

Health Consultation

Arsenic Soil Clean-up Levels

EL PASO COUNTY METALS SURVEY

EL PASO, EL PASO COUNTY, TEXAS

EPA FACILITY ID: TX0000605388

JULY 10, 2003

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES

Public Health Service

Agency for Toxic Substances and Disease Registry

Division of Health Assessment and Consultation

Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

An ATSDR health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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HEALTH CONSULTATION

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Prepared by:

Texas Department of Health
Under a Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

Table of Contents

Table of Contents	1
Summary and Statement of Issues	2
Discussion	2
Non-Carcinogenic Effects	3
Short-Term or Sporadic Pica Behavior	4
Carcinogenic Effects of Arsenic	5
Conclusions	6
Recommendations	6
Public Health Action Plan	6
Authors, Technical Advisors, and Organizations	7
References	8
Certification	10
Appendices	11
Appendix A: Summary of Non-Carcinogenic Daily Doses of Arsenic Resulting from Various Pathways	12
Appendix B: Summary of Non-Carcinogenic Daily Doses of Arsenic Resulting from Short-Term Pica Behavior	17
Appendix C: Summary of Carcinogenic Risk Levels and Daily Doses of Arsenic from Various Pathways	20

Summary and Statement of Issues

In response to recommendations made in previous health consultations, the U.S. Environmental Protection Agency Region 6 (EPA-6) contracted with the College of Veterinary Medicine at the University of Missouri, Columbia (CVMUM) to assess the relative bioavailability of arsenic in soil from the El Paso remediation area. Using data from this study, scientists from the Texas Commission of Environmental Quality (TCEQ) and EPA-6, proposed a residential soil clean-up level of 46 milligrams per kilogram (mg/kg). The EPA has asked the Texas Department of Health (TDH) and the Agency for Toxic Substances and Disease Registry (ATSDR) for an independent assessment to evaluate whether the proposed residential surface soil clean-up level for arsenic would be protective of public health.

Discussion

Arsenic is a naturally occurring element in the earth's crust and is usually found in combination with other elements. Arsenic compounds can be classified into three main groups: 1) inorganic arsenic compounds, 2) organic arsenic compounds, and 3) arsine gas. In the environment, arsenic is most often found as inorganic arsenic, which is formed when arsenic combines with other elements such as oxygen, sulfur, and chlorine. Organic forms of arsenic, which result when arsenic combines with carbon and hydrogen, are generally considered less toxic than the inorganic forms. Background concentrations of arsenic in soil range from 1 to 40 mg/kg with an average value of about 5 mg/kg (ATSDR, 2000).

Analysis of the toxic effects of inorganic arsenic in soil is complicated by several factors. First, arsenic can exist in different valence states. A number of studies have noted differences in the relative toxicity of these compounds, with trivalent arsenites tending to be somewhat more toxic than the pentavalent arsenates (Byron, 1967; Gaines, 1960; Maitani, 1987; Sardana, 1981; Whillhite, 1981). For the purposes of this consultation, we have not emphasized the difference in toxicity between the arsenates and the arsenites because in most instances, this difference is reasonably small (about 2–3 fold) and is often within the bounds of uncertainty regarding the No Observed Adverse Effect Levels (NOAELs) or Lowest Observed Adverse Effect Levels (LOAELs). In addition, the different forms of arsenic may be interconverted, both in the environment and in the body and as in most cases involving human exposure, the precise chemical speciation will not always be known.

Second, although both inorganic and organic arsenic compounds in water generally are well absorbed (over 90 percent of an ingested dose of inorganic trivalent or pentavalent arsenic in water is absorbed), most scientists would agree that arsenic in soil probably is not as well absorbed. While we often do not know the actual bioavailability of arsenic in soil, the average bioavailability of arsenic in the soil from this area (as determined by CVMUM) was 40%. TCEQ used this bioavailability factor to calculate a proposed residential soil clean-up level of 46 mg/kg.

Third, there is some evidence that the mechanisms that the body uses to distribute, metabolize, and excrete arsenic may result in the ability of the body to detoxify much of the arsenic. Most organic and inorganic arsenic leaves the body in urine within a few days of exposure, although some remains in the body for several months or longer. The metabolism of arsenic in humans has been well studied and involves two basic processes: 1) oxidative/reduction reactions that interconvert arsenate and arsenite, and 2) methylation reactions, which convert arsenite to the organic forms monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA). Human exposure to either inorganic arsenites or arsenates results in increased urinary levels of inorganic arsenite, inorganic arsenate, MMA and DMA (ATSDR, 1993). The relative proportions of these metabolites in urine can vary depending upon the type of arsenic administered, the time after exposure, the route of exposure, and the dose of arsenic administered. In humans, the relative proportions are usually about 40-60% DMA, 20-25% inorganic arsenic, and 15-25% MMA. The liver is apparently the main site of the methylation process and the enzymes involved apparently require arsenite as a substrate. Thus, although the methylation products generally predominate, arsenate is not methylated unless it is first reduced to arsenite.

Since the methylated metabolites of arsenic are less toxic than inorganic arsenic, methylation may be an important detoxification mechanism. Because the methylation of arsenic is an enzymatic process that could be saturated, the dose at which this saturation occurs is an important issue. Limited human data suggest that doses up to approximately 200 µg/day are sufficiently methylated, but that doses above this level may begin to saturate the system, leading to inorganic arsenic accumulation in tissues. These observations are uncertain because they are based on limited data. Since the dose rate at which the methylating capacity becomes saturated is uncertain and cannot be precisely defined with current data it would be inappropriate to base public health decisions on these data. In addition, the pattern of arsenic methylation following chronic low-level exposure to arsenic has not been adequately studied. Although under normal conditions, the availability of methyl donors (i.e., methionine, choline, and cysteine) apparently does not affect the rate of detoxification; dietary deficiencies such as low choline, low methionine, and low protein may reduce the ability to detoxify arsenic.

