (ATSDR, 2020).
- (3) Strong evidence that the agent exhibits key characteristics of carcinogens (ATSDR, 2020).

D. **Group 3/Not Classifiable as to Carcinogenicity to Humans (ATSDR, 2020):**

- (1) Agents that do not fall into any other group, including when there is strong evidence that the mechanism of carcinogenicity in experimental animals does not operate in humans for one or more tumor sites in experimental animals, the remaining tumor sites do not support an evaluation of sufficient evidence in experimental animals, and other categories are not supported by data from studies in humans and mechanistic studies (ATSDR, 2020).
- (2) An evaluation in Group 3 is not a determination of non-carcinogenicity or overall safety. It often means that the agent is of unknown carcinogenic potential and that there are significant gaps in research (ATSDR, 2020).

4.1.4. NIOSH

NIOSH will determine whether a chemical is an occupational carcinogen by using one of the three following methods (ATSDR, 2020):

- A. Evaluation of chemical carcinogen hazard assessments developed by the DHHS NTP, USEPA, and IARC (ATSDR, 2020).
- B. Nomination by NIOSH for classification by NTP; or (ATSDR, 2020)
- C. Classification by NIOSH (ATSDR, 2020).

NIOSH may perform its own chemical hazard assessment to determine if the chemical should be classified as an occupational carcinogen when the institute has determined that the chemical has the potential for worker exposure and when (ATSDR, 2020):

- A. No prior carcinogen classification by NTP, EPA or IARC has been published, or (ATSDR, 2020).
- B. Information in the occupational relevance evaluation indicates the need for reconsideration of the evidence underlying a published chemical carcinogen assessment (ATSDR, 2020).

When developing a new chemical carcinogen classification, NIOSH will use the criteria for carcinogenicity contained in the United Nations' Globally Harmonized System for Classification and Labelling of Chemicals (GHS) (ATSDR, 2020).

4.1.5. ACGIH

The ACGIH independently determines chemical carcinogenicity according to the following classifications:

- A. A1 – Confirmed Human Carcinogen
- B. A2 – Suspected Human Carcinogen
- C. A3 – Confirmed Animal Carcinogen with Unknown Relevance to Humans
- D. A4 – Not Classifiable as a Human Carcinogen
- E. A5 – Not Suspected as a Human Carcinogen

4.2. HEALTH SCREENING VALUES (HSVs)

Health Screening Values (HSVs) for all analytes were obtained from credible sources such as USEPA Regional Screening Levels (RSLs) for air and water, California EPA for air, EPA MCLs for drinking water, ATSDR for Minimal Risk Levels, and other state entities such as Florida, Michigan, Minnesota, Nevada, Pennsylvania, and Texas. In some cases, differing exposure timeframes, populations, and/or routes of exposure were encountered. In those situations, the HSV selected was the longer term, general population based HSV corresponding to the route of exposure (i.e. inhalation for air, ingestion for water).

Where applicable, 40 CFR requirements (environmental regulations set by the USEPA) took priority with second priority to ATSDR Minimal Risk Levels (MRLs). The USEPA CompTox portal and PubChem websites were used to search for health screening levels from the USEPA, United States Geological Survey (USGS), DoD, Department of Energy (DoE), and State agencies. The European Chemical Agency's (ECHA) website was used to search for European

standards. The most conservative guideline was used as the HSV with a preference priority of:

- A. Health Advisories (HA)
- B. Screening levels
- C. Regional Screening Levels (RSL)
- D. Health-Based Screening Levels (HBSL)
- E. State or European Derived Standards: Medium Specific Concentrations (MSC)
- F. Environmental Quality Standards (EQS)
- G. Military Exposure Guidelines (MEGs)
- H. Derived No-Effect Level (DNEL)
- I. Protective Action Criteria (PAC)

When no other guidelines could be found for the analyte and exposure route, the USEPA provisional peer reviewed toxicity values (PPRTVs) for inhalation reference concentrations (RfC) or ingestion reference doses (RfD) were used.

When multiple HSVs were being considered, the order of priority in HSV selection were:

- A. 40 CFR (National Primary Drinking Water Regulations Maximum Contaminant Limit and Surface Contamination)
- B. ATSDR MRL
- C. United States Air Force Action Limits
- D. USEPA HA
- E. USEPA RSL Target Hazard Quotient (THQ) = 0.1
- F. USEPA RSL Target Risk (TR)-1e-6
- G. USGS HBSL
- H. State derived (Ex: Pennsylvania Department of Environmental Protection Medium Specific Concentrations)
- I. European Union (EU) EQS
- J. MEG
- K. ECHA DNEL
- L. DOE PAC
- M. USEPA Provisional Peer-Reviewed Toxicity Values (PPRTV) RfC
- N. USEPA PPRTV RfD

When an analyte had multiple levels of risk associated with an adverse outcome, the THQ of 0.1 or target cancer risk TR of 1e-6 (one excess cancer case in one million people who are exposed) was used. Appendix 3 (Malmstrom AFB Statistical Base Exposure, Confidence, Health Screening Value, & Cancer Curves) references the SBE, Confidence, and HSVs for detected chemicals included in the TECRD, NCEHRD, and TORD.

The HSVs are based on long-term, chronic exposure where the exposure timeframe extends well beyond the duration personnel would be present in a MAF. Where appropriate and with the approval of Air Force Global Strike Command Operations (AFGSC/A3), HSVs were recalculated from their original exposure duration to a standardized exposure over an eight (8) year timeframe. Eight years was selected given the duration conforms with the 13N Officer Career Development Briefs: Narrative Guidance (30 January 2023). Where typical 13N duties will transition from routine MAF duties to administrative staff positions, which drastically reduces MAF alert duties and exposure to the agents listed in Appendix 4 (Malmstrom AFB Detected Chemicals Included in the Health Risk Assessment).

Example of the 8-Year Calculation of the Benzene Air HSV:

$$\text{HSV}_{\text{Benzene-Air}} = \text{Total Risk} \times \text{Averaging Time}_{\text{Days}} \div (\text{Inhalation Unit Risk}_{\text{Benzene-Air}} (\text{units})^{-1} \times \text{Exposure Frequency}_{\text{Days/Year}} \times \text{Exposure Duration}_{\text{Years}})$$

$$\text{HSV}_{\text{Benzene-Air}} = 0.0001 \times 25,550 \text{ days} \times \frac{1}{7.80\text{E-}06} (\text{Cubic meter} / \text{microgram})^{-1} \times \frac{\text{year}}{125 \text{ days}} \times \frac{1}{8 \text{ years}}$$

$$\text{HSV}_{\text{Benzene-Air}} = 327.56 \text{ microgram} / \text{Cubic meter} (\mu\text{g}/\text{m}^3)$$

Notes:

(1) Total Risk is 0.0001 given one (1) excess cancer risk in ten thousand (10,000) as defined by National Institute of Occupational Safety and Health, *Current Intelligence Bulletin 68: NIOSH Chemical Carcinogen Policy*.

(2) Averaging Time of 25,550 (equal to 70 years times 365 days per year) is in accordance with the practices published in the United States Environmental Protection Agency *Regional Screen Levels (RSLs) – User's Guide (November 2024)*.

(3) Inhalation Unit Risk is in accordance with United States Environmental Protection Agency Integrated Risk Information System (IRIS).

(4) Exposure Frequency is based on current MAF operations at Malmstrom, Minot, and F.E. Warren AFBs. Historically, Malmstrom and Minot AFBs MAF operations were executed under a one week on, two weeks off tempo while F.E. Warren AFB MAF operations were executed under a one day one, two days off tempo. Under both tempos, MAF operations equate to one-third of a year at the MAF while the remaining two-thirds of the time are at the Main Operating Base, home, or elsewhere. Therefore, 125 days/year is conservatively used considering $1/3 \times 365 \text{ days/year} = 121 \text{ days}$.

(5) Eight (8) years is utilized in accordance with 13N Officer Career Development Briefs: Narrative Guidance (30 January 2023) and with the approval of AFGSC/A3.

Example of the 8-Year Calculation of the 2,3,7,8-Tetrachlorodibenzo-p-dioxin Drinking Water HSV:

$$\text{HSV}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} = \text{Total Risk} \times \text{Averaging Time}_{\text{Days}} \div [\text{Oral Slope Factor}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} (\text{units})^{-1} \times (\text{Exposure Frequency}_{\text{Days/Year}} \times \text{Exposure Duration}_{\text{Years}} \times \text{Daily Water Intake} \div \text{Body Weight})]$$

$$\text{HSV}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} = 0.0001 \times 25,550 \text{ days} \div [130 (\text{micrograms} / \text{kilogram-day})^{-1} \times 125 \frac{\text{days}}{\text{year}} \times 8 \text{ years} \times 2.5 \frac{\text{Liters}}{\text{day}} \times \frac{1}{80 \text{ kilograms}}]$$

$$\text{HSV}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} = 2.555 \div 4062.5 \text{ micrograms} / \text{Liter} (\mu\text{g/L})$$

$$\text{HSV}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} = 6.29\text{E-}04 \mu\text{g/L}$$

Notes:

(1) Total Risk is 0.0001 given one (1) excess cancer risk in ten thousand (10,000) as defined by National Institute of Occupational Safety and Health, *Current Intelligence Bulletin 68: NIOSH Chemical Carcinogen Policy*.

(2) Averaging Time of 25,550 (equal to 70 years times 365 days per year) is in accordance with the practices published in the United States Environmental Protection Agency *Regional Screen Levels (RSLs) – User's Guide (November 2024)*.

(3) Oral Slope is in accordance with United States Environmental Protection Agency Integrated Risk Information System (IRIS).

(4) Exposure Frequency is based on current MAF operations at Malmstrom, Minot, and F.E. Warren AFBs. Historically, Malmstrom and Minot AFBs MAF operations were executed under a one week on, two weeks off tempo while F.E. Warren AFB MAF operations were executed under a one day one, two days off tempo. Under both tempos, MAF operations equate to one-third of a year at the MAF while the remaining two-thirds of the time are at the Main Operating Base, home, or elsewhere. Therefore, 125 days/year is conservatively used considering $1/3 \times 365 \text{ days/year} = 121 \text{ days}$.

(5) Eight (8) years is utilized in accordance with 13N Officer Career Development Briefs: Narrative Guidance (30 January 2023) and with the approval of AFGSC/A3.

(6) Daily Water Intake of 2.5 Liters is in accordance with the practices published in the United States Environmental Protection Agency *Regional Screen Levels (RSLs) – User's Guide (November 2024)*.

(7) Body Weight of 80 kilograms is in accordance with Table 8-1, Chapter 8 of the United States Environmental Protection Agency *Exposure Factors Handbook* (September 2011).

For carcinogenic agents listed in Appendix 3 (Malmstrom AFB Statistical Base Exposure, Confidence, Health Screening Value, & Cancer Curves), the Inhalation Unit Risk and/or Oral Cancer Slope is provided. The USEPA defines Inhalation Unit Risk (USEPA, 2024):

- A. As an estimate of the increased risk from inhalation exposure to a concentration of one microgram per cubic meter ($1 \mu\text{g}/\text{m}^3$) for a lifetime
- B. Can be multiplied by an estimate of lifetime exposure to estimate the lifetime cancer risk to inhalation.

The USEPA defines Oral Slope Factor (USEPA, 2024):

- A. As an estimate of the increased cancer risk from oral exposure to a dose of one milligram per kilogram-day for a lifetime ($1 \text{ mg}/\text{kg-day}$)

B. Can be multiplied by an estimate lifetime exposure to estimate the lifetime cancer risk to ingestion.

Inhalation Unit Risks and Oral Slope Factors are derived assuming a 70-year lifetime exposure and may be adjusted for shorter exposure durations. Due to uncertainty in cancer outcomes at shorter exposure durations and adjustment models (linear, other), this analysis used the more conservative unadjusted Inhalation Unit Risks and Oral Slope Factors for upper bound cancer risk estimates.

4.3. EXPOSURE FACTORS (EFs)

Per the ATSDR, cancer risk can be adjusted to meet the actual duration of exposure by using the appropriate factor calculation (ATSDR, 2021). To recalculate Inhalation Unit Risks and Oral Slope Factors from a 70-year lifetime exposure to an adjusted eight (8) year exposure referenced in paragraph 4.2, the Exposures Factor (EF) formula associated with chronic, cancer exposures is applicable considering 13N exposure exceed a period more than 365 days.

Example of Inhalation Exposure Factor Calculation for an Eight (8) Year MAF Exposure:

$$EF_{\text{Cancer-Chronic-Inhalation}} = \left[\frac{24 \text{ hours}}{\text{day}} \times \frac{7 \text{ days}}{\text{week}} \times \frac{17 \text{ weeks}}{\text{year}} \times 8 \text{ years} \right] \div \left[\frac{24 \text{ hours}}{\text{day}} \times \frac{7 \text{ days}}{\text{week}} \times \frac{52.14 \text{ weeks}}{\text{year}} \times 78 \text{ years} \right]$$

$$EF_{\text{Cancer-Chronic-Inhalation}} = 22,848 \text{ hours} \div 683,243 \text{ hours}$$

$$EF_{\text{Cancer-Chronic-Inhalation}} = 0.033$$

Notes:

(1) Seventeen (17) weeks is based on current MAF operations at Malmstrom, Minot, and F.E. Warren AFBs. Historically, Malmstrom and Minot AFBs MAF operations were executed under a one week on, two weeks off tempo while F.E. Warren AFB MAF operations were executed under a one day one, two days off tempo. Under both tempos, MAF operations equate to one-third of a year at the MAF while the remaining two-thirds of the time are at the Main Operating Base, home, or elsewhere. Therefore, 17 weeks/year is equal to $1/3 \times 52 \text{ weeks/year} = 17 \text{ weeks}$.

(2) Eight (8) years is utilized in accordance with 13N Officer Career Development Briefs: Narrative Guidance (30 January 2023) and with the approval of AFGSC/A3.

(3) Remaining values (24 hours/day, 7 days/week, 52.14 weeks/year & 78 years) are in accordance with the Occupational Exposure Scenarios equation on page 8 of the ATSDR *Guidance for Inhalation Exposures, Version 5* (8 September 2021).

