HEALTH RISK ASSESSMENT AT AN INDUSTRIAL WASTEWATER TREATMENT PLANT

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ABSTRACT

During production and maintenance operations at the Oklahoma City Air Logistics Center [OC-ALC], industrial wastewater streams are generated which contain organic compounds [primarily phenol and methylene chloride]. These streams result from both direct and indirect contact with organic compounds via chemical depainting operations, chemical cleaning processes, and electroplating operations. Organic materials in the combined wastewater are treated at the on-site industrial wastewater treatment facility [IWTF] with unit processes including open surface basins. Some of these treatment processes result in the release of semi-volatile and volatile organic compounds [VOCs] from the wastewater to the ambient air. Because emitted VOCs can create potential health risks for treatment facility workers and the general public in the immediate surrounding areas, Tinker AFB is required to quantify [and report] VOCs released into the atmosphere. Such regulatory reporting can encompass identifying VOC emission sources, estimating emissions from the IWTF, quantifying ambient air concentrations surrounding the facility via dispersion modeling, and evaluating computer-generated numerical concentration estimates with respect to discontinuous field data and an open-path optical remote monitoring system. The focus of this paper is to identify and quantify health risks associated with phenol and methylene chloride releases surrounding the IWTF. The risk assessment will include calculation of an equivalent human dose [based on animal mortality studies], the maximum risk for individuals in the general population, excess number of cases of cancer, the average excess number of cases of cancer generated per year, and loss of life expectancy for the general population.

INTRODUCTION

In production and maintenance operations at the OC-ALC, industrial wastewater streams are generated which contain organic compounds. The organic materials in the wastewater are treated at the industrial wastewater treatment facility in open surface impoundments and collection systems. Some of these collection and treatment steps result in the release of VOCs and SVOCs from the wastewater to the ambient air. Because emitted VOC / SVOCs can create potential health problems for treatment facility workers and the general public in surrounding areas, assessment of VOC / SVOC emissions to the atmosphere is necessary for decision makers who must determine the appropriateness of the inputs to and the design and operation of the IWTF. The chemicals of primary interest are methylene chloride and phenol because they have historically accounted for over 50 percent of all targeted hazardous materials purchased and released at OC-ALC. The initial task involved estimating emissions [emission rates] from the individual IWTF process units via the use of the WATER8 model. Air dispersion [ISC-ST3] modeling software will quantify / estimate the ambient air chemical concentrations surrounding the IWTF. This task involves performing a risk assessment of the IWTF impact region to quantify risks associated with phenol and methylene chloride emissions on the general population in the housing community north of the treatment facility and impact of exposures on industrial wastewater treatment plant personnel. The treatment facility is situated with a small housing addition to the north, open field and creek system [Soldier Creek] to the south, four-lane highway [Douglas Blvd] on the east, and motor-vehicle parking structure on the west perimeter. Historically, there has been concern about chemical exposures on the housing community to the north. The following tasking will attempt to quantify some of the risks to both the surrounding general population and treatment plant workforce. The risk assessment will include calculation of an equivalent human dose [based on animal mortality studies], the maximum risk for individuals in the general population and IWTF personnel, excess number of cases of cancer in the general population and IWTF personnel, the average excess number of cases of cancer generated per year for the general population and IWTF personnel, and loss of life expectancy for the general population and IWTF worker subgroup.

Population characteristics of the housing edition north of the IWTF show that approximately 133 [2.66 persons per household in 50 households] people living in the surrounding area will be exposed to annual average air concentrations of a potential carcinogen [*i.e.*, methylene chloride and phenol]. The majority of the housing community residents are white [85.7 percent], above the age of 18 [72.2 percent], and male [51 percent]. The OC-ALC treatment facility worker subgroup consists of approximately 50 workers of which the population characteristics are white [84 percent] and male [92 percent].