Non-Carcinogenic Effects

By the oral route, the effects most likely to be of human health concern are gastrointestinal irritation, decreased production of red and white blood cells, abnormal heart function, blood vessel damage, impaired nerve function causing a "pins and needles" sensation in the hands and feet, and a group of skin diseases, including hyperkeratosis. Most of the non-cancer effects begin to occur at similar oral exposure levels. Ingestion of food or water with 0.3 to 30 ppm of arsenic can cause stomach and intestinal irritation. The minimal dose at which these effects usually are observed in humans after chronic ingestion of arsenic ranges from 0.012 milligrams of arsenic per kilogram of body weight per day (mg/kg/day) to 0.1 mg/kg/day.

Although there is no evidence to suggest that arsenic can injure pregnant women or their fetuses, studies of animals show that doses large enough to cause illness in pregnant females also may

cause low birth weight, fetal malformations, or fetal death. One of the most characteristic effects of long-term oral exposure to inorganic arsenic is a pattern of skin changes that includes a darkening of the skin and formation of hyperkeratotic warts or corns on the palms, soles, and torso. Currently this end-point is considered the most appropriate basis for establishing a chronic oral Minimal Risk Level (MRL) or Reference Dose (RfD). However, other end-points (liver injury, vascular disease, and neurological effects) also appear to have similar thresholds (ATSDR, 2000).

In one study of a very large population, Tseng (1968), found no adverse effects in any person with an average total daily intake of inorganic arsenic (water plus food) of 0.0008 mg/kg/day. This study has served as the basis for both ATSDR's MRL and EPA's RfD, both of which are 0.0003 mg/kg/day. Both the RfD and the MRL were derived by dividing the 0.0008 mg/kg/day NOAEL by an uncertainty factor of three (3) to account for both the lack of data on reproductive toxicity and to account for some uncertainty as to whether the NOAEL accounts for all sensitive individuals. There is not a clear consensus among scientists regarding the oral RfD. Arguments for various values within a factor of 2-3 of the recommended RfD value have been made.

To evaluate the proposed clean-up level of 46 ppm arsenic in surface soil, we independently evaluated the exposure that children might receive from all sources (soil ingestion, aboveground and belowground vegetables, dermal absorption, and inhalation). We applied the bioavailability factor of 40% to the ingestion scenarios. We used children because they constitute the sub-population most likely to experience the highest levels of exposure to arsenic in soil (due to play activities and normal hand-to-mouth exposure) and because their dose of arsenic relative to body weight is higher than that of adults (ATSDR, 1995). Assuming a maximum soil arsenic concentration of 46 mg/kg and combined exposure from all sources, the estimated daily dose that a child would receive (0.000313 mg/kg/day) is equivalent to EPA's RfD of 0.0003 mg/kg/day. Therefore, with respect to non-carcinogenic health effects the proposed cleanup level of 46 mg/kg for arsenic in soil is adequate to protect children¹ (See Appendix A for pathway-specific parameters and results).

Short-Term or Sporadic Pica Behavior

Soil pica behavior (ingestion of more than 1.0 gram of soil per day) may occur in a sizable portion of children throughout the year (Calabrese, 1997). While any individual child may only exhibit pica behavior infrequently, the behavior is not limited to a small subset of the population. It has been estimated that approximately 62% of children will ingest >1.0 gram of soil on 1-2 days/year. Additionally, 42% of children will ingest >5 grams of soil and 33% will ingest >10 grams of soil on 1-2 days per year. For some contaminants periodic pica episodes potentially could result in acute intoxication (Calabrese, 1997). To explore the potential public health significance of pica behavior at this site, we considered the scenario of a 15 kg child who ingested 5,000 mg of soil per day for 14-21 days. At a soil arsenic concentration of 46 mg/kg and a bioavailability factor of 40%, the daily dose of absorbed arsenic during the pica events

¹ This consideration is in accordance with ATSDR's Child Health Initiative (ATSDR, 1995).

would be approximately 0.006 mg/kg/day – well below the acute LOAEL for serious effects (0.050 mg/kg/day) reported by Mizuta, 1956. Indeed, for such a child, the soil arsenic level would have to exceed 375 mg/kg in order for the child to absorb a dose exceeding the acute LOAEL. Alternatively, the child would have to ingest 40.8 grams of soil per day for 14-21 days at the proposed clean-up level of 46 mg/kg in order to exceed the acute LOAEL for arsenic. The effects associated with this acute LOAEL include nausea, vomiting, diarrhea, occult blood in the feces and gastric and duodenal juice, and abnormal electrocardiogram (Mizuta, 1956). Based on these data, we would not expect to see any children exhibiting signs or symptoms of acute toxicity from arsenic as a result of short-term or sporadic pica behavior (See Appendix B for pathway-specific parameters and results).

Carcinogenic Effects of Arsenic

A large number of epidemiologic studies and case reports provide evidence that ingestion of arsenic increases the risk of developing cancer. The most common effect is increased risk of multiple skin cancers. Some of the skin cancers develop from hyperkeratotic warts or corns characteristic of chronic arsenic exposure. Multiple basal cell carcinomas may also occur, usually from cells not associated with hyperkeratinization. In most cases, skin cancer develops only after prolonged exposure; however, several studies have reported skin cancer in people exposed for less than one year. Liver, bladder, kidney, and lung cancer also have been associated with oral exposure to arsenic (Smith, 1992), but these associations are less well established and currently not suitable for inclusion in risk estimates.

Based on the epidemiological studies, the EPA has classified arsenic as a Group A "known human" carcinogen. This classification is based on consistent evidence of increased risk of lung cancer in workers exposed to airborne arsenic contaminated dust (EPA, 1984) and on the clear dose-dependent relationship between ingested arsenic and skin cancer (Tseng, 1968 & 1977).