Example of Ingestion Exposure Factor Calculation for an Eight (8) Year MAF Exposure:

$$EF_{\text{Cancer-Chronic-Ingestion}} = \left[\frac{24 \text{ hours}}{\text{day}} \times \frac{7 \text{ days}}{\text{week}} \times \frac{17 \text{ weeks}}{\text{year}} \times 8 \text{ years} \right] \div \left[\frac{24 \text{ hours}}{\text{day}} \times \frac{7 \text{ days}}{\text{week}} \times \frac{52.14 \text{ weeks}}{\text{year}} \times 78 \text{ years} \right]$$
$$EF_{\text{Cancer-Chronic-Ingestion}} = 22,848 \text{ hours} \div 683,243 \text{ hours}$$
$$EF_{\text{Cancer-Chronic-Malmstrom-Ingestion}} = 0.033$$

Notes:

(1) Seventeen (17) weeks is based on current MAF operations at Malmstrom, Minot, and F.E. Warren AFBs. Historically, Malmstrom and Minot AFBs MAF operations were executed under a one week on, two weeks off tempo while F.E. Warren AFB MAF operations were executed under a one day one, two days off tempo. Under both tempos, MAF operations equate to one-third of a year at the MAF while the remaining two-thirds of the time are at the Main Operating Base, home, or elsewhere. Therefore, 17 weeks/year is equal to $1/3 \times 52 \text{ weeks/year} = 17 \text{ weeks}$.

(2) Eight (8) years is utilized in accordance with 13N Officer Career Development Briefs: Narrative Guidance (30 January 2023) and with the approval of AFGSC/A3.

(3) Remaining values (24 hours/day, 7 days/week, 52.14 weeks/year & 78 years) are in accordance with the Occupational Exposure Scenarios equation on page 8 of the ATSDR *Exposure Dose Guidance for Water Ingestion, Version 1* (31 January 2023).

Example of Absorption Exposure Factor Calculation for an Eight (8) Year MAF Exposure:

$$EF_{\text{Cancer-Chronic-Absorption}} = \text{Frequency of Exposure} \times \text{Exposure Duration} \div \text{Averaging Time}$$
$$EF_{\text{Cancer-Chronic-Absorption}} = \frac{7 \text{ days}}{\text{week}} \times \frac{17 \text{ weeks}}{\text{year}} \times 8 \text{ years} \div \frac{7 \text{ days}}{\text{week}} \times \frac{52.14 \text{ weeks}}{\text{year}} \times 78 \text{ years}$$
$$EF_{\text{Cancer-Chronic-Absorption}} = \frac{7 \text{ days}}{\text{week}} \times \frac{17 \text{ weeks}}{\text{year}} \times 8 \text{ years} \div \frac{7 \text{ days}}{\text{week}} \times \frac{52.14 \text{ weeks}}{\text{year}} \times 78 \text{ years}$$
$$EF_{\text{Cancer-Chronic-Absorption}} = 952 \text{ days} \div 28,484.8 \text{ days}$$
$$EF_{\text{Cancer-Chronic-Absorption}} = 0.033$$

Notes:

(1) Seventeen (17) weeks is based on current MAF operations at Malmstrom, Minot, and F.E. Warren AFBs. Historically, Malmstrom and Minot AFBs MAF operations were executed under a one week on, two weeks off tempo while F.E. Warren AFB MAF operations were executed under a one day one, two days off tempo. Under both tempos, MAF operations equate to one-third of a year at the MAF while the remaining two-thirds of the time are at the Main Operating Base, home, or elsewhere. Therefore, 17 weeks/year is equal to $1/3 \times 52 \text{ weeks/year} = 17 \text{ weeks}$.

(2) Eight (8) years is utilized in accordance with 13N Officer Career Development Briefs: Narrative Guidance (30 January 2023) and with the approval of AFGSC/A3.

(3) Remaining values (24 hours/day, 7 days/week, 52.14 weeks/year & 78 years) are in accordance with the Occupational Exposure Scenarios equation on page 5 of the ATSDR *Exposure Dose Guidance for Dermal and Ingestion Exposure to Surface Water, Version 2* (25 September 2018).

By using the EFs, a minimum cancer risk can be determined, which is addressed in paragraph 5.

4.4. TOTAL ESTIMATED CANCER RISK DETERMINATION (TECRD) METHODOLOGY

In accordance with EPA-540-R-070-002, the TECRD was calculated from the cancer risk of each individual agent within each exposure pathway combination, then added together (USEPA,

2009). This yields an estimate of total cancer risk, which represents the cumulative estimated cancer risk (USEPA, 2009). This recommended method assumes “independence of action by the compounds involved” (additive effects/risk) and assumes there are no synergistic (compound (agent) interactions resulting in greater than additive effects/risk) or antagonist (compound (agent) interactions resulting in less than additive effects/risk) interactions between chemicals (USEPA, 2009).

To calculate each chemical’s Estimated Cancer Risk Determination (ECRD), the Statistical Base Exposure (SBE) for air & drinking water is multiplied by its individual cancer risk unit (i.e., inhalation unit risk for air, oral unit risk for drinking water). The ECRD for dermal absorption of PCBs is calculated based on Appendix 5 (Malmstrom AFB Estimated PCB Dermal Exposure Cancer Risk Determination). These separate risks are then added together to calculate the TECRD (See example calculations below). The Malmstrom AFB TECRD calculated is then compared to the NIOSH Risk Management Limit for Carcinogens (RL-CA), which is set at one excess cancer case in ten thousand (10,000) workers in a 45-year working lifetime (NIOSH, 2017). The TECRD for Malmstrom AFB is annotated on Appendix 6 (Malmstrom AFB Total Estimated Cancer Risk Determination for Missile Alert Facilities AFSCs).

Example of ECRD Calculation for Benzene in Air:

$$\begin{aligned} \text{ECRD}_{\text{Benzene-Air}} &= \text{SBE}_{\text{Benzene-Air}} \times \text{Inhalation Unit Risk}_{\text{Benzene}} \\ \text{ECRD}_{\text{Benzene-Air}} &= 230 \frac{\text{micrograms}}{\text{Cubic Meter}} \times \frac{7.8\text{E-}06 \text{ Cubic Meter}}{\text{microgram}} \\ \text{ECRD}_{\text{Benzene-Air}} &= 0.00179 \end{aligned}$$

Example of ECRD Calculation for 2,3,7,8-Tetrachlorodibenzo-p-dioxin in Drinking Water:

$$\begin{aligned} \text{ECRD}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} &= \text{BSE}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} \times \text{Daily Water Intake} \div \text{Body Weight} \times \text{Oral Risk Factor}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} \\ \text{ECRD}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} &= 4.3\text{E-}06 \frac{\text{micrograms}}{\text{Liter}} \times 2.5 \frac{\text{Liters}}{\text{Day}} \times \frac{1}{80 \text{ kilograms}} \times \frac{130 \text{ kilogram-day}}{\text{microgram}} \\ \text{ECRD}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} &= 1.75\text{E-}05 \end{aligned}$$

Notes:

- (1) Daily Water Intake of 2.5 Liters is in accordance with the practices published in the United States Environmental Protection Agency *Regional Screen Levels (RSLs) – User’s Guide* (November 2024.)
- (2) Body Weight of 80 kilograms is in accordance with Table 8-1, Chapter 8 of the United States Environmental Protection Agency *Exposure Factors Handbook* (September 2011).

Example of ECRD Calculation for Radon in Air:

$$ECRD_{\text{Radon-Air}} = SBE_{\text{Radon-Air}} \times \text{Inhalation Unit Risk}_{\text{Radon}}$$

$$ECRD_{\text{Benzene-Air}} = 0.2 \frac{\text{Working Level Months}}{\text{year}} \times 5E-04 \frac{\text{year}}{\text{Working Level Months}}$$

$$ECRD_{\text{Benzene-Air}} = 1E-04$$

Note: Inhalation Unit Risk for Radon is based on a “nominal probability coefficient” in Publication 115, *Lung Cancer Risk from Radon Progeny and Statement on Radon* published by the International Commission on Radiological Protection (ICRP). In Publication 115, the ICRP states “Based on recent results from combined analyses of epidemiological studies of miners, a lifetime excess absolute risk of 5×10^{-4} per WLM should now be used as the nominal probability coefficient for radon and radon progeny induced lung cancer”.

Example of TECRD Calculation for Malmstrom AFB:

$$TECRD_{\text{Malmstrom-AFB}} = \sum ECRD_{\text{Detected-Air-Chemicals}} + \sum ECRD_{\text{Detected-Drinking-Water-Chemicals}} + ECRD_{\text{Worst-Case-Dermal}}$$

$$ECRD_{\text{Detected-Air-Chemicals}} = ECRD_{\text{Benzene-Air}} + ECRD_{\text{Syrene-Air}} + ECRD_{\text{1,2-Dichloroethane-Air}} + ECRD_{\text{Radon}}$$

$$ECRD_{\text{Detected-Air-Chemicals}} = 0.00179 + 7.98E-06 + 3.38E-04 + 1E-04$$

$$ECRD_{\text{Detected-Air-Chemicals}} = 0.00223$$

$$ECRD_{\text{Detected-Drinking-Water-Chemicals}} = ECRD_{\text{Di(2-ethylhexyl)phthalate-Water}} + ECRD_{\text{2-3-7-8-Tetrachlorodibenzo-p-dioxin-Water}}$$

$$ECRD_{\text{Detected-Drinking-Water-Chemicals}} = 4.81E-07 + 1.75E-05$$

$$ECRD_{\text{Detected-Drinking-Water-Chemicals}} = 1.79E-05$$

$$ECRD_{\text{Worst-Case-Dermal}} = ECRD_{\text{Aroclor-1260}} + ECRD_{\text{Aroclor-1254}}$$

$$ECRD_{\text{Worst-Case-Dermal}} = 4.6E-05 + 4.6E-05 \text{ (Per Appendix 5)}$$

$$ECRD_{\text{Worst-Case-Dermal}} = 9.20E-05$$

$$TECRD_{\text{Malmstrom-AFB}} = 0.00223 + 1.79E-05 + 9.20E-05E-04$$

$$TECRD_{\text{Malmstrom-AFB}} = 0.00234$$

4.5 ESTIMATED CONSERVATIVE, UPPER-BOUND NON-CANCER HEALTH RISK DETERMINATION (NCEHRD) METHODOLOGY

All detected chemicals, both carcinogens and non-carcinogens were included in the conservative, upper-bound NCEHRD. In accordance with EPA-540-R-070-002, the conservative, upper-bound NCEHRD from multiple chemicals were assessed via each individual Health Quotient (HQ) for each substance (ATSDR, 2020). Conservative, upper-bound NCEHRDs are calculated by dividing the BSE of a detected air and/or drinking water chemical by its respective HSV. NCEHRDs are assumed to be overly conservative since these exposures are compared to HSVs, defined in paragraph 4.2, are non-compliance screening values, and are not supported by studies validating adverse health impacts from exposure.

The Total NCEHRDs (TNCEHRD) are summed from each individual NCEHRD only when exposures to these chemicals occurred simultaneously (previously referred to as Exposure Profiles). Exposure pathway combinations (referred to as an Exposure Profile) for the TNCEHRD are MAF exposures consisting of Radon, air inhalation, & drinking water ingestion. Per EPA 540-R-070-002, any incident of the TNCEHRD being greater than one (1) was repeated by deriving a TORD for each target organ (ATSDR, 2020).

Example of Conservative, Upper-Bound NCEHRD Calculation for Benzene in Air:

$$\text{NCEHRD}_{\text{Benzene-Air}} = \text{BSE}_{\text{Benzene-Air}} / \text{HSV}_{\text{Benzene-Air}}$$

$$\text{NCEHRD}_{\text{Benzene-Air}} = 230 \frac{\text{micrograms}}{\text{Cubic Meter}} \times \frac{\text{Cubic Meter}}{327.56 \text{ micrograms}}$$

$$\text{NCEHRD}_{\text{Benzene-Air}} = 0.702$$

Example of NCEHRD Calculation for Dioxin in Drinking Water:

$$\text{NCEHRD}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} = \text{BSE}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} / \text{HSV}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}}$$

$$\text{NCEHRD}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} = 4.3\text{E-}06 \frac{\text{micrograms}}{\text{Liter}} \times \frac{\text{Liter}}{3\text{E-}05 \text{ micrograms}}$$

$$\text{NCEHRD}_{2,3,7,8\text{-Tetrachlorodibenzo-p-dioxin-Water}} = 0.143$$

Example of NCEHRD Calculation for Aroclor-1254 Dermal Exposure:

$$\text{NCEHRD}_{\text{Aroclor-1254-Skin}} = \text{Maximum-High-Touch-Concentration}_{\text{Aroclor-1254}} / \text{HSV}_{\text{Aroclor-1254}}$$

$$\text{NCEHRD}_{\text{Aroclor-1254-Skin}} = 9.25 \frac{\text{micrograms}}{100 \text{ cm}^2} \times \frac{100 \text{ cm}^2}{10 \text{ micrograms}}$$

$$\text{NCEHRD}_{\text{Aroclor-1254-Skin}} = 0.925$$

Example of Conservative, Upper-Bound TNCEHRD Calculation for Malmstrom AFB:

$$\text{TNCEHRD}_{\text{Malmstrom AFB}} = \Sigma \text{NCEHRD}_{\text{Detected-Air-Chemicals}} + \Sigma \text{NCEHRD}_{\text{Detected-Drinking-Water-Chemicals}} + \text{NCEHRD}_{\text{Aroclor-1260-Dermal}} + \text{NCEHRD}_{\text{Aroclor-1254-Dermal}}$$

$$\text{NCEHRD}_{\text{Detected-Air-Chemicals}} = \text{NCEHRD}_{\text{Benzene-Air}} + \text{NCEHRD}_{\text{Styrene-Air}} + \text{NCEHRD}_{\text{1,2-Dichloroethane-Air}} + \text{NCEHRD}_{\text{Radon}} + \text{NCEHRD}_{\text{P+M Xylene-Air}} + \text{NCEHRD}_{\text{Toluene-Air}} + \text{NCEHRD}_{\text{Trans-1,2-Dichloroethylene-Air}}$$

$$\text{NCEHRD}_{\text{Detected-Air-Chemicals}} = 0.702 + 0.005 + 0.636 + 0.050 + 0.058 + 0.007 + 0.265$$

$$\text{NCEHRD}_{\text{Detected-Air-Chemicals}} = 1.723$$

$$\text{NCEHRD}_{\text{Detected-Drinking-Water-Chemicals}} = \text{NCEHRD}_{\text{Di(2-ethylhexyl)phthalate-Water}} + \text{NCEHRD}_{\text{2,3,7,8-Tetrachlorodibenzo-p-dioxin-Water}} + \text{NCEHRD}_{\text{Total-Nitrate/Nitrite-Water}}$$

$$\text{NCEHRD}_{\text{Detected-Drinking-Water-Chemicals}} = 0.183 + 0.143 + 0.460$$

$$\text{NCEHRD}_{\text{Detected-Drinking-Water-Chemicals}} = 0.786$$

$$\text{NCEHRD}_{\text{Detected-Dermal-Chemicals}} = \text{NCEHRD}_{\text{Aroclor-1260-Dermal}} + \text{NCEHRD}_{\text{Aroclor-1254-Skin}}$$

$$\text{NCEHRD}_{\text{Detected-Dermal-Chemicals}} = 0.925 + 0.925$$

$$\text{NCEHRD}_{\text{Detected-Dermal-Chemicals}} = 1.850$$

$$\text{TNCEHRD}_{\text{Malmstrom-AFB}} = 1.723 + 0.786 + 1.850$$

$$\text{TNEHCRD}_{\text{Malmstrom-AFB}} = 4.359$$

4.6 TARGET ORGAN RISK DETERMINATION (TORD)

Target organs for each chemical are referenced in Appendix 7 (Malmstrom AFB Exposure Pathway and Non-Cancerous Target Organ Listing). When determining target organs for each chemical, USAFSAM referenced the online NIOSH Pocket Guide, ACGIH 2024 Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices, the ATSDR, and the National Institute of Health PubChem database.