RISK ASSESSMENT

Risk assessment is defined as a body of knowledge [methodology] that evaluates and derives a probability of an adverse effect of an agent [chemical, physical, or other], industrial process, technology, or natural process [1]. Traditionally, most risk assessments deal with health effects. The elements of a risk assessment includes the characterization of the types of health effects expected, characterization of the exposure, evaluation of experimental studies [animal and/or epidemiological], characterization of the relationship between dose and response, estimation of the risk of occurrence of health effects, estimation of the number of cases expected, characterization of the uncertainty of the analysis, and recommendation of an acceptable concentration in air, food, or water [2]. The risk assessment demonstration of this effort will attempt to satisfy some of these elements. Risk assessments are necessary for informed regulatory decisions regarding worker exposures, industrial emissions and effluents, ambient air and water contaminants, chemical residues in foods, cleanup of hazardous waste sites, and naturally occurring contaminants [2]. This portion of the effort will calculate the following for both phenol and methylene chloride: equivalent human dose [based on animal mortality studies], the maximum risk for individuals in the general population and IWTF personnel, excess number of cases of cancer in the general population and IWTF personnel, the average excess number of cases of cancer generated per year for the general population and IWTF personnel, and loss of life expectancy for the general population and IWTF worker subgroup [2].

The risk assessments will be conducted with information from the Integrated Risk Information System [IRIS] prepared and maintained by the U.S. EPA [3]. IRIS is an electronic database containing information on human health effects that may result from exposure to various chemicals in the environment. IRIS was initially developed for EPA staff in response to a growing demand for consistent information on chemical substances for use in risk assessments, decision-making and regulatory activities. The heart of the IRIS system is its collection of computer files covering individual chemicals. These chemical files contain descriptive and quantitative information in the following categories: oral reference doses and inhalation reference concentrations, hazard identification, slope factors, and oral and inhalation risks for carcinogenic effects [3]. It is important to note that although the IRIS system is a tool that provides hazard identification and dose-response assessment information, it does not provide situational information on individual instances of exposure. Combined with specific exposure information [via coupled modeling], the data in IRIS can be used for characterization of the public health risks of a given chemical in a given situation that can ultimately lead to a risk management decision designed to protect the public health [3].

METHYLENE CHLORIDE

Methylene chloride is widely used as a multi-purpose solvent and paint remover that is not known to occur naturally in the environment [4,5,6]. High concentrations have been measured in industrial indoor environments and during the use of methylene chloride as a paint remover. The general population is exposed to much lower levels of the solvent in the ambient air, drinking water, and food. About 80 percent of the world production of methylene chloride is estimated to be released into the atmosphere, but photodegradation takes place at a rate that make accumulation in the atmosphere unlikely [4,5,6]. In surface water, volatilization is the major process of removal, hydrolysis and photodegradation being insignificant. The solvent is readily aerobically biodegradable. The major route of human exposure is through inhalation, while absorption of liquid methylene chloride via the skin is slow [4,5,6].

Methylene Chloride is dichloromethane [CH_2Cl_2], molecular weight of 84.93, vapor pressure of 349 mm Hg, and odor threshold of 743 mg per m^3 [208 PPM]. Tinker AFB utilizes methylene chloride in depot maintenance operations as a chemical depainting agent used to chemically remove coatings from aircraft surfaces and components. In 1993, methylene chloride purchases accounted for 33 percent of all hazardous materials brought on the installation.