Using the dose-response data from the 1968 Tseng study, the EPA derived an oral cancer slope factor of $1.5 \text{ (mg/kg/day)}^{-1}$ for inorganic arsenic using a model that assumes the dose-response curve is linear at low doses. The fact that the body may detoxify arsenic through methylation suggests that the dose-response curve for arsenic may be non-linear at low doses. Thus, the slope factor based on the linear model may over-estimate cancer risks at low doses. The EPA has concluded that although the current slope factor might overestimate low dose risk, data are too limited to permit a quantitative adjustment of the slope factor (EPA, 1988). Based on the above slope factor, we estimated the excess lifetime risk for developing cancer, associated with exposure from soil ingestion, above- and below-ground home-grown vegetable ingestion, soil dermal contact, and air/dust inhalation combined to 46 ppm arsenic in surface soil from all pathways for 30 years, to be 5.74×10^{-6} . Qualitatively, we would interpret this risk level as no apparent increased lifetime risk for developing cancer (See Appendix C for pathway-specific parameters and results).

Conclusions

Based on what we know about the effects of arsenic on the human body under normal exposure conditions and after applying the results of the arsenic bioavailability study conducted by CVMUM to the ingestion exposure scenarios, TDH and ATSDR conclude the following:

1. Considering all pathways of exposure to inorganic arsenic in surface soil, we would not expect a soil clean-up level of 46 mg/kg to result in adverse non-carcinogenic health effects in children or adults.
2. The proposed clean-up level of 46 mg/kg of arsenic in surface soil is not expected to be a problem (with respect to serious or less serious adverse health effects) even in children with short-term or sporadic pica behavior who may eat up to 5,000 mg soil per day for up to 14 days in any one year period.
3. Long-term exposures (30 years) associated with the proposed clean-up level of 46 mg/kg of arsenic in surface soil would result in no apparent increased lifetime risk of developing cancer.
4. Based on conclusions 1, 2, and 3 above, the proposed cleanup level of 46 mg/kg for arsenic in surface soil at this site would pose no apparent public health hazard.
5. This assessment does not evaluate exposure risks associated with significant chronic pica behavior.

Recommendations

Not applicable

Public Health Action Plan

Not applicable

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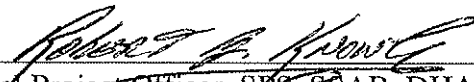
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Certification

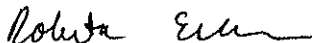
This public health consultation was prepared by the Texas Department of Health (TDH) under a Cooperative Agreement with the Agency for Toxic Substances and Disease Registry (ATSDR).

It is in accordance with approved methodology and procedures existing at the time the health consultation was initiated.



Technical Project Officer, SP6, SSAB, DHAC, ATSDR

The Division of Health Assessment and Consultation, ATSDR, has reviewed this health consultation and concurs with its findings.



Chief, State Programs Section, SSAB, DHAC, ATSDR

Appendices

Appendix A: Summary of Non-Carcinogenic Daily Doses of Arsenic from Various Pathways

Appendix B: Summary of Non-Carcinogenic Daily Doses of Arsenic from Various Pathways
Including Short-Term Pica

Appendix C: Summary of Carcinogenic Risk Levels of Arsenic from Various Pathways

**Appendix A: Summary of Non-Carcinogenic Daily Doses of Arsenic Resulting from
Various Pathways**

Appendix A. Non-Carcinogenic CoCs

Page 1 of 4

Summary of Hazard Quotients and Daily Doses of Arsenic Resulting from Combined Exposure Through Various Pathways to a Given Residential Soil Arsenic Concentration:

Param1	CoC Concentration in Soil (mg As/kg soil) (Soil As Conc. of 44.0845 mg/kg gives hazard quotient of 1.000000)	Conc_{Soil}	46.0000	mg As/kg soil
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Item #	Result for Exposure Pathway	Term	Value	Units
HQ - 3.2	Hazard Quotient for Soil Ingestion	Soil HQ_{Ing-NC}	0.784170	-
HQ - 7.2	Hazard Quotient for HG AbgVeg Ingestion	AbgVeg HQ_{Ing-NC}	0.099382	-
HQ - 7.4	Hazard Quotient for HG BgVeg Ingestion	BgVeg HQ_{Ing-NC}	0.030496	-
HQ - 2.2	Hazard Quotient for Soil Dermal Contact	Soil HQ_{Derm-NC}	0.129388	-
HQ - 1.2	Hazard Quotient for Air/Dust Inhalation	Air HQ_{Inh-NC}	0.000015	-
HQ - Tot	Total HQ from Soil & Vege Ingestion, Dust Inhalation, and Dermal Contact =		1.043451	-

Item #	Result for Exposure Pathway	Term	Value	Units
DD - 3.2	Daily Dose of As from Soil Ingestion	Soil Dose_{Ing-NC}	2.353E-04	mg As/kg BW/day
DD - 7.2	Daily Dose of As from HG AbgVeg Ingestion	AbgVeg Dose_{Ing-NC}	2.981E-05	mg As/kg BW/day
DD - 7.4	Daily Dose of As from HG BgVeg Ingestion	BgVeg Dose_{Ing-NC}	9.149E-06	mg As/kg BW/day
DD - 2.2	Daily Dose of As from Soil Dermal Contact	Soil Dose_{Derm-NC}	3.882E-05	mg As/kg BW/day
DD - 1.2	Daily Dose of As from Soil Dermal Contact	Air Dose_{Inh-NC}	4.445E-09	mg As/kg BW/day
DD - Tot	Total DD from Soil & Vege Ingestion, Dust Inhalation, and Dermal Contact =		3.130E-04	mg As/kg BW/day