Appendix 8 (Malmstrom AFB Conservative, Upper-Bound Target Organ Risk Determination) documents the TORD for Malmstrom AFB. The conservative, upper-bound target organ risk calculated in Appendix 8 is assumed to be overly conservative since these exposures are compared to HSVs, defined in paragraph 4.2, are non-compliance screening values, and are not supported by studies validating adverse health impacts from exposures. Per EPA 540-R-070-002, any incident of the TNCEHRD being greater than one (1) was repeated by deriving a TORD for each target organ (ATSDR, 2020). Any TORD being greater than one (1) indicates environmental conditions have the potential to adversely impact that specific target organ and warrant further assessment.

In the event Appendix 8 identifies one or more target organs exceeding one (1), a Health-Based Target Organ Risk Determination (HBTORD) was conducted. An HBTORD replicated the process of the conservative, upper-bound TORD, but is a more accurate tool to assess health risk considering exposures are compared to Federal health compliance standards in lieu of

HSVs. For chemical inhalation exposures, the United States Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) is used (the ACGIH TLV is used only in absence of an OSHA PEL). For ingestion exposures, the USEPA MCL is used. Absorption exposures remain compared to limits set forth by 40 CFR 761 while radon exposure remain compared to limits in AFMAN 48-148. Appendix 9 (Malmstrom AFB Health-Based Target Organ Risk Determination) documents the HBTORD for Malmstrom AFB.

Example of Conservative, Upper-Bound TORD Calculation for the Cardiovascular System for Malmstrom AFB:

$$\text{TORD}_{\text{Cardiovascular-System}} = \text{NCEHRD}_{\text{Styrene-Air}} + \text{NCEHRD}_{\text{1,2-Dichloroethane-Air}} + \text{NCEHRD}_{\text{Toluene-Air}} + \text{NCEHRD}_{\text{Total-Nitrate/Nitrite-Water}}$$

$$\text{TORD}_{\text{Cardiovascular-System}} = 0.005 + 0.636 + 0.007 + 0.460$$

$$\text{TORD}_{\text{Cardiovascular-System}} = 1.108$$

Example of Health-Based TORD Calculation for the Cardiovascular System for Malmstrom AFB:

$$\text{HBTORD}_{\text{Cardiovascular-System}} = \text{HBNCEHRD}_{\text{Styrene-Air}} + \text{HBNCEHRD}_{\text{1,2-Dichloroethane-Air}} + \text{HBNCEHRD}_{\text{Toluene-Air}} + \text{HBNCEHRD}_{\text{Total-Nitrate/Nitrite-Water}}$$

$$\text{HBTORD}_{\text{Cardiovascular-System}} = 0.000 + 0.000 + 0.000 + 0.460$$

$$\text{HBTORD}_{\text{Cardiovascular-System}} = 0.460$$

4.7 STATISTICAL ANALYSIS

A tolerance interval of sample concentration was chosen as the most relevant feature to report for the cancer study. The upper-bound for the 95th percentiles were percentiles calculated with 95% statistical confidence. There are two scenarios present which require different analysis methods to make full use of available information from the data:

A. Scenario 1: In The Presence of Measurable Concentrations

In this scenario there are some samples with detected concentrations of an agent/compound. However, most of the data is left-censored, meaning there is a known minimum detectable concentration such as an analytical Reporting Limit (RL) and/or LOD, and no detected presence of the agent/compound. In this situation, there are not enough observed/detected values to verify whether the data was parametrically distributed, so the non-parametric estimation was used. The Kaplan Meier estimator was used to construct tolerance intervals (a range of values within a statistical level of confidence) for the analyte concentrations.

B. Scenario 2: No Measurable Concentrations:

The USEPA provides guidance to improve the quality and consistency of risk assessments from data near the RL/LOD (USEPA, 2024). Under this guidance, USEPA proposes four options where data is below the RL/LOD:

(1) **Non-Detect concentrations are assumed to be same as the RL/LOD:** The USEPA guidance indicates assuming the Non-Detect to be the same as the RL/LOD is highly conservative, biased, and not consistent with the best science in risk assessments (USEPA, 2024).

(2) Non-Detect concentrations are reported as zero (0): The USEPA indicates this approach is the “best-case approach” when the risk assessor determines the chemicals are unlikely to be present (USEPA, 2024).

(3) Non-Detect concentrations are reported as half the RL/LOD: The USEPA states this approach assumes that, on average, all values are between the LOD and zero (USEPA, 2024).

(4) Statistical estimates for concentrations below the LOD: The USEPA states this approach is superior to reporting non-detects as half the RL/LOD; however, is most effective for data sets having greater than 50% detects (USEPA, 2024).

To balance risk calculation without erroneously inflating the risk, USAFSAM used the USEPA “best-case approach” (Non-detect concentrations reported as zero) for chemicals which were non-detected throughout the three phases of the study. Therefore, the TECRD, TNCEHRD, and TORD were based on detected chemicals only. All concentrations below the LOD/LOQ were not included in the TECRD or NCEHRD (See Appendix 10, Malmstrom AFB Chemicals Not Assessed for Health Risk: All Sample Results Less Than LOQ). Those chemical agents listed in Appendix 10 were not included in the TECRD or NCEHRD:

4.7.1 Because the air sample results were less than the sampling and analytical method RL/LOD, the remaining forty-four (44) non-detected VOCs are concluded to not be present in the MAFs at concentrations impacting occupant health.

4.7.2 Because all PCB air samples were below the sampling and analytical method RL/LOD, the conclusion is they are not present in the MAFs at concentrations impacting occupant health.

4.7.3 Because all organophosphate air sample results were below the sampling and analytical method RL/LOD, the conclusion is they are not present in the MAFs at concentrations impacting occupant health.

4.7.4 Because the drinking water sample results were less than the sampling and analytical RL/LOD, the remaining non-detected SVOCs & organophosphates are concluded to not be present in MAF drinking water at concentrations impacting occupant health.

4.7.5 Because all diquat/paraquat drinking water sample results were below the sampling and analytical method RL/LOD, the conclusion is they are not present in MAF drinking water at concentrations impacting occupant health.

4.7.5 Because all PCB drinking water sample results were below the sampling and analytical method RL/LOD, the conclusion is they are not present in MAF drinking water at concentrations impacting occupant health.

4.7.6 Because all concentrations of organophosphates in the ninety (90) soil samples were less than the sampling and analytical method RL/LOD, the conclusion is they are not present in the soil surrounding the MAFs at concentrations impacting occupant health.

5. ANALYSIS

Appendices 7, 8 and 10 document the TECRD, NCEHRD, and TORD for Malmstrom AFB.

5.1 TOTAL ESTIMATED CANCER RISK DETERMINATION (TECRD)

Statistical analysis at a confidence exceeding 95% confirms dermal exposures to Aroclor 1254 and Aroclor 1260 are below the surface contamination mitigation thresholds mandated by

40 CFR 761. Appendix 5 (Malmstrom AFB Estimated PCB Dermal Exposure Cancer Risk Determination) conservatively estimates the cancer risk associated with PCB dermal exposure on frequently touched surfaces. The Right-Side Visual Display Screen in India-01 revealed Aroclor 1254 at 9.25 micrograms per one-hundred square centimeters ($\mu\text{g}/100\text{ cm}^2$). The absolute worst-case conditions were assumed and include; a) the entire hand being exposed; b) complete concentration transfer between surface and hand; c) complete chemical absorption through the skin; and d) contact between hand and contaminated surface occurring for 350 continuous days each year. Even with these assumptions, the excess cancer risk was calculated to be less than one MAF occupant per 10,000 MAF occupants (<1 per 10,000). The risk associated with dermal contact to PCBs is incorporated into the overall cancer and non-cancer risks

5.1.1. CONSERVATIVE, UPPER-BOUND CANCER RISK ESTIMATE

The American Cancer Society calculates males have a 39.9% probability of developing cancer across their lifetime while females have a 39% probability of developing cancer in their lifetime (American Cancer Society, 2025). Per Appendix 6, the cumulative cancer risk at Malmstrom AFB has a conservative, upper-bound estimate of 23.4 excess cancers in 10,000 MAF occupants. This cumulative cancer risk does not imply the conditions within the Malmstrom AFB MAFs are 23.4 times more likely to cause an incident of occupational-induced cancer, but that the most conservative estimates determine a potential for elevated incidences of occupationally induced cancer based on the current occupational and environmental conditions at the Malmstrom AFB MAFs. An excess cancer risk of 23 out of 10,000 MAF occupants equates to a potential 0.23% increase in probability of developing cancer across a 70-year lifetime ($0.23\% = 23 / 10,000 \times 100[\%]$). The excess cancer risk from MAF occupancy has the potential to increase a:

- A. Male MAF workers' probability of developing cancer from 39.9% to 40.13%, and a
- B. Female MAF workers' probability of developing cancer from 39% to 39.23%.

5.1.2. CONSERVATIVE, LOWER-BOUND CANCER RISK ESTIMATE

As discussed in paragraph 4.3, the inhalation, ingestion, and absorption EFs are 0.033. When applying these EFs to the conservative, upper-bound cancer estimate, the conservative, lower-bound cancer estimate is calculated. Table 3 captures the conservative, lower-bound cancer risk estimate by utilizing equations endorsed by the ATSDR. Specifically, the ATSDR states:

- A. Inhalation cancer risk can be adjusted by multiplying the long-term air concentration by the Inhalation Unit risk using the equation *Inhalation Cancer Risk = Inhalation Unit Risk x Exposure Point Concentration x EF* (ATSDR, 2021).
- B. Ingestion cancer risk can be adjusted by the number of years of exposure divided by 78 years (the average human life span) using the equation *Ingestion Cancer Risk = Inhalation Unit Risk x Exposure Point Concentration x EF* (ATSDR, 2023).

Therefore, Table 3 and Appendix 6 demonstrate the cumulative cancer risk at Malmstrom AFB is estimated to be between a lower-bound estimate of less than one (1) excess cancer risk in ten thousand (10,000) assigned MAF personnel to a conservative, upper-bound estimate of 23.4 excess cancer risks in 10,000 MAF occupants.

Table 3: Lower-Bound Cancer Estimate for Malmstrom AFB Based on Eight-Years of Exposure

Route of Exposure	Chemical Name	CAS Number	Cancer Risk	Lower-Bound Cancer Risk	Lower-Bound Estimated Cancer Risk By Exposure Pathway	Total Lower-Bound Cancer Risk	Lower-Bound Cancer Risk
Inhalation	Benzene	71-43-2	0.00179	5.92E-05	6.4E-05	9E-05	Potential Lower-Bound Cancer Risk is less than 1 in 10,000 MAF Occupants
	Styrene	100-42-5	7.98E-06	2.63E-07			
	1,2-Dichloroethane	107-06-2	3.38E-04	1.12E-06			
	Radon-222	14859-67-7	1E-4	3E-06			
Ingestion	Di(2-ethylhexyl)phthalate	117-81-7	4.81E-07	5.08E-06	2.3E-05		
	2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	1.75E-05	1.84E-05			
Dermal	Aroclor 1260	11096-82-5	4.6E-05	1.52E-06	3E-06		
	Aroclor 1254	11097-69-1	4.6E-05	1.52E-06			

5.2 NON-CANCER ESTIMATED HEALTH RISK DETERMINATION (NCEHRD)

The NCEHRD considers carcinogens and non-carcinogens detected at Malmstrom AFB. The NCEHRD was calculated from any chemical containing one-or-more detectable concentrations. Appendix 4 (Malmstrom AFB Detected Chemicals Included in the Health Risk Assessment) documents the:

A. Seven (7) carcinogens:

- (1) Air: 1,2-Dichloroethane, Styrene, Benzene, Radon;
- (2) Drinking Water: 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Di(2-ethylhexyl)phthalate;
- (3) Dermal: Aroclor-1254; and

B. Four (4) non-carcinogens:

- (1) Air: p+m-xylene, Toluene, Trans-1,2-Dichloroethylene;
- (2) Drinking Water: Total Nitrate/Nitrite.

Appendix 11 (Malmstrom AFB Conservative, Upper-Bound Total Non-Cancer Estimated Health Risk Determination for Missile Alert Facilities AFSCs) calculates the most conservative, cumulative non-cancer health risk for Malmstrom AFB to be greater than one, (>1) prompting an analysis by target organs known to be impacted by these twelve (12) chemicals. The cumulative non-cancer health risk calculated in Appendix 11 is assumed to be overly conservative since these exposures are compared to HSVs, defined in paragraph 4.2, are non-compliance screening values and are not supported by studies validating adverse health impacts from exposure.