RISK ASSESSMENT COMPUTATIONS FOR METHYLENE CHLORIDE EXPOSURES

Given the following assumptions, calculate the equivalent human dose, maximum risk for individuals in the general population and IWTF personnel, excess cases in the general population and IWTF personnel, average excess cases generated per year for the general population and IWTF personnel. Existing air emission sources are assumed to operate continuously. Air dispersion modeling data show that approximately 133 people living in the surrounding area [housing area to the north of the facility] and 50 white male workers will be exposed to an annual average pollutant concentration of potential carcinogens obtained from air dispersion modeling [7]. The following assumptions will be made: the source of emission [IWTF process units] will operate for 45 years, the general population will be continuously exposed for 45 years, the number of people in the general population exposure subgroup [IWTF personnel] will remain constant for 45 years, the exposure concentration for the general population subgroup [IWTF staff] will remain constant for 45 years, workers will be exposed for eight hours per day, five days per week, 50 weeks per year for 45 years [45 years maximum for an individual worker], the size of the worker risk group will remain constant for 45 years, all workers will be exposed to one concentration over 45 years.

Human and animal dose rates are frequently reported in terms of the lowest observed adverse effect level [LOAEL]. The LOAEL is the lowest experimentally determined dose rate which produces a statistically or biologically significant adverse effect [1]. From documented animal mortality studies, the methylene chloride LOAEL of inhalation exposure of non-smoking healthy individual is 694 mg per m^3 [200 PPM] for 24 months, 6 hours per day, and 5 days per week. There were 11 of the 95 that reported a dose-related increase in the total number of benign tumors with an associated 8 of 95 in the control group [1]. The intake [*I*] in units of mass or volume of contaminated media per day is determined from tables of standard values of intake [1], and converted to units of volume of contaminated air per day, as given. Note that the average air intake for a male rat is 0.10 liter per minute [1]. The *T* is the median time [exposure frequency] of exposure in days and the average male rat body weight [*W*] is 0.50 kilograms [1].

To account for interspecies and intraspecies variability, the literature recommends use of a safety factor, *F*. This safety factor is the product of three components F_1, F_2, and F_3. The potential for interspecies variation in response sensitivity is represented by F_1. Values for F_1 may range from one to ten for animal data depending on the match of biokinetics [absorption, distribution, storage, biotransformation, and elimination as a function of time] and mechanism of the toxicity. If the biokinetics and mechanism of the toxicity match, F_1 is equal to one for an animal study. For human data, F_1 is typically unity. For methylene chloride, there appears to be a wide range of response sensitivity between species [rats to mice, hamsters, etc.], therefore, F_1 is assumed to be a value of ten [1]. The potential for intraspecies variation in human sensitivity is represented by F_2. Values may range from one to ten. If there is no human data regarding human variation in sensitivity, the suggested value for F_2 is one. The third safety factor component [F_3] is derived from the length of the study. A F_3 safety factor element of ten can be applied if the LOAEL is derived from a short-term study [as in this case]. Thus, the safety factor [*F*] is 100. Note that this safety factor is recommended by the IRIS database [3].

The lifespan [*L*] is the lifetime of the experimental species [male rat] expressed in days. The equivalent human dose [*D*] can be calculated from the animal study as follows. The equivalent human dose is a function of the LOAEL, contaminated air intake, exposure duration, weight of the animal species, lifespan of the experimental species, human lifetime [75 years], human body weight [70 kilograms], and a safety factor. The equivalent human dose is 540,000 mg.

$$D = 75 \cdot 365 \cdot 70 \left[\frac{C \cdot I \cdot T}{W \cdot F \cdot L} \right] \qquad 1$$

For determining the maximum dose to an individual in the general population, the maximum methylene chloride concentration is used. From the literature [7], the maximum methylene chloride exposure to the general population is 70 PPB [0.250 mg/m^3] as shown in Figure 1. This maximum exposure was obtained from computer models, *i.e.*, general fate models [WATER8] to determine an air emission rate and air dispersion model [ISC-ST3] to determine the ambient concentration [5].

$$D = C \cdot I \cdot T = 0.25 \cdot 10.8 \cdot 27{,}375 = 73{,}913 \; mg \qquad 2$$

The general population risk group dose of 73,913 mg is well below the equivalent human dose of 540,000 mg from the animal study. The maximum dose calculation for an individual in the general population is repeated for each of the receptor locations over the impact area in Figure 1 and illustrated in Figure 2. Note that the interest is the maximum dose to an individual in the general population as exists in the housing community located north of the treatment facility [right upper quadrant of Figure 1].