HQ - 3.2 Ingestion of NonCarcinogenic CoCs in Soil - Soil HQ Ing.NC

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Soil Ingestion Rate - Child - Residential (mg/day)	IR _{Soil.Ch.Res}	200	mg soil/day
3	Conversion Factor (mg to kg)	CF _{mg:kg}	1.00E-06	kg soil/mg soil
4	Exposure frequency - Child - Residential (days/yr)	EF _{Ch.Res}	350	days/yr
5	Exposure Duration - Child - Residential (yr)	ED _{Ch.Res}	6	yr
6	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
7	Oral Reference Dose (mg/kg/day)	RfD _{Or}	0.0003	mg As/kg BW/day
8	Average Body Weight - Child 0-6 (kg)	AvgBW _{Ch 0-6}	15	kg BW
9	Averaging Time - NonCarcinogens - Child - Residential (yr)	AT _{NC.Ch.Res}	6	yr
10	Days per Year	DpY	365	days/yr
HQ - 3.2	Hazard Quotient for Soil Ingestion	Soil HQ_{Ing.NC}	0.784170	-
DD - 3.2	Daily Dose of As from Soil Ingestion	Soil Dose_{Ing.NC}	2.353E-04	mg As/kg BW/day

Appendix A. Non-Carcinogenic CoCs

Page 2 of 4

HQ - 7.2 Ingestion of NonCarcinogenic CoCs in Home-Grown Above-Ground Vegetables - AbgVeg HQ Ing.NC

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Partition coefficient for As in Abg vege vs soil (g soil/g DW)	PC _{Abg:Soil}	0.01	g soil/g DW
3	Vege Ingestion Rate - Child - HG AbgVege (g As Consumed/day)	IR _{Abg.Ch.Res}	14.567	g AC/day
4	Conversion Factor (g As Consumed to g Dry Weight)	CF _{AC:DW}	17.4%	g DW/g AC
5	Conversion Factor (g to kg)	CF _{g:kg}	1.000E-03	kg soil/g soil
6	Exposure Frequency - Child - Residential (days/yr)	EF _{Ch.Res}	350	days/yr
7	Exposure Duration - Child - Residential (yr)	ED _{Ch.Res}	6	yr
8	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
9	Oral Reference Dose (mg/kg/day)	RfD _{Or}	0.0003	mg As/kg BW/day
10	Average Body Weight - Child 0-6 (kg)	Avg _{BW} _{Ch 0-6}	15	kg BW
11	Days per Year	DpY	365	days/yr
12	Averaging Time - NonCarcinogens - Child - Residential (yr)	AT _{NC.Ch.Res}	6	yr
HQ - 7.2	Hazard Quotient for HG AbgVeg Ingestion	AbgVegHQ _{Ing.NC}	0.099382	-
DD - 7.2	Daily Dose of As from HG AbgVeg Ingestion	AbgVegDose _{Ing.NC}	2.981E-05	mg As/kg BW/day

HQ - 7.4 Ingestion of NonCarcinogenic CoCs in Home-Grown Below-Ground Vegetables - BgVeg HQ Ing.NC

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Partition coefficient for As in Abg vege vs soil (g soil/g DW)	PC _{Abg:Soil}	0.008	g soil/g DW
3	Vegetable Ingestion Rate - Child - BelowGround Vegetables	IR _{Bg.Ch.Res}	4.379	g AC/day
4	Conversion Factor (As Consumed to Dry Weight)	CF _{AC:DW}	22.2%	g DW/g AC
5	Conversion Factor (g to kg)	CF _{g:kg}	1.000E-03	kg soil/g soil
6	Exposure Frequency (days/yr)	EF _{Ch.Res}	350	days/yr
7	Exposure Duration - Child	ED _{Ch.Res}	6	yr
8	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
9	Oral Reference Dose (mg/kg/day)	RfD _{Or}	0.0003	mg As/kg BW/day
10	Average Body Weight - Child 0-6 (kg)	Avg _{BW} _{Ch 0-6}	15	kg BW
11	Days per Year	DpY	365	days/yr
12	Averaging Time - NonCarcinogens - Child - Residential (yr)	AT _{NC.Ch.Res}	6	yr
HQ - 7.4	Hazard Quotient for HG BgVeg Ingestion	BgVegHQ _{Ing.NC}	0.030496	-
DD - 7.4	Daily Dose of As from HG BgVeg Ingestion	BgVegDose _{Ing.NC}	9.149E-06	mg As/kg BW/day

Appendix A. Non-Carcinogenic CoCs

Page 3 of 4

HQ - 2.2 Dermal Contact with NonCarcinogenic CoCs in Soil - Soil HQ Derm-NC

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Soil-to-Skin Adherence Factor - Child - Res (mg soil/cm ² /day)	AF _{Ch,Res}	0.2	mg soil/cm ² /day
3	Dermal Absorption Fraction (unitless)	ABS _d	0.03	-
4	Skin Surface Area - Child - Residential (cm ²)	SA _{C,Res}	2200	cm ²
5	Conversion Factor (mg to kg)	CF _{mg:kg}	1.00E-06	kg soil/mg soil
6	Exposure Duration - Child - Residential (yr)	ED _{Ch,Res}	6	yr
7	Exposure frequency - Residential	EF _{Res}	350	days/yr
8	Reference Dose Dermal (mg/kg-day)	RfD _d	0.0003	mg As/kg BW/day
9	Average Body Weight - Child 0-6 (kg)	Avg ^{BW} _{Ch 0-6}	15	kg BW
10	Averaging Time - NonCarcinogens - Child - Residential (yr)	AT _{NC,Ch,Res}	6	yr
11	Days per Year	DpY	365	days/yr
HQ - 2.2	Hazard Quotient for Soil Dermal Contact	Soil ^{HQ} _{Derm,NC}	0.129388	-
DD - 2.2	Daily Dose of As from Soil Dermal Contact	Soil ^{Dose} _{Derm,NC}	3.882E-05	mg As/kg BW/day