5.3. TARGET ORGAN RISK DETERMINATION (TORD)

The conservative, upper-bound TORD shown in Appendix 8 (Malmstrom AFB Target Organ Risk Determination) calculates a potential elevated risk to eleven (11) human organs. This conservative, upper-bound TORD does not imply the conditions within the Malmstrom AFB MAFs are more likely to impact these eleven organs, but that the most conservative estimates determine a potential for elevated incidences of target organ impacts based on the current occupational and environmental conditions at Malmstrom AFB MAFs. The conservative, upper-

bound TORD identifies potential elevated non-cancer health risk to the central nervous, cardiovascular, gastrointestinal, immune, respiratory, reproductive, and skin organ systems and blood, eyes, liver, and kidneys.

The HBTORD shown in Appendix 9 (Malmstrom AFB Health-Based Target Organ Risk Determination) is a regulatory-based analysis which assess target organ risk against known, scientifically accepted health limits. The HBTORD calculates a potential elevated risk to the skin. This TORD does not imply the conditions within the Malmstrom AFB MAFs are more likely to impact the skin, but that the most conservative estimates determine a potential for elevated incidences of skin impacts based on the current occupational and environmental conditions at Malmstrom AFB MAFs. Therefore, the current conditions within the Malmstrom AFB MAFs have the potential to contribute to health-based non-cancer health risk which impacts the skin to a conservative, upper-bound non-cancer health risk which impact the central nervous, cardiovascular, gastrointestinal, immune, respiratory, reproductive, and skin organ systems and blood, eyes, liver, and kidneys.

6. UNCERTAINTIES AND LIMITATIONS

Per the USEPA Science Policy Council Handbook: Risk Characterization, the principle of Transparency is fulfilled through the communication of Uncertainty (USEPA, 2000). Appendix 12 (MCCS Risk Assessment Areas of Uncertainty and Mitigating Steps) consolidates all known uncertainties identified by USAFSAM/OE throughout this study.

7. ACKNOWLEDGMENTS

Appendix 13 (Acknowledgements) lists all individuals who assisted with this study.

8. COMPLETION

If you have any questions, comments, or concerns, please contact the undersigned at 937-255-3865 or by e-mail at scott.boyd.2@us.af.mil.

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THIRTEEN (13) APPENDICES

1. Malmstrom AFB Consolidated Surface Contamination Exposures
2. Malmstrom AFB MAF Carcinogen Listing
3. Malmstrom AFB Statistical Base Exposure, Confidence, Health Screening Value, & Cancer Curves
4. Malmstrom AFB Detected Chemicals Included in the Health Risk Assessment
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11. Malmstrom AFB Conservative, Upper-Bound Total Non-Cancer Estimated Health Risk Determination for Missile Alert Facilities AFSCs Per 10,000 Personnel Based on 8-Years of Exposure
12. MCCS Risk Assessment Areas of Uncertainty and Mitigating Steps
13. Acknowledgements

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AFB	Air Force Base
AFGSC/A3	Air Force Global Strike Command Operations
AFIT	Air Force Institute of Technology
AFMAN	Air Force Manual
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATSDR	Agency for Toxic Substances and Disease Registry
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO ₂	Carbon dioxide
DHHS	United States Department of Health and Human Services
DNEL	Derived No-Effect Level
DoD	Department of Defense
DoE	Department of Energy
DTIC	Defense Technical Information Center
ECHA	European Chemical Agency
ECRD	Estimated Cancer Risk Determination
EF	Exposure Factor
EFH	Exposure Factors Handbook
EPA	Environmental Protection Agency
EQS	Environmental Quality Standards
EU	European Union
GHS	United Nations' Globally Harmonized System for Classification and Labelling of Chemicals
GLP	Good Laboratory Practice
HA	Health Advisory
HBSL	Health-Based Screening Levels
HBTORD	Health-Based Target Organ Risk Determination
HQ	Health Quotient
HSV	Health Screening Values
IARC	International Agency for Research on Cancer
ICBM	Intercontinental Ballistic Missile
ICRP	the International Commission on Radiological Protection
IRIS	Integrated Risk Information System
LCC	Launch Control Centers
LOD	Limit of Detection
LOQ	Limit of Quantification
MAF	Missile Alert Facility
MCCS	Missile Community Cancer Study
MCL	Maximum Contaminant Level
MEG	Military Exposure Guidelines
MPT	Missile Procedure Trainer
MRL	Minimal Risk Levels

ACRONYMS
(Continued)

MSC	Medium Specific Concentrations
NCEHRD	Non-Cancer Estimated Health Risk Determination
NECi	National Environmental Compliance Institute
NHL	Non-Hodgkin Lymphoma
NIOSH	National Institute of Occupational Safety and Health
NTP	National Toxicology Program
OPPTS	Office of Prevention, Pesticides, and Toxic Substances
OSHA	Occupational Safety and Health Administration
PAC	Protective Action Criteria
PCB	Polychlorinated Biphenyl
PEL	Permissible Exposure Limit
pH	Potential of Hydrogen
PPM	Parts Per Million
PPRTV	Provisional Peer Reviewed Toxicity Values
RfC	Reference Concentration
RfD	Reference Dose
RH	Relative Humidity
RL	Reporting Limit
RoC	Report on Carcinogens
RSL	Regional Screening Levels
SBE	Statistical Base Exposure
SFB	Space Force Base
STATCOE	Scientific Test and Analysis Techniques Center of Excellence
SVOC	Semi-Volatile Organic Compounds
TECRD	Total Estimated Cancer Risk Determination
TEG	Test and Evaluation Group
THQ	Target Hazard Quotient
TLV	Threshold Limit Value
TNCEHRD	Total Non-Cancer Estimated Health Risk Determination
TORD	Target Organ Risk Determination
TR	Target Risk
TRS	Training Squadron
USAFSAM	United States Air Force School of Aerospace Medicine
USAFSAM/OE	United States Air Force School of Aerospace Medicine Occupational and Environmental Health Department
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compounds
WHO	World Health Organization
WLM	Working Level Months
Yr	Year

APPENDIX 1 – MALMSTROM AFB CONSOLIDATED SURFACE CONTAMINATION EXPOSURES

CHEMICAL	CAS REGISTRY NUMBER	STATISTICAL BASE EXPOSURE	CONFIDENCE	HEALTH SCREENING VALUE
		[µg/100 cm ²]		[µg/100 cm ²]*
Aroclor 1016	12674-11-2	Non-Detect (<1 microgram per wipe (µg/wipe)	N/A	10
Aroclor 1221	11104-28-2	Non-Detect (<1 µg/wipe)	N/A	10
Aroclor 1232	11141-16-5	Non-Detect (<1 µg/wipe)	N/A	10
Aroclor 1242	53469-21-9	Non-Detect (<1 µg/wipe)	N/A	10
Aroclor 1248	12672-29-6	Non-Detect (<1 µg/wipe)	N/A	10
Aroclor 1254	11097-69-1	1.04	96.7%	10
Aroclor 1260	11096-82-5	2.32	97.9%	10
Total PCBs as Aroclor	1336-36-3	1.24	95.2%	10
µg/100 cm ² = micrograms per 100 square centimeters				
* Per 40 CFR 761				

APPENDIX 2 – MALMSTROM AFB MAF CARCINOGEN LISTING

CHEMICAL NAME	CAS NUMBER	IARC GROUP ¹	USEPA IRIS CLASSIFICATION ²	DHHS NTP CLASSIFICATION ³	NIOSH DETERMINATION ⁴	ACGIH DETERMINATION ⁵
Benzene	71-43-2	1 - Carcinogenic	A – Carcinogenic	Currently Not Classified	Potential Carcinogen	A1 – Confirmed Carcinogen
Methylene Chloride	75-09-2	2A - Probably Carcinogenic	“Likely” Carcinogenic	Currently Not Classified	Potential Carcinogen	A3 – Animal Carcinogen
Styrene	100-42-5	2A - Probably Carcinogenic	Currently Not Classified	Reasonably Anticipated	Currently Not Classified	A3 – Animal Carcinogen
1,2-Dichloroethane	107-06-2	2B – Possibly Carcinogenic	B2 – Probably Carcinogenic	Currently Not Classified	Potential Carcinogen	A4 – Not Classified
Di(2-ethylhexyl)phthalate	117-81-7	2B – Possibly Carcinogenic	B2 – Probably Carcinogenic	Currently Not Classified	Potential Carcinogen	A3 – Animal Carcinogen
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	1 - Carcinogenic	Not Applicable	Known Carcinogen	Potential Carcinogen	Currently Not Classified
Aroclor-1260	11096-82-5	Not Assessed	Not Assessed	Reasonably Anticipated	Not Assessed	Not Assessed
Aroclor-1254	11097-69-1	2A - Probably Carcinogenic	Not Assessed	Reasonably Anticipated	Potential Carcinogen	A3 – Animal Carcinogen
Radon-222	14859-67-7	1 - Carcinogenic	Carcinogen Assessment Withdrawn	Currently Not Classified	Currently Not Classified	Currently Not Classified

1. Agents Classified by the IARC Monographs, Volumes 1-136 (Accessed on 23 September 2024)
2. USEPA Integrated Risk Information System (IRIS), Last Updated on 20 August 2024 (Accessed on 24 September 2024)
3. 15th Report on Carcinogens, DHHS, Last Updated on 21 December 2021 (Accessed on 24 September 2024)
4. NIOSH Pocket Guide to Chemical Hazards, Last Reviewed on 18 February 2020 (Accessed on 24 September 2024)
5. ACGIH

APPENDIX 3 – MALMSTROM AFB STATISTICAL BASE EXPOSURE, CONFIDENCE, HEALTH SCREENING VALUE & CANCER CURVES

CHEMICAL	CAS REGISTRY NUMBER	STATISTICAL BASE EXPOSURE	CONFIDENCE	HEALTH SCREENING VALUE	INHALATION UNIT RISK	NUMBER OF SAMPLES WITH DETECTS [%]
		[µg/m ³]		[µg/m ³]	[m ³ /µg]	
Benzene	71-43-2	230	95.9%	327.56 ¹	7.8E-06 ²	8 [9%]
Styrene	100-42-5	14	97.9%	2,920 ¹	5.7E-07 ⁴	1 [2%]
1,2-Dichloroethane	107-06-2	13	95.9%	20.44 ¹	2.6E-05 ²	2 [3%]
Toluene	108-88-3	99	95.9%	14,600 ⁵	N/A	5 [6%]
Trans-1,2-Dichloroethylene	156-60-5	31	95.9%	116.80 ³	N/A	3 [4%]
p+m Xylene	179601-23-1	17	97.9%	292 ⁵	N/A	1 [2%]
CHEMICAL	CAS REGISTRY NUMBER	STATISTICAL BASE EXPOSURE	CONFIDENCE	HEALTH SCREENING VALUE	INHALATION UNIT RISK	NUMBER OF SAMPLES WITH DETECTS [%]
		[WLM/yr]		[WLM/yr]	[yr/WLM]	
Radon-222	14859-67-7	0.2	96.5%	4 ⁶	5E-04 ⁷	75 [100%]
CHEMICAL	CAS REGISTRY NUMBER	STATISTICAL BASE EXPOSURE	CONFIDENCE	HEALTH SCREENING VALUE	ORAL SLOPE FACTOR	NUMBER OF SAMPLES WITH DETECTS [%]
		[µg/L]		[µg/L]	[kg-day/µg]	
Di(2-ethylhexyl)phthalate	117-81-7	1.1	95.9%	6 ⁸	1.4E-05 ²	1 [2%]
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	4.3E-06	97.9%	3E-05 ⁸	130 ⁹	2 [3%]
Total Nitrate/Nitrite	14797-55-8	4,600	95.9%	10,000 ⁸	N/A	31 [35%]
µg = Micrograms; m ³ = Cubic Meter; WLM/yr = Working Level Months per Year; L = Liter; kg = Kilograms						
<ol style="list-style-type: none"> Tier 1: Health Screening Value based on United States Environmental Protection Agency Integrated Risk Information System (Accessed 19 December 2024) and recalculated assuming routine 13N occupancy within MAFs are limited to no-more-than eight (8) years of their military career. Tier 1: Inhalation Unit Risk or Oral Slope Factor obtained from United States Environmental Protection Agency Integrated Risk Information System (Accessed 19 December 2024) Provisional Peer-Reviewed Toxicity Values (PPRTV), United States Environmental Protection Agency (Accessed 1 July 2024) Tier 3: Inhalation Unit Risk obtained from New Jersey Department of Environmental Protection Standards for Drinking Water, Ground Water, Surface Water, Soil, and Indoor Air, Styrene/CAS# 100-42-5, 30 September 2008 (Accessed 15 May 2025) Tier 1: Regional Screening Level, United States Environmental Protection Agency Integrated Risk Information System (Accessed 1 July 2024) Tier 3: Air Force Manual 48-148, <i>Ionizing Radiation Protection</i> (20 July 2020) Tier 3: Inhalation Unit Risk based on “nominal probability coefficient” published in Publication 115 by the International Commission on Radiological Protection (Accessed 16 May 2025) Tier 1 Equivalent: Maximum Contaminant Level, United States Environmental Protection Agency (Accessed 1 July 2024) Tier 3: Oral Slope Factor obtained from California Office of Environmental Health Hazard Assessment (Accessed 14 May 2025) 						

APPENDIX 4 – MALMSTROM AFB DETECTED CHEMICALS INCLUDED IN THE HEALTH RISK ASSESSMENT

CHEMICAL NAME	CAS NUMBER	MATRIX	ROUTE OF EXPOSURE	TOTAL NUMBER OF SAMPLES ANALYZED*	TOTAL NUMBER OF TIMES DETECTED	PERCENT DETECTS	LOWEST VALUE OF DETECTS [µg/m³]	HIGHEST VALUE OF DETECTS [µg/m³]	MEDIAN VALUE OF DETECTS** [µg/m³]	CARCINOGEN OR NON-CARCINOGEN
Benzene***	71-43-2	Air	Inhalation	90	8	9	17	1600	349	Carcinogen
Styrene***	100-42-5			90	1	2	14	14	14	Carcinogen
1,2-Dichloroethane***	107-06-2			90	2	3	13	15	14	Carcinogen
Toluene	108-88-3			90	5	6	14	180	68	Non-Carcinogen
Trans-1,2-Dichloroethylene	156-60-5			90	2	3	26	36	31	Non-Carcinogen
p+m-Xylene	179601-23-1			90	1	2	17	17	17	Non-Carcinogen
CHEMICAL NAME	CAS NUMBER	MATRIX	ROUTE OF EXPOSURE	TOTAL NUMBER OF SAMPLES ANALYZED*	TOTAL NUMBER OF TIMES DETECTED	PERCENT DETECTS	LOWEST VALUE OF DETECTS [µg/L]	HIGHEST VALUE OF DETECTS [µg/L]	MEDIAN OF DETECTS VALUE** [µg/L]	CARCINOGEN OR NON-CARCINOGEN
Di(2-ethylhexyl)phthalate***	117-81-7	Drinking Water	Ingestion	90	1	2	0.95	0.95	0.95	Carcinogen
2,3,7,8-Tetrachlorodibenzo-p-dioxin***	1746-01-6			90	2	3	4.3E-07	4.3E-07	4.3E-07	Carcinogen
Total Nitrate/Nitrite	14797-55-8			90	31	35	100	4,700	2,035	Non-Carcinogen
*Excludes Media Blanks and Trip Blanks.										
** Includes Median Value of Detects only, while disregarding all Non-Detects										
*** Indicates chemical has been deemed a carcinogen per the National Toxicology Program, United States Environmental Protection Agency, International Agency for Research on Cancer, National Institute of Occupational Safety and Health, and/or American Conference of Governmental Industrial Hygienists										