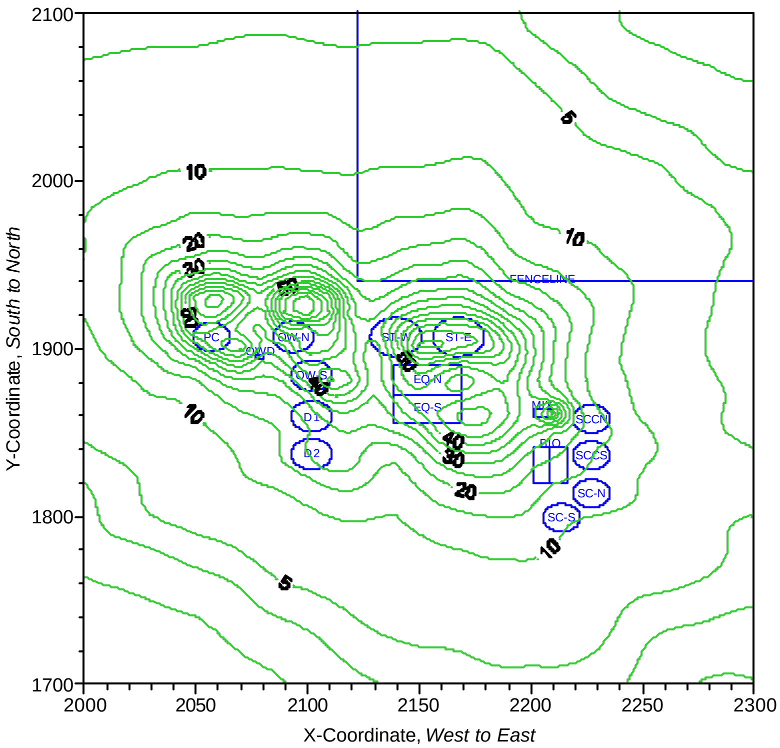

Figure 1. Methylene chloride concentration [PPB]

In calculating the maximum individual worker dose, the maximum methylene chloride dose is approximately 180 PPB [7]. The worker risk group dose of 100,527 mg is well below the lowest effective dose of 540,000 mg from the animal study. The maximum dose calculation for an individual worker is repeated for each of the receptor locations and illustrated in Figure 3.

The risk factor [R] in inverse milligrams is defined as the excess risk per unit of dose [derived from the lowest available experimental equivalent human dose-response point]. IRIS tabulates the risk factor for specific chemicals and exposure routes [oral, inhalation, etc.]. For methylene chloride, IRIS documents a risk factor of 4.7E-7 [3]. Maximum individual excess risk [P_e] for the general population and workers are determined as follows. The maximum individual excess risk for the general population and worker subgroup calculations are repeated for each of the receptor locations and illustrated in Figures 4 and 5.

$$P_{e,\,general\,population} = R \cdot D = 4.7E-7 \cdot [73{,}913] = 0.035 \; general\ population \qquad 3$$

$$P_{e,\,worker} = R \cdot D = 4.7E-7 \cdot [100{,}527] = 0.047 \; workers \qquad 4$$