HQ - 1.2 Inhalation of NonCarcinogenic CoCs in Air - Air HQ Inh-NC

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Suspended Particulate Level (kg soil/m ³)	SPL	2.160E-10	kg soil/m ³
3	Conversion Factor (mg:μg)	CF _{mg:μg}	1000	μg As/mg As
4	Exposure Frequency - Child - Residential (days/yr)	EF _{Ch,Res}	350	days/yr
5	Exposure Duration - Child - Residential (yr)	ED _{Ch,Res}	6	yr
6	Reference Concentration (μg As/m ³) (RAB Estimate)	RfC	0.64286	μg As/m ³
7	Days per Year	DpY	365	days/yr
8	Averaging Time - NonCarcinogens - Child - Residential (yr)	AT _{NC,Ch,Res}	6	yr
HQ - 1.2	Hazard Quotient for Air/Dust Inhalation	Air ^{HQ} _{Inh,NC}	1.482E-05	-
9	Average Respiratory Daily Volume 0-6 (m ³ /day)	Avg ^{RDV} ₀₋₆	7.00	m ³ /day
10	Average Body Weight - Child 0-6 (kg)	Avg ^{BW} _{Ch 0-6}	15.0	kg BW
11	Conversion Factor (mg:μg)	CF _{mg:μg}	1000	μg/mg
DD - 1.2	Daily Dose of As from Soil Dermal Contact	Air ^{Dose} _{Inh,NC}	4.4453E-09	mg As/kg BW/day

Appendix A. Non-Carcinogenic CoCs

Page 4 of 4

HQ - 1.2b Calculation of Particulate Emission Factor (PEF) and Suspended Particulate Level (SPL)

Item #	Parameter Description	Term	Value	Units
1	Width of Contaminated Area (m)	LS	45	m
2	Wind Speed in Mixing Zone (m/sec)	V	2.25	m/sec
3	Diffusion Height (m)	DH	2	m
4	Conversion Factor (hr to sec)	CF _{Hr:Sec}	3600	sec/hr
5	Conversion Factor (kg to g)	CF _{kg:g}	1000	g soil/kg soil
6	Area of Contamination (2023.5 m ² = 0.5 acre) (m ²)	A	2025	m ²
7	Respirable Fraction (g/m ² -hr)	RF	0.036	g/m ² -hr
8	Fraction of Vegetative Cover (unitless)	G	0	-
9	Mean Annual Wind Speed (m/sec)	U _m	4.5	m/sec
10	Equivalent Threshold Value of Wind Speed at 10 m (m/sec)	U _t	12.8	m/sec
11	Function Dependent on U _m /U _t (unitless)	F(x)	0.0497	-
12	Particulate Emission Factor (m ³ /kg soil)	PEF	4.631E+09	m ³ /kg soil
13	Suspended Particulate Level (kg soil/m ³)	SPL	2.160E-10	kg soil/m ³

Appendix B: Summary of Non-Carcinogenic Daily Doses of Arsenic Resulting from Short-Term Pica Behavior

Appendix B. Non-Carcinogenic CoCs - Sporadic or Short-Term Pica

Page 1 of 2

HQ - 3.2_{p2/365} Ingestion of NonCarcinogenic CoCs in Soil (Pica Behavior x 2 days out of 365) - ^{Soil}HQ_{PCh.Ing.NC}

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Soil Ingestion Rate - Pica Child - Residential (mg/day)	IR _{Soil.PCh.Res}	5000	mg soil/day
3	Conversion Factor (mg soil to kg soil)	CF _{mg/kg}	1.00E-06	kg soil/mg soil
4	Exposure days - Pica Child - Residential (days/yr)	EF _{PCh.Res}	2	days/yr
5	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
6	Acute Oral LOAEL for Serious Effects ¹ (mg/kg/day)	LOAEL _{Ac.Or}	0.05	mg As/kg BW/day
7	Average Body Weight - Child 0-6 (kg)	Avg _{BW} _{Ch 0-6}	15	kg BW
8	Days per Year	DpY	365	days/yr
HQ - 3.2_{p2/365}	Annualized HQ for Short-Term Pica Soil Ing - 2/365	^{Soil} HQ _{PCh.Ing.NC}	0.00067	-
DD - 3.2_{p2/365}	Annualized DD of As, Short-Term Pica Soil Ingest.	^{Soil} Dose _{PCh.Ing.NC}	3.361E-05	mg As/kg BW/day

¹Acute Oral LOAEL for Serious Effects = 0.05 mg/kg/day with 2-3 week exposure duration (Mizuta et al., 1956)

HQ - 3.2_{p2/14} Ingestion of NonCarcinogenic CoCs in Soil (Pica Behavior x 2 days out of 14) - ^{Soil}HQ_{PCh.Ing.NC}

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Soil Ingestion Rate - Pica Child - Residential (mg/day)	IR _{Soil.PCh.Res}	5000	mg soil/day
3	Conversion Factor (mg soil to kg soil)	CF _{mg/kg}	1.00E-06	kg soil/mg soil
4	Exposure days - Pica Child - Residential (days/yr)	EF _{PCh.Res}	2	days/yr
5	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
6	Acute Oral LOAEL for Serious Effects ¹ (mg/kg/day)	LOAEL _{Ac.Or}	0.05	mg As/kg BW/day
7	Average Body Weight - Child 0-6 (kg)	Avg _{BW} _{Ch 0-6}	15	kg BW
8	Days Exposure Producing Less Serious to Serious Symptoms	DpS	14	days/yr
HQ - 3.2_{p2/14}	HQ for Short-Term Pica Soil Ingestion - 2/14	^{Soil} HQ _{PCh.Ing.NC}	0.01752	-
DD - 3.2_{p2/14}	Daily Dose of As, Short-Term Pica Soil Ingestion	^{Soil} Dose _{PCh.Ing.NC}	8.762E-04	mg As/kg BW/day