APPENDIX 4 – MALMSTROM AFB DETECTED CHEMICALS INCLUDED IN THE HEALTH RISK ASSESSMENT (Continued)

CHEMICAL NAME	CAS NUMBER	MATRIX	ROUTE OF EXPOSURE	TOTAL NUMBER OF SAMPLES ANALYZED*	TOTAL NUMBER OF TIMES DETECTED	PERCENT DETECTS	LOWEST VALUE OF DETECTS [µg/Swipe]	HIGHEST VALUE OF DETECTS [µg/Swipe]	MEDIAN VALUE OF DETECTS [µg/Swipe]	CARCINOGEN OR NON-CARCINOGEN
Aroclor-1260***	11096-82-5	Surface	Absorption	336	8	3	2.32	2010	255.28	Carcinogen
Aroclor-1254***	11097-69-1	Surface	Absorption	336	13	4	1.04	10.4	2.19	Carcinogen
CHEMICAL NAME	CAS NUMBER	MATRIX	ROUTE OF EXPOSURE	TOTAL NUMBER OF SAMPLES ANALYZED*	TOTAL NUMBER OF TIMES DETECTED	PERCENT DETECTS	LOWEST VALUE OF DETECTS [WLM/yr]	HIGHEST VALUE OF DETECTS [WLM/yr]	MEDIAN VALUE OF DETECTS** [WLM/yr]	CARCINOGEN OR NON-CARCINOGEN
Radon-222***	14859-67-7	Air	Inhalation	75	75	100	0.03	0.60	0.15	Carcinogen
*Excludes Media Blanks and Trip Blanks.										
** Average of the highest radon values for each MAF.										
*** Indicates chemical has been deemed a carcinogen per the National Toxicology Program, United States Environmental Protection Agency, International Agency for Research on Cancer, National Institute of Occupational Safety and Health, and/or American Conference of Governmental Industrial Hygienists										

APPENDIX 5: MALMSTROM AFB ESTIMATED PCB DERMAL EXPOSURE CANCER RISK DETERMINATION PER 10,000 PERSONNEL

BASED ON HIGHEST SURFACE CONCENTRATION DETECTED ON A FREQUENT CONTACT AREA SUCH AS CONSOLE KEYBOARD OR VISUAL DISPLAY SCREEN

POLYCHLORINATED BIPHENYL (PCB) Wipes	CAS REGISTRY NUMBER	BASE EXPOSURE	Location with Greatest Concentration	DERMAL UNIT RISK*	CANCER RISK	TOTAL SURFACE SAMPLES
		[µg/100 cm ²]		[mg/kg-day]		
Aroclor 1016	12674-11-2	<1	Not Applicable	0.4	0.46	336
Aroclor 1260	11096-82-5	<1	Not Applicable			
Aroclor 1221	11104-28-2	<1	Not Applicable			
Aroclor 1232	11141-16-5	<1	Not Applicable			
Aroclor 1242	53469-21-9	<1	Not Applicable			
Aroclor 1248	12672-29-6	<1	Not Applicable			
Aroclor 1254	11097-69-1	9.25	India, Rt Side Visual Display Screen			
Total PCBs [unspecified]	12767-79-2	9.25	ibid			
PCB Dermal Exposure Risk for Cancer per 10,000 Personnel					Less than 1	

* Source: United States Environmental Protection Agency, Hudson River PCBs Superfund Site/Human Health Tables/PCB Cancer Slope Factors

Background: 100 cm² is approx. surface area of the hand. µg/1000 = mg. 80 kg body weight [EPA Factors Handbook, Chapter 8]

Dose Calculation: (9.25 ug /1000 ug/mg)/80 kg = 0.00011 mg/kg-day

Cancer Risk Calculation = Dose x Dermal Unit Risk = 0.00011 x 0.4 = 0.0000046

Exposure Risk per 10,000 personnel = 0.0000046 x 10,000 = 0.46

Assumptions: a) Entire hand surface exposed; b) Entire concentration transferred to the hand; c) Not washed off /complete absorption; and d) Frequency and duration of exposure are aligned to a residential exposure where the occupant encounter dermal contact with the contaminated surface continuously for 24 hours per day, 350 days per year.

APPENDIX 5: MALMSTROM AFB ESTIMATED PCB DERMAL EXPOSURE CANCER RISK DETERMINATION PER 10,000 PERSONNEL (Continued)

BASED ON HIGHEST SURFACE CONCENTRATION DETECTED ON A FREQUENT CONTACT AREA SUCH AS CONSOLE KEYBOARD OR VISUAL DISPLAY SCREEN						
POLYCHLORINATED BIPHENYL (PCB) Wipes	CAS REGISTRY NUMBER	BASE EXPOSURE	Location with Greatest Concentration	DERMAL UNIT RISK*	CANCER RISK	TOTAL SURFACE SAMPLES
		[µg/100 cm²]		[mg/kg-day]		
Aroclor 1016	12674-11-2	<1	Not Applicable	0.4	0.53	336
Aroclor 1260	11096-82-5	9.25	India, Rt Side Visual Display Screen			
Aroclor 1221	11104-28-2	<1	Not Applicable			
Aroclor 1232	11141-16-5	<1	Not Applicable			
Aroclor 1242	53469-21-9	<1	Not Applicable			
Aroclor 1248	12672-29-6	<1	Not Applicable			
Aroclor 1254	11097-69-1	<1	Not Applicable			
Total PCBs [unspecified]	12767-79-2	9.25	ibid			
PCB Dermal Exposure Risk for Cancer per 10,000 Personnel					Less than 1	
* Source: United States Environmental Protection Agency, Hudson River PCBs Superfund Site/Human Health Tables/PCB Cancer Slope Factors Background: 100 cm² is approx. surface area of the hand. µg/1000 = mg. 70 kg body weight [EPA Factors Handbook, Chapter 8] Dose Calculation: (9.25 ug /1000 ug/mg)/80 kg = 0.00011 mg/kg-day Cancer Risk Calculation = Dose x Dermal Unit Risk = 0.00013 x 0.4 = 0.000046 Exposure Risk per 10,000 personnel = 0.000046 x 10,000 = 0.46 Assumptions: a) Entire hand surface exposed; b) Entire concentration transferred to the hand; c) Not washed off /complete absorption; and d) Frequency and duration of exposure are aligned to a residential exposure where the occupant encounter dermal contact with the contaminated surface continuously for 24 hours per day, 350 days per year.						

**APPENDIX 6 – MALMSTROM AFB TOTAL ESTIMATED CANCER RISK DETERMINATION FOR MISSILE ALERT FACILITIES AFSCs PER 10,000
PERSONNEL BASED ON 70-YEARS OF EXPOSURE**

CHEMICAL NAME	CAS NUMBER	MATRIX	ROUTE OF EXPOSURE	INHALATION CANCER RISK	INGESTION CANCER RISK	DERMAL CANCER RISK	CUMULATIVE CANCER RISK BY EXPOSURE PATHWAY	TOTAL ESTIMATED CANCER RISK	EXCEEDS ONE EXCESS CANCER RISK IN TEN THOUSAND [0.0001]?*	CANCER RISK**			
Benzene	71-43-2	Air	Inhalation	0.00179	---	---	0.00223	0.00234	Yes	Potential Cancer Risk Equals 23 in 10,000 MAF Occupants			
Styrene	100-42-5			7.98E-06	---	---							
1,2-Dichloroethane	107-06-2			3.38E-04	---	---							
Radon-222	14859-67-7			1E-4	---	---							
Di(2-ethylhexyl)phthalate	117-81-7	Drinking Water	Ingestion	---	4.81E-07	---	1.79E-05						
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6			---	1.75E-05	---							
Aroclor 1260	11096-82-5	Surface	Absorption	---	---	4.6E-05	9.26E-05						
Aroclor 1254	11097-69-1			---	---	4.6E-05							
* Source: National Institute of Occupational Safety and Health, <i>Current Intelligence Bulletin 68: NIOSH Chemical Carcinogen Policy</i> (2017)													
** Number is attributed to Total Cancer Risk, which may include Non-Hodgkins Lymphoma (NHL)													

APPENDIX 7 – MALMSTROM AFB EXPOSURE PATHWAY AND NON-CANCEROUS TARGET ORGAN LISTING

CHEMICAL NAME	CAS NUMBER	EXPOSURE PATHWAY	NON-CANCEROUS TARGET ORGANS
Benzene	71-43-2	Inhalation	BL ¹ , BM ¹ , CNS ¹ , EY ¹ , GIT ⁴ , IS ⁴ , RP ¹ , SK ¹
Methylene Chloride	75-09-2		BL ² , CNS ¹ , CVS ¹ , EY ¹ , Li ⁴ , SK ¹
Styrene	100-42-5		BL ⁴ , CNS ¹ , EY ¹ , Li ¹ , PNS ² , RP ¹ , RS ¹ , SK ¹
1,2-Dichloroethane	107-06-2		CNS ¹ , CVS ¹ , EY ¹ , GIT ⁴ , IS ⁴ , Ki ¹ , Li ¹ , RS ⁴ , UT ⁴
Toluene	108-88-3		CNS ¹ , CVS ⁴ , EY ¹ , IS ⁴ , Ki ¹ , Li ¹ , RP ¹ , RS ² , SK ¹ , UT ⁴
Trans-1,2-Dichloroethylene	156-60-5		CNS ² , EY ² , IS ⁴ , SK ⁴
Radon-222	14859-67-7		RP ³
p+m-Xylene ¹	179601-23-1		BL, CNS, GIT, Ki, Li, RP, SK
Di(2-ethylhexyl)phthalate	117-81-7	Ingestion	CNS ¹ , EY ¹ , GIT ¹ , IS ⁴ , Ki ⁴ Li ¹ , RP ¹ , RS ¹ , UT ⁴
2-3-7-8-Tetrachlorodibenzo-p-dioxin	1746-01-6		EY ¹ , Ki ¹ , Li ¹ , RS ¹ , SK ¹
Total Nitrate/Nitrite	14797-55-8		BL ³ , CVS ³ , RS ³
Aroclor-1254	11097-69-1	Dermal	SK ²
Target Organs: BL – Blood, BM – Bone Marrow, CNS – Central Nervous System, CVS – Cardiovascular System, EY – Eyes, GIT – Gastrointestinal Tract, IS – Immune System, Ki – Kidneys, Li – Liver, RP – Respiratory System, RS – Reproductive System, SK-Skin, UT – Urinary Tract			
1. NIOSH Pocket Guide to Chemical Hazards, Last Reviewed on 18 February 2020 (Accessed on 25 September 2024) 2. American Conference of Governmental Industrial Hygienists 2024 Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices (Accessed 13 November 2024) 3. Agency for Toxic Substances and Disease Registry Toxic Substances Portal (Accessed 13 November 2024) 4. National Institute of Health – PUBCHEM (Accessed 13 November 2024)			

APPENDIX 8 – MALMSTROM AFB CONSERVATIVE, UPPER-BOUND TARGET ORGAN RISK DETERMINATION BASED ON 8-YEARS OF EXPOSURE

BY TARGET ORGAN														
Chemical Name	CAS Number	BL	BM	CNS	CVS	EY	GIT	IS	Ki	Li	RP	RS	SK	UT
Benzene	71-43-2	0.702	0.702	0.702	---	0.702	0.702	0.702	---	---	0.702	---	0.702	---
Styrene	100-42-5	0.005	---	0.005	0.005	0.005	---	---	---	0.005	---	---	0.005	---
1,2-Dichloroethane	107-06-2	---	---	0.636	0.636	0.636	0.636	0.636	0.636	0.636	---	0.636	---	0.636
Toluene	108-88-3	---	---	0.007	0.007	0.007	---	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Trans-1,2-Dichloroethylene	156-60-5	---	---	0.265	---	0.265	---	0.265	0.265	0.265	0.265	---	0.265	---
Radon-222	14859-67-7	---	---	---	---	---	---	---	---	---	0.050	---	---	---
p+m-Xylene	179601-23-1	0.058	---	0.058	---	---	0.058	---	0.058	0.058	0.058	---	0.058	---
Di(2-ethylhexyl)phthalate	117-81-7	---	---	0.183	---	0.183	0.183	0.183	0.183	0.183	0.183	0.183	0.183	---
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	---	---	---	---	0.143	---	---	0.143	0.143	---	0.143	0.143	---
Total Nitrate/Nitrite	14797-55-8	0.460	---	---	0.460	---	---	---	---	---	---	0.460	---	---
Aroclor-1260	11096-82-5	---	---	---	---	---	---	---	---	---	---	---	0.925	---
Aroclor-1254	11097-69-1	---	---	---	---	---	---	---	---	---	---	---	0.925	---
Cumulative Risk By Target Organ		1.225	0.702	1.852	1.108	1.942	1.580	1.794	1.293	1.298	1.266	1.429	3.214	0.643
Target Organs: BL – Blood, BM – Bone Marrow, CNS – Central Nervous System, CVS – Cardiovascular System, EY – Eyes, GIT – Gastrointestinal Tract, IS – Immune System, Ki – Kidneys, Li – Liver, RP – Respiratory System, RS – Reproductive System, SK–Skin, UT – Urinary Tract														
Note: Values represented in the Cumulative Risk By Target Organ are conservative given they do not consider the Toxicokinetic properties of each contaminant. The Cumulative Risk By Target Organ reflect risk associated with EXPOSURE only without consideration of ABSORPTION, INTERNAL DOSE, DISTRIBUTION, METABOLISM, and EXCRETION. Per the Agency for Toxic Substance and Disease Registration Public Health Assessment Guidance Manual (PHAGM), BIOLOGICAL EFFECTIVE CHANGE to a TARGET ORGAN is impacted by contamination source, exposure point, biological uptake (exposure), absorption, distribution, metabolism, and excretion. Further information on Toxicokinetic can be found at: https://www.atsdr.cdc.gov/pha-guidance/conducting_scientific_evaluations/indepth_toxicological_analysis/reviewContaminantToxInfo.html .														