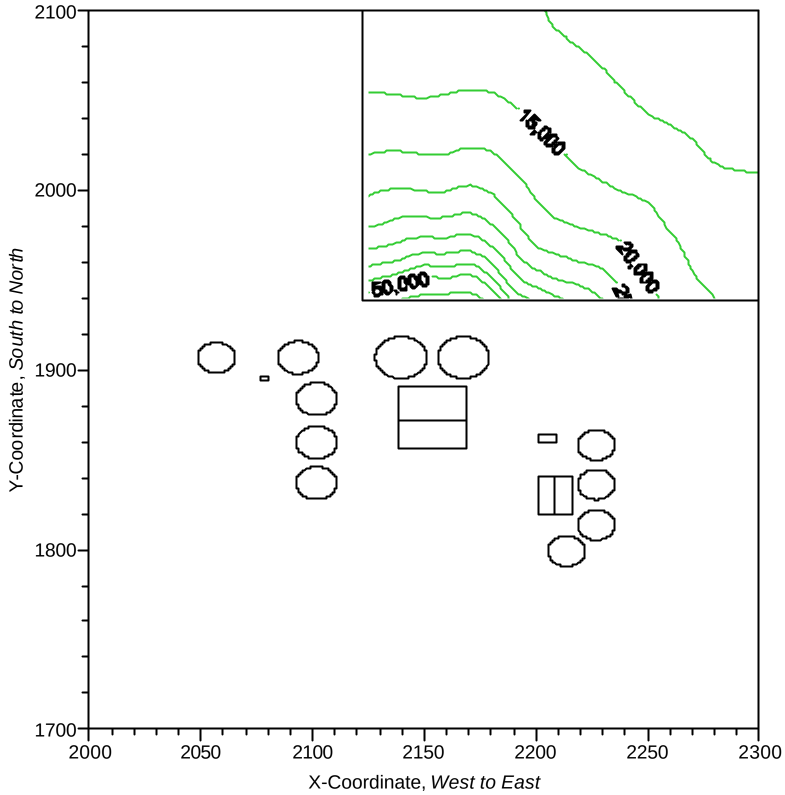

Figure 2. Equivalent methylene chloride human dose for individuals in the general population, mg