¹Acute Oral LOAEL for Serious Effects = 0.05 mg/kg/day with 2-3 week exposure duration (Mizuta et al., 1956)

Appendix B. Non-Carcinogenic CoCs - Sporadic or Short-Term Pica

Page 2 of 2

HQ - 3.2_{P14/14} Ingestion of NonCarcinogenic CoCs in Soil (Pica Behavior x 14 days out of 14) - ^{Soil}HQ_{PCh,Ing,NC}

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Soil Ingestion Rate - Pica Child - Residential (mg/day)	IR _{Soil,PCh,Res}	5000	mg soil/day
3	Conversion Factor (mg soil to kg soil)	CF _{mg/kg}	1.00E-06	kg soil/mg soil
4	Exposure days - Pica Child - Residential (days/yr)	EF _{PCh,Res}	14	days/yr
5	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
6	Acute Oral LOAEL for Serious Effects ¹ (mg/kg/day)	LOAEL _{Ac,Or}	0.05	mg As/kg BW/day
7	Average Body Weight - Child 0-6 (kg)	Avg _{BW} _{Ch 0-6}	15	kg BW
8	Days Exposure Producing Less Serious to Serious Symptoms	DpS	14	days/yr
HQ - 3.2_{P14/14}	HQ for Short-Term Pica Soil Ingestion - 14/14	^{Soil} HQ _{PCh,Ing,NC}	0.12267	-
DD - 3.2_{P14/14}	Daily Dose of As, Short-Term Pica Soil Ingestion	^{Soil} Dose _{PCh,Ing,NC}	6.133E-03	mg As/kg BW/day

¹Acute Oral LOAEL for Serious Effects = 0.05 mg/kg/day with 2-3 week exposure duration (Mizuta et al., 1956)

RBEL 3.2_{LOAEL} - Soil Arsenic Concentration Needed to Exceed the Acute LOAEL¹ for Serious Effects for Arsenic Under Soil Pica Conditions (assuming a 15 kg child ingesting 5,000 mg soil per day for 2-3 weeks)

Item #	Exposure Factor	Term	Value	Units
1	Acute Oral LOAEL for Serious Effects ¹ (mg/kg/day)	LOAEL _{Ac,Or}	0.05	mg As/kg BW/day
2	Hazard Quotient for Short-Term Pica Soil Ingestion	^{Soil} HQ _{P,Ing,NC}	1.00000	-
3	Average Body Weight - Child 0-6 (kg)	Avg _{BW} _{Ch 0-6}	15	kg BW
4	Days Exposure Producing Less Serious to Serious Symptoms	DpS	14	days/yr
5	Soil Ingestion Rate - Pica Child - Residential (mg/day)	IR _{Soil,PCh,Res}	5000	mg soil/day
6	Conversion Factor (mg soil to kg soil)	CF _{mg/kg}	1.00E-06	kg soil/mg soil
7	Exposure days - Pica Child - Residential (days/yr)	EF _{PCh,Res}	14	days/yr
8	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
^{Soil} Conc _{LOAEL}	CoC Concentration in Soil (mg As/kg soil)	^{Soil} RBEL _{PCh,14}	375.00	mg As/kg soil
DD - 3.2_{P14/14}	Daily Dose of As, Short-Term Pica Soil Ingestion	^{Soil} Dose _{PCh,Ing,NC}	0.0500	mg As/kg BW/day

¹Acute Oral LOAEL for Serious Effects = 0.05 mg/kg/day with 2-3 week exposure duration (Mizuta et al., 1956)

**Appendix C: Summary of Carcinogenic Risk Levels and Daily Doses of Arsenic from
Various Pathways**

Appendix C. Carcinogenic CoCs

Page 1 of 4

Summary of Carcinogenic Risk Levels and Daily Doses of Arsenic Resulting from Combined Exposure Through Various Pathways to a Given Residential Soil Arsenic Concentration:

Param1	CoC Concentration in Soil (mg As/kg soil) (A soil As Conc. of 80.0779 mg/kg produces a risk of 1.00000E-05)	Conc_{Soil}	46.0000	mg As/kg soil
Param2	Exposure Duration - Adult - Residential (yr)	ED_{Ad.Res}	30	yr

Item #	Result for Exposure Pathway	Term	Value	Units
Risk - 3.1	Carcinogenic Risk Level for Soil Ingestion	Soil_{RL}ing-C	1.620E-06	-
Risk - 7.1	Carcinogenic Risk Level for AbgVeg Ingestion	AbgVeg_{RL}ing-C	2.418E-06	-
Risk - 7.3	Carcinogenic Risk Level for BgVeg Ingestion	BgVeg_{RL}ing-C	6.914E-07	-
Risk - 2.1	Carcinogenic Risk Level for Soil Dermal Contact	Soil_{RL}derm-C	9.971E-07	-
Risk - 1.1	Carcinogenic Risk Level for Air/Dust Inhalation	Air_{RL}inh-C	1.755E-08	-
Risk - Tot	Total Risk from Soil & Vege Ingestion, Dust Inhalation, and Dermal Contact	=	5.744E-06	-

Item #	Result for Exposure Pathway	Term	Value	Units
DD - 3.1	Daily Dose of As from Soil Ingestion	Soil_{Dose}ing-C	1.080E-06	mg As/kg BW/day
DD - 7.1	Daily Dose of As from AbgVeg Ingestion	AbgVeg_{Dose}ing-C	1.612E-06	mg As/kg BW/day
DD - 7.3	Daily Dose of As from BgVeg Ingestion	BgVeg_{Dose}ing-C	4.609E-07	mg As/kg BW/day
DD - 2.1	Daily Dose of As from Soil Dermal Contact	Soil_{Dose}derm-C	6.647E-07	mg As/kg BW/day
DD - 1.1	Daily Dose of As from Air/Dust Inhalation	Air_{Dose}inh-C	1.166E-09	mg As/kg BW/day
DD - Tot	Total Daily Dose of As from Soil & Vege Ing, Dust Inh, and Dermal Contact	=	3.819E-06	mg As/kg BW/day