APPENDIX 9 – MALMSTROM AFB HEALTH-BASED TARGET ORGAN RISK DETERMINATION

BY TARGET ORGAN															
Chemical Name	CAS Number	Federal Health Limit [µg/m³]	BL	BM	CNS	CVS	EY	GIT	IS	Ki	Li	RP	RS	SK	UT
Benzene	71-43-2	3,190	0.072	0.072	0.072	---	0.072	0.072	0.072	---	---	0.072	---	0.072	---
Styrene	100-42-5	426,180	0.000	---	0.000	0.000	0.000	---	---	---	0.000	---	---	0.000	---
1,2-Dichloroethane	107-06-2	200,000	---	---	0.000	0.000	0.000	0.000	0.000	0.000	0.000	---	0.000	---	0.000
Toluene	108-88-3	753,370	---	---	0.000	0.000	0.000	---	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Trans-1,2-Dichloroethylene	156-60-5	793,000	---	---	0.000	---	0.000	---	0.000	0.000	0.000	0.000	---	0.000	---
p+m-Xylene	179601-23-1	435,000	0.000	---	0.000	---	---	0.000	---	0.000	0.000	0.000	---	0.000	---
Chemical Name	CAS Number	Federal Health Limit [WLM/yr]	BL	BM	CNS	CVS	EY	GIT	IS	Ki	Li	RP	RS	SK	UT
Radon-222	14859-67-7	4	---	---	---	---	---	---	---	---	---	0.050	---	---	---
Chemical Name	CAS Number	Federal Health Limit [µg/L]	BL	BM	CNS	CVS	EY	GIT	IS	Ki	Li	RP	RS	SK	UT
Di(2-ethylhexyl)phthalate	117-81-7	6	---	---	0.183	---	0.183	0.183	0.183	0.183	0.183	0.183	0.183	0.183	---
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	3E-06	---	---	---	---	0.143	---	---	0.143	0.143	---	0.143	0.143	---
Total Nitrate/Nitrite	14797-55-8	10,000	0.460	---	---	0.460	---	---	---	---	---	---	0.460	---	---
Chemical Name	CAS Number	Federal Health Limit [µg/100 cm²]	BL	BM	CNS	CVS	EY	GIT	IS	Ki	Li	RP	RS	SK	UT
Aroclor-1260	11096-82-5	10	---	---	---	---	---	---	---	---	---	---	---	0.925	---
Aroclor-1254	11097-69-1	10	---	---	---	---	---	---	---	---	---	---	---	0.925	---
Cumulative Risk By Target Organ			0.532	0.072	0.255	0.460	0.398	0.255	0.255	0.326	0.326	0.305	0.786	2.248	0.000
Target Organs: BL – Blood, BM – Bone Marrow, CNS – Central Nervous System, CVS – Cardiovascular System, EY – Eyes, GIT – Gastrointestinal Tract, IS – Immune System, Ki – Kidneys, Li – Liver, RP – Respiratory System, RS – Reproductive System, SK–Skin, UT – Urinary Tract															

Note: Values represented in the Cumulative Risk By Target Organ are conservative given they do not consider the Toxicokinetic properties of each contaminant. The Cumulative Risk By Target Organ reflect risk associated with EXPOSURE only without consideration of ABSORPTION, INTERNAL DOSE, DISTRIBUTION, METABOLISM, and EXCRETION. Per the Agency for Toxic Substance and Disease Registration Public Health Assessment Guidance Manual (PHAGM), BIOLOGICAL EFFECTIVE CHANGE to a TARGET ORGAN is impacted by contamination source, exposure point, biological uptake (exposure), absorption, distribution, metabolism, and excretion. Further information on Toxicokinetic can be found at: https://www.atsdr.cdc.gov/pha-guidance/conducting_scientific_evaluations/indepth_toxicological_analysis/reviewContaminantToxInfo.html.

APPENDIX 10 – MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION* [µg/m³]	TOTAL NUMBER OF SAMPLES ANALYZED**	
Carbon Tetrachloride	56-23-5	Inhalation	EPA TO17	All Results < 10	90	
Parathion	56-38-2		NIOSH 5600	All Results < 10	90	
Chloroform	67-66-3		EPA TO17	All Results < 10	90	
1,1,1-Trichloroethane	71-55-6		EPA TO17	All Results < 10	90	
Bromochloromethane	74-97-5		EPA TO17	All Results < 10	90	
Methylene Chloride	75-09-2		EPA TO17	All Results < 10	60	
Bromoform	75-25-2		EPA TO17	All Results < 10	90	
Bromodichloromethane	75-27-4		EPA TO17	All Results < 10	90	
1,1-Dichloroethane	75-34-3		EPA TO17	All Results < 10	90	
1,1-Dichloroethylene	75-35-4		EPA TO17	All Results < 10	90	
1,2-Dichloropropane	78-87-5		EPA TO17	All Results < 10	90	
1,1,2-Trichloroethane	79-00-5		EPA TO17	All Results < 10	90	
Trichloroethylene	79-01-6		EPA TO17	All Results < 10	90	
1,1,2,2-Tetrachloroethane	79-34-5		EPA TO17	All Results < 10	90	
1,2,3-Trichlorobenzene	87-61-6		EPA TO17	All Results < 10	90	
Hexachlorobutadiene	87-68-3		EPA TO17	All Results < 10	90	
Naphthalene	91-20-3		EPA TO17	All Results < 10	90	
o-Xylene	95-47-6		EPA TO17	All Results < 10	90	
2-Chlorotoluene	95-49-8		EPA TO17	All Results < 10	90	
1,2-Dichlorobenzene	95-50-1		EPA TO17	All Results < 10	90	
1,2,4-Trimethylbenzene	95-63-6		EPA TO17	All Results < 10	90	
1,2-Dibromo-3-chloropropane (DBCP)	96-12-8		EPA TO17	All Results < 10	90	
1,2,3-Trichloropropane	96-18-4		EPA TO17	All Results < 10	90	
Tert-Butylbenzene	98-06-6		EPA TO17	All Results < 10	90	
Isopropylbenzene	98-82-8		EPA TO17	All Results < 10	90	
p-Isopropyltoluene	99-87-6		EPA TO17	All Results < 10	90	
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.						
** Excludes Media Blanks and Trip Blanks.						

APPENDIX 10 - MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ (Continued)

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION* [µg/m³]	TOTAL NUMBER OF SAMPLES ANALYZED**	
Ethylbenzene	100-41-4	Inhalation	EPA TO17	All Results < 10	90	
n-Propylbenzene	103-65-1		EPA TO17	All Results < 10	90	
n-Butylbenzene	104-51-8		EPA TO17	All Results < 10	90	
4-Chlorotoluene	106-43-4		EPA TO17	All Results < 10	90	
1,4-Dichlorobenzene	106-46-7		EPA TO17	All Results < 10	90	
Ethylene Dibromide	106-93-4		EPA TO17	All Results < 10	90	
1,3,5-Trimethylbenzene	108-67-8		EPA TO17	All Results < 10	90	
Bromobenzene	108-86-1		EPA TO17	All Results < 10	90	
Chlorobenzene	108-90-7		EPA TO17	All Results < 10	90	
1,2,4-Trichlorobenzene	120-82-1		EPA TO17	All Results < 10	90	
Malathion	121-75-5		NIOSH 5600	All Results < 10	90	
Dibromochloromethane	124-48-1		EPA TO17	All Results < 10	90	
Tetrachloroethylene	127-18-4		EPA TO17	All Results < 10	90	
sec-Butylbenzene	135-98-8		EPA TO17	All Results < 10	90	
Dicrotophos	141-66-2		NIOSH 5600	All Results < 10	90	
1,3-Dichloropropane	142-28-9		EPA TO17	All Results < 10	90	
Cis-1,2-Dichloroethylene	156-59-2		EPA TO17	All Results < 10	90	
Methyl Parathion	298-00-0		NIOSH 5600	All Results < 10	90	
Phorate	298-02-2		NIOSH 5600	All Results < 10	90	
Diazinon	333-41-5		NIOSH 5600	All Results < 10	90	
1,3-Dichlorobenzene	541-73-1		EPA TO17	All Results < 10	90	
1,1-Dichloropropylene	563-58-6		EPA TO17	All Results < 10	90	
1,1,1,2-Tetrachloroethane	630-20-6		EPA TO17	All Results < 10	90	
Chlorpyrifos	2921-88-2		NIOSH 5600	All Results < 10	90	
Trans-1,3-Dichloropropene	10061-02-6		EPA TO17	All Results < 10	90	
Methamidophos	10265-92-6		NIOSH 5600	All Results < 17	90	
Aroclor 1260	11096-82-5		NIOSH 5503	All Results < 2.7	32	
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.						
** Excludes Media Blanks and Trip Blanks.						

APPENDIX 10 - MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ (Continued)

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION* [µg/m³]	TOTAL NUMBER OF SAMPLES ANALYZED**
Aroclor 1254	11097-69-1	Inhalation	NIOSH 5503	All Results < 2.7	32
Aroclor 1221	11104-28-2		NIOSH 5503	All Results < 2.7	32
Aroclor 1232	11141-16-5		NIOSH 5503	All Results < 2.7	32
Aroclor 1248	12672-29-6		NIOSH 5503	All Results < 2.7	32
Aroclor 1016	12674-11-2		NIOSH 5503	All Results < 2.7	32
Terbufos	13071-79-9		NIOSH 5600	All Results < 10	90
Ethoprophos	13194-48-4		NIOSH 5600	All Results < 10	90
Aroclor-1242	53469-21-9		NIOSH 5503	All Results < 2.7	32
Cis-1,3-Dichloropropene	100061-01-5		EPA TO17	All Results < 10	90
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.					
** Excludes Media Blanks and Trip Blanks.					

APPENDIX 10 - MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ (Continued)

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION* [µg/L]	TOTAL NUMBER OF SAMPLES ANALYZED**
Dichlorodiphenyltrichloroethane (DDT)	50-29-3	Ingestion	EPA 525.2	All Results < 0.1	30
Benzo[a]pyrene	50-32-8		EPA 525.2	All Results < 0.11	90
Dibenz[a,h]anthracene	53-70-3		EPA 525.2	All Results < 0.1	30
Parathion	56-38-2		EPA 525.2	All Results < 0.52	30
Benzo[a]anthracene	56-55-3		EPA 525.2	All Results < 0.11	90
Gamma-BHC Lindane	58-89-9		EPA 525.2	All Results < 0.11	90
Dimethoate	60-51-5		EPA 525.2	All Results < 0.54	30
Dieldrin	60-57-1		EPA 525.2	All Results < 0.22	90
Endrin	72-20-8		EPA 525.2	All Results < 0.22	90
Methoxychlor	72-43-5		EPA 525.2	All Results < 0.22	90
Dichlorodiphenyl dichloroethane (DDD)	72-54-8		EPA 525.2	All Results < 0.1	30
Dichlorodiphenyldichloroethylene (DDE)	72-55-9		EPA 525.2	All Results < 0.22	90
Heptachlor	76-44-8		EPA 525.2	All Results < 0.11	90
Hexachlorocyclopentadiene	77-47-4		EPA 525.2	All Results < 0.22	90
Acenaphthene	83-32-9		EPA 525.2	All Results < 0.11	90
Diethyl Phthalate	84-66-2		EPA 525.2	All Results < 1.1	90
Di-n-butylphthalate	84-74-2		EPA 525.2	All Results < 2.1	90
Phenanthrene	85-01-8		EPA 525.2	All Results < 0.19	90
Butylbenzylphthalate	85-68-7		EPA 525.2	All Results < 1.1	90
Fluorene	86-73-7		EPA 525.2	All Results < 0.11	90
1-Methylnaphthalene	90-12-0		EPA 525.2	All Results < 0.1	30
Naphthalene	91-20-3		EPA 525.2	All Results < 0.22	90
2-Methylnaphthalene	91-57-6		EPA 525.2	All Results < 0.22	90
Di(2-ethylhexyl)adipate	103-23-1	EPA 525.2	All Results < 1.1	90	
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.					
** Excludes Media Blanks and Trip Blanks.					

APPENDIX 10 - MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ (Continued)

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION* [µg/L]	TOTAL NUMBER OF SAMPLES ANALYZED**	
Di-n-octylphthalate	117-84-0	Ingestion	EPA 525.2	All Results < 2.2	30	
Hexachlorobenzene	118-74-1		EPA 525.2	All Results < 0.11	90	
Anthracene	120-12-7		EPA 525.2	All Results < 0.22	90	
Malathion	121-75-5		EPA 525.2	All Results < 0.1	30	
Simazine	122-34-9		EPA 525.2	All Results < 0.22	90	
Pyrene	129-00-0		EPA 525.2	All Results < 0.11	90	
Dimethyl Phthalate	131-11-3		EPA 525.2	All Results < 1	90	
Benzo[g,h,i]perylene	191-24-2		EPA 525.2	All Results < 0.11	90	
Indeno[1,2,3-cd]pyrene	193-39-5		EPA 525.2	All Results < 0.11	90	
Benzo[b]fluoranthene	205-99-2		EPA 525.2	All Results < 0.11	90	
Fluoranthene	206-44-0		EPA 525.2	All Results < 0.11	90	
Benzo[k]fluoranthene	207-08-9		EPA 525.2	All Results < 0.11	90	
Acenaphthylene	208-96-8		EPA 525.2	All Results < 0.11	90	
Chrysene	218-01-9		EPA 525.2	All Results < 1.1	90	
Aldrin	309-00-2		EPA 525.2	All Results < 0.22	90	
Bromacil	314-40-9		EPA 525.2	All Results < 0.1	30	
Diazinon	333-41-5		EPA 525.2	All Results < 0.1	30	
Ethyl Dipropylthiocarbamate (EPTC)	759-94-4		EPA 525.2	All Results < 0.22	90	
Deisopropylatrazine	1007-28-9		EPA 525.2	All Results < 1	30	
Heptachlor Epoxide	1024-57-3		EPA 525.2	All Results < 0.11	90	
Total PCBs	1336-36-3		EPA 505	All Results < 0.51	88	
Trifluralin	1582-09-8		EPA 525.2	All Results < 0.22	90	
Chlorothalonil	1897-45-6		EPA 525.2	All Results < 0.1	30	
Atrazine	1912-24-9		EPA 525.2	All Results < 0.22	90	
Propachlor	1918-16-7		EPA 525.2	All Results < 0.22	90	
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.						
** Excludes Media Blanks and Trip Blanks.						