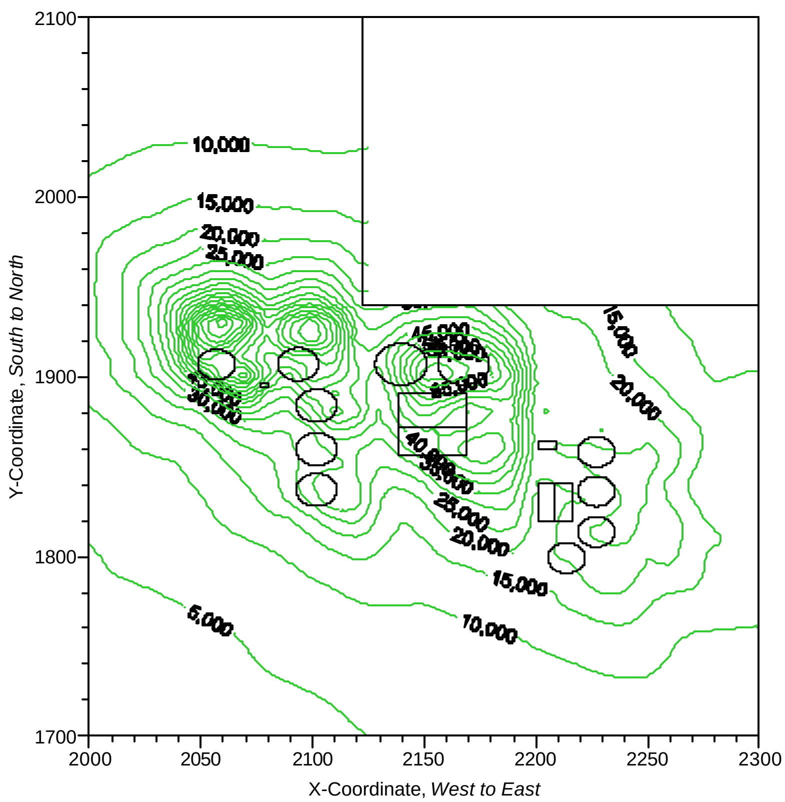

Figure 3. Equivalent methylene chloride human dose for individual workers, mg

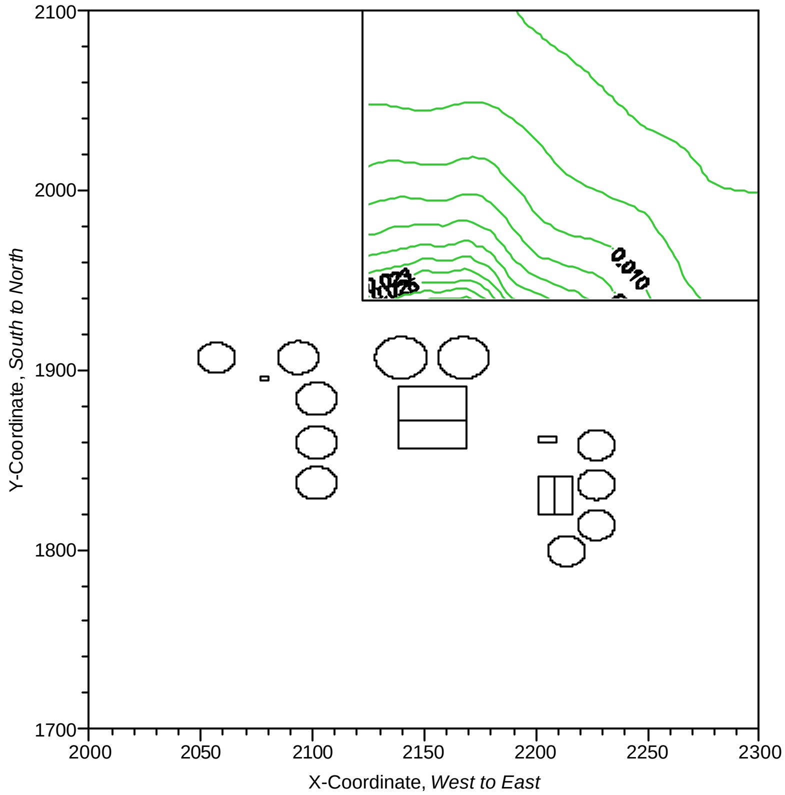

Figure 4. Maximum individual risk for methylene chloride in the general population