Risk - 3.1 Ingestion of Carcinogenic CoCs in Soil - Soil Risk Ing-C (mg/kg)

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc_{Soil}	46.00	mg As/kg soil
2	Age-Adjusted Soil Ingestion Rate	IR_{soil.AgeAdj.res}	100.0	mg soil/day
3	Conversion Factor (mg:kg)	CF_{mg:kg}	1.00E-06	kg soil/mg soil
4	Exposure Frequency - Adult - Residential (days/yr)	EF_{Ad.Res}	350	days/yr
5	Exposure Duration - Adult - Residential (yr)	ED_{Ad.Res}	30.0	yr
6	Oral Slope Factor (mg/kg/day) ⁻¹	SFo	1.5	(mg As/kg BW/day) ⁻¹
7	Modifying Factor (for As) (unitless)	MF	0.1	-
8	Relative Bioavailability Factor (unitless)	RBAF	0.4	-
9	Averaging Time - Carcinogens	ATc	70.0	yr
10	Average Body Weight - Adult (kg BW)	Avg_{BWAd}	70.0	kg BW
11	Days per Year	DpY	365	days/yr
Risk - 3.1	Carcinogenic Risk Level for Soil Ingestion	Soil_{RL}ing-C	1.620E-06	-
DD - 3.1	Daily Dose of As from Soil Ingestion	Soil_{Dose}ing-C	1.080E-06	mg As/kg BW/day

Appendix C. Carcinogenic CoCs

Page 2 of 4

Risk - 7.1 Ingestion of Carcinogenic CoCs in Above-Ground Vegetables - AbgVeg Risk Ing-C (mg/kg)

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Ingestion Rate for Above-Ground Vegetables (g AC/day)	IR _{Abg, AgeAdj, Res}	34.306	g AC/day
3	Exposure Frequency (days/yr)	EF _{Ad, Res}	350	days/yr
4	Exposure Duration - Adult - Residential (yr)	ED _{Ad, Res}	30.0	yr
5	Conversion Factor (g As Consumed to g Dry Weight)	CF _{AC:DW}	17.4%	g DW/g AC
6	Partition coefficient for As in Abg vege vs soil (g soil/g DW)	PC _{Abg:Soil}	0.01	g soil/g DW
7	Oral Slope Factor (mg/kg/day) ⁻¹	SF _{Or}	1.5	(mg As/kg BW/day) ⁻¹
8	Modifying Factor (for As) (unitless)	MF _{As}	0.1	-
9	Relative Bioavailability Factor	RBAF	1	-
10	Conversion Factor (g/kg)	CF _{kg:g}	1.000E+03	g soil/kg soil
11	Lifetime Average body weight (males & females combined)	Avg BW ₀₋₇₀	70.0	kg BW
12	Days per Year	DpY	365	days/yr
13	Averaging Time - Carcinogens	AT _{C, Ad, Res}	70	yr
Risk - 7.1	Carcinogenic Risk Level for AbgVeg Ingestion	AbgVeg _{RL} Ing-C	2.418E-06	-
DD - 7.1	Daily Dose of As from AbgVeg Ingestion	AbgVeg _{Dose} Ing-NC	1.612E-06	mg As/kg BW/day

Risk - 7.3 Ingestion of Carcinogenic CoCs in Below-Ground Vegetables - BgVeg RBEL Ing-C (mg/kg)

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Ingestion Rate for Below-Ground Vegetables (g AC/day)	IR _{Bg, AgeAdj, Res}	9.610	g AC/day
3	Exposure Frequency (days/yr)	EF _{Ad, Res}	350	days/yr
4	Exposure Duration (yr)	ED _{Ad, Res}	30	yr
5	Conversion Factor (As Eaten to Dry Weight)	CF _{AE:DW}	22.2%	g DW/g AC
6	Partition coefficient for As in Bg vege vs soil (g soil/g DW)	PC _{Bg:Soil}	0.008	g soil/g DW
7	Oral Slope Factor (mg/kg/day) ⁻¹	SF _{Or}	1.5	(mg As/kg BW/day) ⁻¹
8	Modifying Factor (for As) (unitless)	MF _{As}	0.1	-
9	Relative Bioavailability Factor	RBAF	1	-
10	Conversion Factor (kg to g)	CF _{kg:g}	1.000E+03	g soil/kg soil
11	Lifetime Average body weight (males & females combined)	Avg BW ₀₋₇₀	70.00	kg BW
12	Days per Year	DpY	365	days/yr
13	Averaging Time - Carcinogens	AT _{C, Ad, Res}	70	yr
Risk - 7.3	Carcinogenic Risk Level for BgVeg Ingestion	BgVeg _{RL} Ing-C	6.914E-07	-
DD - 7.3	Daily Dose of As from BgVeg Ingestion	BgVeg _{Dose} Ing-NC	4.609E-07	mg As/kg BW/day

Appendix C. Carcinogenic CoCs

Page 3 of 4

Risk - 2.1 Dermal Contact with Carcinogenic CoCs in Soil - Soil RBEL Derm-C (mg/kg)

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil (mg As/kg soil)	Conc _{Soil}	46.00	mg As/kg soil
2	Exposure Frequency - Residential	EF _{Res}	350	days/yr
3	Dermal Slope Factor (mg/kg-day) ⁻¹	SF _D	1.5	(mg As/kg BW/day) ⁻¹
4	Dermal Adjustment Factor (mg/kg/day)-yrs	DF _{Adj}	351.6	(mg soil/kg BW/day)-yrs
5	Dermal Absorption Fraction (unitless)	ABS _d	0.03	-
6	Conversion Factor (mg to kg)	CF _{mg:kg}	1.00E-06	kg soil/mg soil
7	Modifying Factor for Arsenic (unitless)	MF	0.1	-
8	Averaging Time - Carcinogens	AT _c	70	yr
9	Days per Year	DpY	365	days/yr
Risk - 2.1	Carcinogenic Risk Level for Soil Dermal Contact	Soil _{RL} _{Derm-C}	9.971E-07	-
DD - 2.1	Daily Dose of As from Soil Dermal Contact	Soil _{Dose} _{Derm-C}	6.647E-07	mg As/kg BW/day