APPENDIX 10 - MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ (Continued)

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION* [µg/L]	TOTAL NUMBER OF SAMPLES ANALYZED**	
Molinate	2212-67-1	Ingestion	EPA 525.2	All Results < 0.22	90	
Diquat	2764-72-9		EPA 549.2	All Results < 2	90	
Paraquat	4685-14-7		EPA 549.2	All Results < 2	90	
Chlordane (Alpha)	5103-71-9		EPA 525.2	All Results < 0.1	30	
Chlordane (Gamma)	5103-74-2		EPA 525.2	All Results < 0.1	30	
Terbacil	5902-51-2		EPA 525.2	All Results < 0.55	90	
Atrazine-Desethyl	6190-65-4		EPA 525.2	All Results < 1	30	
Prometryn	7287-19-6		EPA 525.2	All Results < 1	30	
Toxaphene	8001-35-2		EPA 505	All Results < 2	88	
Aroclor 1260	11096-82-5		EPA 505	All Results < 0.51	88	
Aroclor 1254	11097-69-1		EPA 505	All Results < 0.51	88	
Aroclor 1221	11104-28-2		EPA 505	All Results < 0.51	88	
Aroclor 1232	11141-16-5		EPA 505	All Results < 0.51	88	
Aroclor 1248	12672-29-6		EPA 505	All Results < 0.51	88	
Aroclor 1016	12674-11-2		EPA 505	All Results < 0.51	88	
Chlordane (Technical)	12789-03-6		EPA 505	All Results < 0.1	88	
Alachlor	15972-60-8		EPA 525.2	All Results < 0.22	90	
Metribuzin	21087-64-9		EPA 525.2	All Results < 0.22	90	
Cyanazine	21725-46-2		EPA 525.2	All Results < 0.1	30	
Butachlor	23184-66-9		EPA 525.2	All Results < 0.22	90	
Thiobencarb	28249-77-6		EPA 525.2	All Results < 0.1	30	
Trans-Nonachlor	39765-80-5		EPA 525.2	All Results < 0.1	30	
Metolachlor	51218-45-2		EPA 525.2	All Results < 0.1	30	
Aroclor 1242	53469-21-9		EPA 505	All Results < 0.51	88	
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.						
** Excludes Media Blanks and Trip Blanks.						

APPENDIX 10 - MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ (Continued)

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION* [mg/kg-dry]	TOTAL NUMBER OF SAMPLES ANALYZED**
Parathion	56-38-2	Adsorption	EPA 1699	All Results < 0.246	264
Methyl Parathion	298-00-0				
Phorate	298-02-2				
Malathion	121-75-5				
Dicrotophos	141-66-2				
Diazinon	333-41-5				
Chlorpyrifos	2921-88-2				
Methamidophos	10265-92-6				
Terbufos	13071-79-9				
Ethoprophos	13194-48-4				
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.					
** Excludes Media Blanks and Trip Blanks.					

APPENDIX 10 - MALMSTROM AFB CHEMICALS NOT ASSESSED FOR HEALTH RISK: ALL SAMPLE RESULTS LESS THAN RL/LOQ (Continued)

CHEMICAL NAME	CAS NUMBER	ROUTE OF EXPOSURE	LABORATORY METHOD	LIMIT OF QUANTIFICATION [µg/Swipe]	TOTAL NUMBER OF SAMPLES ANALYZED**
Aroclor 1221	11104-28-2	Adsorption	EPA 8082A	All Results < 1.00	336
Aroclor 1232	11141-16-5				
Aroclor 1242	53469-21-9				
Aroclor 1248	12672-29-6				
Aroclor 1016	12674-11-2				
* Limit of Quantification (LOQ) based on maximum LOQ between Rounds 1, 2 & 3.					
** Excludes Media Blanks and Trip Blanks.					

**APPENDIX 11 – MALMSTROM AFB CONSERVATIVE, UPPER-BOUND TOTAL NON-CANCER ESTIMATED HEALTH RISK DETERMINATION FOR
MISSILE ALERT FACILITIES AFSCs BASED ON 8-YEARS OF EXPOSURE**

CHEMICAL NAME	CAS NUMBER	MATRIX	ROUTE OF EXPOSURE	ESTIMATED HEALTH INHALATION RISK	ESTIMATED HEALTH INGESTION RISK	ESTIMATED HEALTH DERMAL RISK	CUMULATIVE HEALTH RISK	TOTAL NON-CANCER HEALTH RISK	EXCEEDANCE IN HEALTH RISK?	HEALTH RISK
Benzene	71-43-2	Air	Inhalation	0.702	---	---	1.723	4.359	Yes	See Appendix 8 & 9.
Styrene	100-42-5			0.005	---	---				
1,2-Dichloroethane	107-06-2			0.636	---	---				
Toluene	108-88-3			0.007	---	---				
Trans-1,2-Dichloroethylene	156-60-5			0.265	---	---				
Radon-222	14859-67-7			0.050	---	---				
p+m-Xylene	179601-23-1			0.058	---	---				
Di(2-ethylhexyl)phthalate	117-81-7	Drinking Water	Ingestion	---	0.183	---	0.786			
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6			---	0.143	---				
Total Nitrate/Nitrite	14797-55-8			---	0.460	---				
Aroclor-1260	11096-82-5	Surface	Dermal	---	---	0.925	1.850			
Aroclor-1254	11097-69-1			---	---	0.925				

APPENDIX 12 – MCCS Risk Assessment Areas of Uncertainty and Mitigating Steps

Acronym Table

E-PERM	Trade name for a Radon measurement system
EPA	United States Environmental Protection Agency
EPA TO-17	Compendium Method TO-17 – Determination of volatile organic compounds in ambient air using active sampling onto sorbent tubes
HSV	Health Screening Value
IUR	Inhalation Unit Risk
L	Liters
LCC	Launch Control Center
LOQ	Limit of Quantitation
MAF	Missile Alert Facility
MCL	Maximum Contaminant Level (Drinking water)
NIOSH	National Institute of Occupational Safety and Health
- Method 5503	NIOSH Air Sampling Method for Polychlorobiphenyls
- Method 5600	NIOSH Air Sampling Method for Organophosphorus Pesticides
OEL	Occupational Exposure Limit (Air)
PCB	Polychlorinated Biphenyl
pH	
QA	Quality Assurance
QC	Quality Control
RL	Reporting Limit
SVOC	Semi-Volatile Organic Compound
TD	Thermal Desorption
USAF	United States Air Force
USAFSAM	United States Air Force School of Aerospace Medicine
VOC	Volatile Organic Compound

APPENDIX 12 – MCCS Risk Assessment Areas of Uncertainty and Mitigating Steps

Table 1 - Sampling of Air for VOCs, Pesticides, PCBs

Uncertainty	Direction of Bias in Exposure and Risk Estimates	Mitigating Step
<p>1. Air sampling not sufficiently sensitive to detect concentrations that are less than the Inhalation Unit Risk (IUR) level for cancer and the Health Screening Value for non-cancer.</p>	<p>Overall Directionality if True: Overestimate.</p> <p>Note: The Reporting Limit (RL) or Limit of Quantification (LOQ) was the same for all EPA TO -17 analytes at 10 µg/m³ and varied for NIOSH Method 5600 for organophosphorus pesticides and for PCBs via NIOSH Method 5503.</p>	<p>+ Validated, current, comprehensive NIOSH and EPA air sampling & analytical methods utilized.</p> <p>+ These methods were developed to have Reporting Limits (RLs) or Limits of Quantification (LOQs) that are 10 times below the occupational exposure limits (OELs) and Health Screening Values (HSVs).</p> <p>+ Cancer risk factors such as Inhalation Unit Risk (IUR) or non-cancer risk factors such as health screening values (HSVs) are geared towards sensitive individuals such as children. Thus, they are set at much lower concentrations than OELs.</p> <p>+ Even if all results for a contaminant were less than the RL/LOQ, if the RL or LOQ were higher than the IUR or HSV, there is a region of uncertainty between RL or LOQ and the IUR or HSV.</p> <p>+ The uncertainty was accounted for in the cancer and non-cancer risk estimates given the cancer estimate was based on 70-year exposures and HSVs were many times more conservative than the chemicals' corresponding OEL.</p>

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2. Point in time sample collection versus potential environmental variability in concentrations over time.	<p>Overall Directionality if True:</p> <p>Unknown – depends on environmental factor that could lead to overestimation or underestimation.</p>	<p>+ A sampling strategy that incorporates randomness and sampling at different times of the year can compensate for environmental variability.</p> <p>+ Three rounds of sampling occurred during different seasons on random days within each season.</p>
3. Insufficient air volume collected versus specified range for method.	<p>Overall Directionality if True:</p> <p>Overestimate</p>	<p>+ Validated NIOSH and EPA sampling and analytical methods were used.</p> <p>+ Air volumes collected via Method 5503 were within the minimum and maximum allowed volumes.</p>
4. Greater air volume collected versus typical range for method.	<p>Overall Directionality if True:</p> <p>Potentially underestimate ambient concentration if tube had no backup section.</p> <p>Underestimate if analyte found on backup section of media.</p>	<p>+ Air volumes collected via Method 5600 were at the maximum allowed volume of 60L for Malathion & 240L for other Organophosphorus pesticides</p> <p>+ Air volumes collected via TO-17 were greater than the 4L maximum volume. Per EPA documents, the method allows for one tube to screen sample locations and collection of volumes greater than 4L is allowed to fit target lists and monitoring objectives.</p>
5. Sample flow rate above specified range for method.	<p>Overall Directionality if True:</p> <p>Potentially Underestimate ambient concentration.</p> <p>“Potentially” because a higher flow rate could strip the higher volatility VOCs off the sample media.</p>	<p>+ NIOSH and EPA sampling and analytical methods were followed.</p> <p>+ The methods specify the acceptable flow rate or range of flow rates.</p> <p>+ Sample pumps that drew air through the sample media were calibrated before and after sampling to verify flow rates were intended to be within the specified ranges.</p>

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<p>6. Sample flow rate below specified range for method.</p>	<p>Overall Directionality if True:</p> <p>Potentially underestimate ambient concentration.</p> <p>“Potentially” because the flow rate does not effectively capture the VOCs.</p>	<p>+ NIOSH and EPA sampling and analytical methods were followed. The methods specify the acceptable flow rate or range of flow rates.</p> <p>+ Sample pumps that drew air through the sample media were calibrated before and after sampling to verify flow rates were intended to be within the specified ranges.</p>
<p>7. <u>Applicable to EPA TO-17:</u> Sampling for volatile and semi-volatile organic compounds with thermal desorption (TD) tubes: inadequate purge of TD tubes obtained from contract laboratory.</p>	<p>Overall Directionality if True:</p> <p>Likely overestimation of actual ambient concentration.</p>	<p>+ Carbotrap 300 tubes were used and VOCs detected on field and media (Lab) sample blanks when there should have been no VOCs present.</p> <p>+ Carbotrap 300 tubes can be reused and there is a protocol for purging them.</p> <p>+ When the issue was discovered, the USAFSAM lab was informed, and the contract laboratory was notified the QC control media (i.e. lab and field blanks) had positive results.</p> <p>+ LCC and Topside sample results were not adjusted.</p>
<p>8. Media, because of manufacturing process, contains residual chemical constituents.</p>	<p>Overall Directionality if True:</p> <p>Overestimate.</p>	<p>+ Lab blanks (not unsealed or opened sample media) and field blanks (unsealed and resealed media with no air drawn through) submitted for each Missile Alert Facility.</p> <p>+ The lab and field blanks were analyzed as part of the QC process to determine if residual chemicals were present on the unsampled media.</p>

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<p>9. Outdoor air samples not collected while indoor samples were collected.</p>	<p>Overall Directionality if True: Overestimate.</p>	<p>+ Some VOCs, (e.g. toluene, benzene, and others) are ubiquitous in the outdoor environment or present because of local industry or agricultural practices. + Buildings exchange air with the outdoors, VOCs from outdoors could be present in the indoor environment. + Outdoor samples are typically collected for indoor air quality assessments when TO-17 sampling occurs, and positive outdoor results are accounted for since VOCs present outdoors can influence indoor levels.</p>
<p>10. Samples were tampered with between the time they were shipped to when they arrived at the lab.</p>	<p>Overall Directionality if True: Unknown.</p>	<p>+ Chain of custody forms were used and physical custody maintained until shipped. + Each lab report contains a copy of the chain of custody and any notes as to condition of the samples as received.</p>
<p>11. Inadequate quality control (QC) steps.</p>	<p>Overall Directionality if True: Depends on quality control results. Unable to determine if no quality control.</p>	<p>+ Laboratories utilized had accreditations by independent entities. + Operating procedures, quality assurance/control, personnel qualifications, and analytical proficiency typically evaluated as part of accreditation process. + Sample blanks (field and lab) submitted. + Each lab conducted its own QC analysis to check instrument performance. Any anomalies regarding instrument performance or analysis were noted in the report.</p>

APPENDIX 12 – MCCS Risk Assessment Areas of Uncertainty and Mitigating Steps

Table 2 - Sampling of Air for Radon

Uncertainty	Direction of Bias in Exposure and Risk Estimates	Mitigating Step
1. Radon sampling strategy not sufficient to quantify cancer risk.	Overall Directionality if True: Underestimate.	+ Uranium 238 is found in soil at varying concentrations. Radon 222 (a radioisotope of Radon) is a gas that has short-lived decay products such as Polonium-218 and -214, which emit alpha particles. In the lung the alpha particles can damage the lining, potentially leading to lung cancer. + E-PERM Electrets were used to detect alpha particle decay. + Sampling was consistent with where Radon could partition within the indoor environment. + Sampling occurred Topside and in the LCC and repeated with each round. + To compensate for environmental variability, three rounds of sampling occurred during different seasons on random days within each season.
2. Sampling strategy in MAFs not sufficient.	Overall Directionality if True: Underestimate.	+ E-PERM Electret devices were deployed to locations within each MAF where personnel spend significant time: A) Topside Facility Manager Bedroom; B) Topside Common Area; C) Topside Security Forces Room; D) Launch Control Center (LCC); and E) Hallway Corridor outside LCC.
3. High humidity (steam).	Overall Directionality if True: Overestimate.	+ E-PERM Electrets were not placed in areas where steam could be present such as bathrooms, shower facilities, and Topside Kitchen.