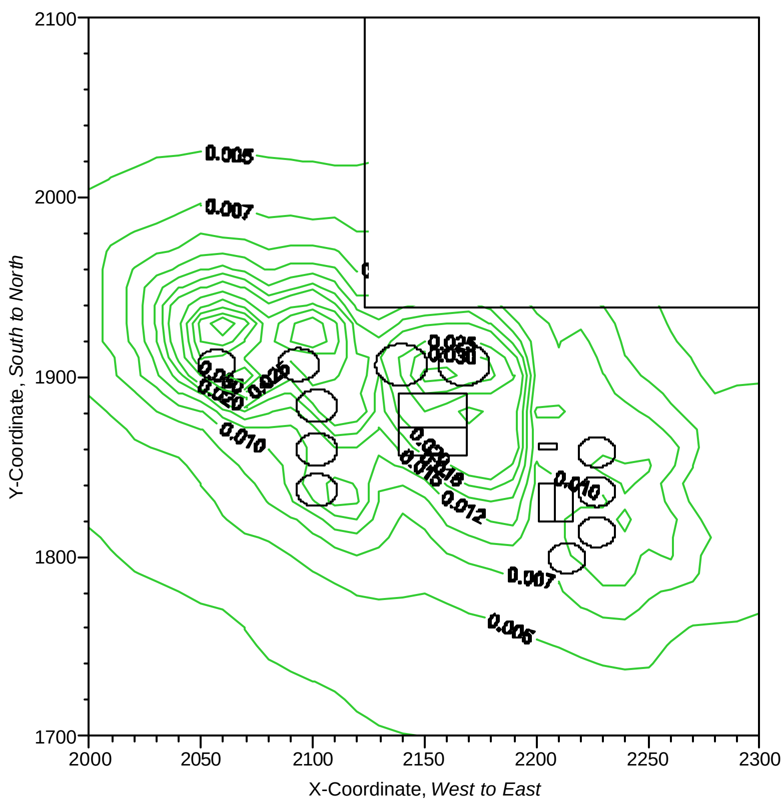

Figure 5. Maximum individual risk for methylene chloride in workers

An important part of risk analysis is the estimation of the number of cases, which may be generated by a certain scenario of exposure [1]. Risk groups of primary concern are the general population and subsets of the general population such as worker groups. The following expressions are used to quantify the excess cases [*EC*] and average number of excess cases generated per year for the general population. The computation determining the number of excess cases for the general population is the following.

$$EC = R \cdot I \cdot T \sum_{i=1}^{n} [C \cdot N]_i \tag{5}$$

The average number of excess cases generated per year of exposure can be calculated from the following expression. The computation determining the number of excess cases for the general population for a given year is repeated for each of the receptor locations and illustrated in Figure 6. Figure 7 illustrates the number of excess cases for workers for each of the receptor locations.

$$\overline{EC} = \left[\frac{excess\ cases}{year} \right] = \left[\frac{excess\ cases}{years\ of\ risk\ group\ exposure} \right] \tag{6}$$

The loss of life expectancy [*LLE*] is the life [days or years] lost due to a particular exposure or activity [1]. For example, smoking will shorten the average male smoker's life by 6.2 years. Any risk factor to which a person is exposed can affect that person's life expectancy, the decrease or increase in life expectancy can be calculated using the following. The projected loss of life expectancy is decreased by roughly 0.000018 years or less than 10 minutes.

$$LLE = individual\ lifetime\ risk \cdot average\ remaining\ lifetime \tag{7}$$

$$LLE = 0.00000047 \cdot (37.5) = 0.000018\ years \tag{8}$$

PHENOL

Phenol is a colorless or white solid when it is pure, but usually used as a liquid [8,9,10]. It has a characteristically strong odor that is sickeningly sweet and irritating. It evaporates more slowly than water and dissolves fairly well in water. Phenol is a primarily man-made chemical, although it is found in nature in animal wastes and organic material [formed during the natural decomposition process of organic materials]. The largest single use is in the manufacturing of plastics, but it is used to synthesize phenolic resins. It is also used as a slimicide [which kills bacteria and fungi found in watery slimes] and as a disinfectant in medical products. The main emissions of phenol occur to air with an estimated half-life of four to five hours [because of photochemical reactivity] [8,9,10]. Phenol is usually found in the environment [background levels] below 100 parts per billion, although much higher levels have been reported. Occupational exposure to phenol may occur during the production of phenol and phenolic derivatives, during the application of phenolic resins [wood and iron / steel industry] and during other industrial activities. For the general population, cigarette smoke and smoked food products [liquid smoke derivatives] are the most important sources of phenol exposure, apart from the