RBEL - 2.1b Calculation of Dermal Adjustment Factor (mg/kg/day)-yrs - DF_{Adj}

Item #	Parameter Description	Term	Value	Units
1	Age-Specific Skin Surface Area 0-6 (cm ²)	SA ₀₋₆	2200	cm ²
2	Age-Specific Adherence Factor 0-6 (mg/cm ² /day)	AF ₀₋₆	0.2	mg soil/cm ² /day
3	Age-Specific Exposure Duration 0-6 (yr)	ED ₀₋₆	6	yr
4	Age-Specific Body Weight 0-6 (kg)	BW ₀₋₆	15	kg BW
5	Age-Specific Skin Surface Area 6-18 (cm ²)	SA ₆₋₁₈	3500	cm ²
6	Age-Specific Adherence Factor 6-18 (mg/cm ² /day)	AF ₆₋₁₈	0.1	mg soil/cm ² /day
7	Age-Specific Exposure Duration 6-18 (yr)	ED ₆₋₁₈	12	yr
8	Age-Specific Body Weight 6-18 (kg)	BW ₆₋₁₈	45	kg BW
9	Age-Specific Skin Surface Area 18-30 (cm ²)	SA ₁₈₋₃₀	4800	cm ²
10	Age-Specific Adherence Factor 18-30 (mg/cm ² /day)	AF ₁₈₋₃₀	0.1	mg soil/cm ² /day
11	Age-Specific Exposure Duration 18-30 (yr)	ED ₁₈₋₃₀	12	yr
12	Age-Specific Body Weight 18-30 (kg)	BW ₁₈₋₃₀	70	kg BW
13	Dermal Adjustment Factor (mg/kg/day)-yrs	DF _{Adj}	351.6	(mg soil/kg BW/day)-yrs

Appendix C. Carcinogenic CoCs

Page 4 of 4

Risk - 1.1 Inhalation of Carcinogenic CoCs in Air - Air RBEL Inh-C (mg/m^3)

Item #	Exposure Factor	Term	Value	Units
1	CoC Concentration in Soil ($\text{mg As}/\text{kg soil}$)	$\text{Conc}_{\text{Soil}}$	46.00	$\text{mg As}/\text{kg soil}$
2	Suspended Particulate Level ($\text{kg soil}/\text{m}^3$)	SPL	$2.16\text{E}-10$	$\text{kg soil}/\text{m}^3$
3	Conversion Factor ($\text{mg}/\mu\text{g}$)	$\text{CF}_{\text{mg},\mu\text{g}}$	1000	$\mu\text{g As}/\text{mg As}$
4	Exposure Frequency - Adult - Residential (days/yr)	EF_{Res}	350	days/yr
5	Exposure Duration - Adult - Residential (yr)	$\text{ED}_{\text{Ad,Res}}$	30	yr
6	Inhalation Unit Risk Factor ($\mu\text{g}/\text{m}^3$) ⁻¹	URF	0.0043	($\mu\text{g As}/\text{m}^3$) ⁻¹
8	Days per Year	DpY	365	days/yr
9	Averaging Time - Carcinogens (yr)	ATc	70	yr
Risk - 1.1	Carcinogenic Risk Level for Air/Dust Inhalation	$\text{Air}^{\text{RL}}_{\text{Inh-C}}$	1.755E-08	-
10	Respiratory Daily Volume - Adult (m^3/day)	RDV_{Ad}	20.0	m^3/day
11	Average Body Weight - Adult 0-70 (kg)	$\text{AvgBW}_{\text{Ch 0-6}}$	70.0	kg BW
DD - 1.1	Daily Dose of As from Air/Dust Inhalation	$\text{Air}^{\text{Dose}}_{\text{Inh-C}}$	1.166E-09	mg As/kg BW/day

Risk - 1.1b Calculation of Particulate Emission Factor (PEF) and Suspended Particulate Level (SPL) for Air RBEL

Item #	Parameter Description	Term	Value	Units
1	Width of Contaminated Area (m)	LS	45	m
2	Wind Speed in Mixing Zone (m/sec)	V	2.25	m/sec
3	Diffusion Height (m)	DH	2	m
4	Conversion Factor (hr to sec)	$\text{CF}_{\text{Hr,Sec}}$	3600	sec/hr
5	Conversion Factor (kg to g)	$\text{CF}_{\text{kg,g}}$	1000	g soil/kg soil
6	Area of Contamination ($2023.5 \text{ m}^2 = 0.5 \text{ acre}$) (m^2)	A	2025	m^2
7	Respirable Fraction ($\text{g}/\text{m}^2\text{-hr}$)	RF	0.036	$\text{g}/\text{m}^2\text{-hr}$
8	Fraction of Vegetative Cover (unitless)	G	0	-
9	Mean Annual Wind Speed (m/sec)	U_m	4.5	m/sec
10	Equivalent Threshold Value of Wind Speed at 10 m (m/sec)	U_t	12.8	m/sec
11	Function Dependent on U_m/U_t (unitless)	$F(x)$	0.0497	-
12	Particulate Emission Factor ($\text{m}^3/\text{kg soil}$)	PEF	4.631E+09	$\text{m}^3/\text{kg soil}$
13	Suspended Particulate Level ($\text{kg soil}/\text{m}^3$)	SPL	2.160E-10	$\text{kg soil}/\text{m}^3$