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<p>4. Inadequate ventilation resulting in high humidity or not enough air flow to mitigate gaseous concentrations of Radon 222 and Radon daughters.</p>	<p>Overall Directionality if True: Overestimate.</p>	<p>+ Radon levels detected were well below the Annual Working Level Months – suggesting adequate ventilation. + Radon concentrations within each MAF were similar and suggests consistent airflow throughout each MAF.</p>
<p>5. The number of days for sampling not sufficient</p>	<p>Overall Directionality if True: Unknown/Unclear.</p>	<p>+ Per Federal and USAF requirements, duration >90 days for all samples. Total 24-hr sample days for each sample location exceeded 270 days (3 x 90 days).</p>
<p>6. Variation in sample duration between MAFs</p>	<p>Overall Directionality if True: Unknown/Unclear.</p>	<p>+ While all E-PERMs deployed met Federal requirements to sample the air for >90 days, logistics prevented deploying all or collecting all on the same day. + Because they were not deployed or collected on the same day, there were differences in the overall number of sampling days for each electret. For Round 1, the maximum difference was 9 days, 6 days for Round 2, and 8 days for Round 3. + When they were collected, they were read on the same at that time.</p>
<p>7. Inadequate quality control steps.</p>	<p>Overall Directionality if True: Unknown/Unclear.</p>	<p>+ Personnel from the Bioenvironmental Shop familiar with the E-PERM electrets and consequences of dropping them; deployed the electrets for Round 1. + Local Bioenvironmental shop personnel conducted the radon reading Topside because the reader was not allowed in the LCC. Results were recorded in a logbook + When the E-PERM electrets were redeployed back to the sample locations, the serial number and voltage recorded.</p>

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Table 3 - Sampling of Drinking Water for SVOCs, Diquat/Paraquat, PCBs, Dioxin, Total Nitrate/Nitrite

Uncertainty	Direction of Bias in Exposure and Risk Estimates	Mitigating Step
<p>1. Drinking water sampling not sufficiently sensitive to detect concentrations that are less than the Inhalation Unit Risk (IUR) level for cancer and the Health Screening Value for non-cancer.</p>	<p>Overall Directionality if True: Overestimate.</p> <p>Note: The RL or LOQ varied for the contaminants, except for Nitrate/Nitrite.</p>	<p>+ Validated, current, comprehensive EPA drinking water sampling & analytical methods utilized.</p> <p>+ These methods were developed to have Reporting Limits (RLs) or Limits of Quantification (LOQs) that are below local, state or federal maximum contaminant levels (MCLs).</p> <p>+ Cancer risk factors such as cancer slopes for ingestion or non-cancer risk factors such as health screening values (HSVs) are geared towards sensitive individuals such as children. Thus, they are set at much lower concentrations than OELs and HSVs.</p> <p>+ Even if all results for a contaminant were less than the RL/LOQ, if the RL or LOQ were higher than the IUR or HSV, there is a region of uncertainty between RL or LOQ and the IUR or HSV.</p> <p>+ The uncertainty was accounted for in the cancer and non-cancer risk estimates.</p>
<p>2. Differing drinking water sources between MAFs: 1) Wells in different aquifers; 2) Small local municipal facilities; 3) Wholesale water trucked in (under limited circumstances) resulting in localized differences.</p>	<p>Overall Directionality if True: Uncertain/Unclear.</p>	<p>+ Cancer risk estimates apply to all 15 MAFs at the installation regardless of drinking water source.</p>

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3. Reverse Osmosis filters not changed within the serviceable timeframe.	Overall Directionality if True: No bias.	+ Not determined. + The results associated with the sample would indicate the current state of the water quality.
4. Reverse Osmosis system disconnected.	Overall Directionality if True: No bias.	The results associated with the sample would indicate the current state of the water quality.
5. Cross-contamination between samples by collector.	Overall Directionality if True: Overestimate.	+ Standard protocol is to wear disposable gloves when collecting samples at a sample location and changing to new gloves when sampling at a subsequent location.
6. Timing of sample collection not first draw but after running the water for 5 minutes.	Overall Directionality if True: Unknown/Unclear.	+ MAFs are remotely located and manned 24/7, meaning first draw is meaningless. + Overall directionality of uncertainty mostly influenced by water source. + Timing of draw standardized.
7. Samples were tampered with between the time they were shipped to when they arrived at the lab.	Overall Directionality if True: Unknown/Unclear.	+ Chain of custody forms were used and physical custody maintained until shipped. + Each lab report contains a copy of the chain of custody and any notes as to condition of the samples as received (e.g. when sample containers broke during shipping, it is noted in reports).
8. Water samples not at required temperature parameter upon arrival to the laboratory.	Overall Directionality if True: Underestimate due to potential degradation of sample constituents.	+ Laboratories provided instructions for the collection and shipping of samples. All exceptions were documented in laboratory reports.

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<p>9. Inadequate quality control (QC) steps.</p>	<p>Overall Directionality if True:</p> <p>Depends on quality control results.</p> <p>Unable to determine if no quality control.</p>	<p>+ Laboratories utilized had accreditations by independent entities.</p> <p>+ Operating procedures, quality assurance/control, personnel qualifications, and analytical proficiency typically evaluated as part of accreditation process.</p> <p>+ Collection of Matrix Spike (MS) and Matrix Spike Duplicate (MSD) samples at each sample location.</p> <p>+ Laboratories prepared Laboratory Control Samples and compared against each contaminant in the MS and MSD samples to determine if analytical bias for contaminants in the water sources was high, neutral, or low.</p> <p>+ Results not adjusted.</p>
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APPENDIX 12 – MCCS Risk Assessment Areas of Uncertainty and Mitigating Steps

Table 4 - Sampling of Soil for Organophosphate Pesticides

Uncertainty	Direction of Bias in Exposure and Risk Estimates	Mitigating Step
1. Analytical instrument capability to detect contaminants in soil samples (e.g. RL, or LOQ) is not sufficiently sensitive compared to health screening values.	Overall Directionality if True: None.	+ The purpose of soil samples was to inform the air samples and indicate whether organophosphorus pesticides were present due to overspray from adjacent farmland. + Ingestion of soil or dermal exposure unlikely for adults in occupational settings + Utilized validated sampling and analytical methods.
2. Analysis for Organophosphate pesticides not comprehensive enough.	Overall Directionality if True: Underestimate.	+ Analytical scan utilized. The scan consisted of 10 common crop organophosphate pesticides.
3. Laboratory qualification.	Overall Directionality if True: Unknown/Unclear.	+ Selected laboratory had accreditations based upon proficiency testing by independent entities. + Operating procedures, quality assurance/control, personnel qualifications, and analytical proficiency are evaluated as part of certification process.
4. Samples were tampered with between the time they were shipped to when they arrived at the lab.	Overall Directionality if True: Unknown/Unclear.	+ Chain of custody forms used. + Physical custody of samples maintained until shipped to laboratory. + Each lab report contains a copy of the chain of custody and any notes as to condition of the samples as received.

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<p>5. Inadequate quality control (QC) steps.</p>	<p>Overall Directionality if True: Depends on Quality Control results.</p>	<ul style="list-style-type: none"> + Collection of background soil sample outside the fenceline at each MAF. + The depth of the sample was according to a protocol. A shovel was used to remove the top layer of soil and individual trowels were used at each sample location to prevent cross-contamination. + Laboratory prepared Method Blank, Matrix Spike, Matrix Spike Duplicate, and LCS samples and compared against each contaminant in each sample to determine if bias was high, neutral, or low.
<p>6. Inadequate depth of samples. Depth not randomized.</p>	<p>Overall Directionality if True: Unknown/Unclear.</p>	<ul style="list-style-type: none"> + Soil samples were collected according to a sample strategy at a depth of 8 to 12 inches. + Sample strategy was for presence/absence of organophosphate pesticides. + Moisture levels were detected.
<p>7. Sample locations not sufficient to characterize presence of organophosphate pesticides.</p>	<p>Overall Directionality if True: Underestimate.</p>	<ul style="list-style-type: none"> + Samples collected at each corner of the MAF within the fenceline, at the location of the ventilation air intake, and at a random location within the fenceline. + Background soil sample collected outside of the fenceline, which include MAFs situated within agricultural areas where pesticides are reportedly used.

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Table 5 - Collection of Surface Swipe Samples for Polychlorinated Biphenyls (PCBs)

Uncertainty	Direction of Bias in Exposure and Risk Estimates	Mitigating Step
<p>1. Surface swipe sampling not sufficiently sensitive to detect concentrations that are less than the Cancer Slope Factor for dermal exposure.</p>	<p>Overall Directionality if True: Overestimate.</p> <p>Note: The RL (expressed at Practical Quantification Limit (PQL)) did not vary.</p>	<p>+ Validated, current, comprehensive EPA sampling & analytical method utilized. + The method was developed to have a Reporting Limit (RL) that is less than the EPA surface limit for PCBs. + Cancer risk factors such as Cancer Slope for dermal exposure or non-cancer risk factors such as health screening values (HSVs) are geared towards sensitive individuals such as children – in this case, workers dermally exposed to PCBs in water. Thus, they are set at a lower concentration than the EPA surface limits. + The determination of risk was artificially elevated as 100% of the detected PCB was transferred to the skin and 100% was absorbed through skin and not washed or wiped off.</p>
<p>2. Analytical instrument capability to detect contaminants in swipe samples (e.g. RL, or LOQ) is not sufficiently sensitive compared to EPA limit for PCB surface concentrations.</p>	<p>Overall Directionality if True: Underestimate.</p>	<p>+ Validated EPA sampling and analytical methods specific to detect concentrations at a 1 microgram per wipe, which is 10x below the EPA limit.</p>

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3. Analysis for PCBs not comprehensive enough.	Overall Directionality if True: Underestimate.	+ Analytical scan utilized. The scan consisted of 7 of the most common PCBs. + Total PCBs also included in the sampling and analytical method.
4. Laboratory qualification.	Overall Directionality if True: Unknown/Unclear.	+ Selected Laboratory utilized has certifications based upon proficiency testing by independent entities. + Operating procedures, quality assurance/control, personnel qualifications, and analytical proficiency are evaluated as part of certification process.
5. Inadequate quality control (QC) steps.	Overall Directionality if True: Depends on Quality Control results.	+ Round 1 supplies procured from a source not associated with the lab that performed the analysis. No media blanks submitted for analysis. + Round 2 supplies procured from the lab that performed the analysis. No media blanks submitted for analysis. + Laboratory prepared Method Blank, Matrix Spike, Matrix Spike Duplicate, and LCS samples and compared against each contaminant in each sample to determine if bias was high, neutral, or low.

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Table 6 – Overall Uncertainty

Uncertainty	Direction of Bias in Exposure and Risk Estimates	Mitigating Step
<p>1. Sampling results indicate the current environmental conditions within (outside in the case of soil samples) the 15 Missile Alert Facilities. Past environmental conditions could be similar or dissimilar to current conditions.</p>	<p>Overall Directionality if True: Unknown/Unclear.</p> <p>Facilities have undergone upgrades/changes.</p>	<p>+ Sampling represents current conditions, but environmentally persistent compounds that could represent past environmental conditions were sampled such as PCBs, dioxins, and other persistent semi-volatile compounds.</p> <p>+ Rapid response when concerns were raised.</p>
<p>2. Laboratory Limit of Quantification (LOQ) was less than the applicable Health Screening Value (HSV) and concentrations reported were less than the LOQ.</p>	<p>Overall Directionality if True: Potential to artificially inflate/ overestimate risk when added together.</p>	<p>+ Results statistically treated according to USEPA policy/protocols/guidance.</p>
<p>3. Laboratory RL, LOQ, or PQL were greater than the Cancer Slope Factor or HSV and concentrations reported were less than the RL, LOQ, or PQL.</p>	<p>Overall Directionality if True: Potential to artificially inflate/ overestimate risk when added together.</p>	<p>+ Situations where the RL, LOQ, or PQL were greater than the IUR, Cancer Slope Factor, or HSV were areas of uncertainty that were accounted for in the cancer and non-cancer risk estimates.</p>

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Table 7 - Computation of Risk

Uncertainty	Direction of Bias in Exposure and Risk Estimates	Notes
<p>1. Duration of exposure to airborne and waterborne chemicals at a MAF would not be equal to a residential, 24-hr, 365 day, lifetime exposure</p>	<p>Overall Directionality: Overestimate risk.</p>	<p>13N AFSC typically serve two, three-year terms at operational missile wings with broadening assignments afterwards within 6 to 12-year time-in-service thresholds. While at operational missile wings, schedule is 24 hrs at MAF followed by 48-hours away, or 1 week at MAF followed by 2-weeks away. During broadening assignments, time in LCC reduced to a non-routine, non-consistent tempo.</p> <p>Upon consultation with AFGSC, 13Ns would work 1/3-year (2,290 hours/year) in a MAF for an upper bound of 8-years.</p>
<p>2. Dermal cancer risk based on assumptions maximizing the potential for risk</p>	<p>Overall Directionality (Overestimate risk)</p>	<p>Based on highest detected concentration on frequent, high likelihood of contact to contaminated surface for each installation.</p> <p>Assumptions: + whole surface area of hand (100 cm²) exposed. + Entire concentration transferred to skin. + Not washed off. + 100% of PCB on skin was absorbed + Frequency and duration of exposure aligned to a residential exposure (24-hrs/day, 350 days/year)</p>

APPENDIX 13 – ACKNOWLEDGMENTS

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