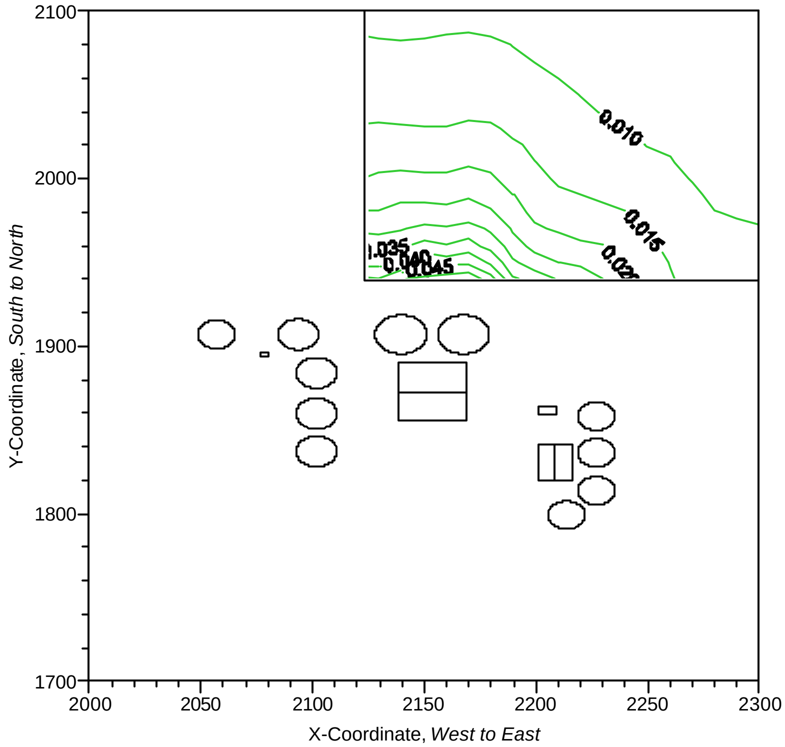

Figure 6. Maximum number of excess cases per year for methylene chloride for the general population

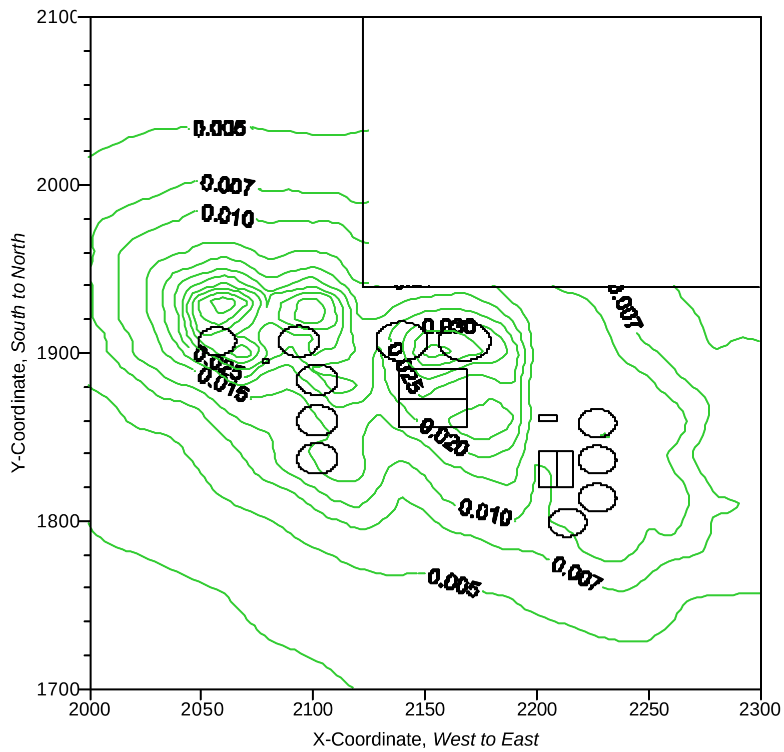

Figure 7. Maximum number of excess cases per year for methylene chloride for workers

industrial exposure via air. Exposure by way of drinking water and inadvertently contaminated food products is assumed to be low, primarily because of the objectable phenolic smell and taste.

Phenol is monohydroxybenzene [C_6H_5OH], molecular weight of 94.11, vapor pressure of 0.357 mm Hg [20°C], and odor threshold of 1.0 part per million. Tinker AFB utilizes phenol in depot maintenance operations as a chemical-depainting agent used to chemically remove coatings from aircraft surfaces and components. In 1993, phenol purchases accounted for almost 17 percent of all hazardous materials brought on installation.

RISK ASSESSMENT COMPUTATIONS FOR THE PHENOL EXPOSURES

From documented animal mortality studies, the phenol LOAEL for inhalation exposure conditions is as follows: 100-200 mg per m^3, 5 days per week, 7 hours per day for a median of 5.8 weeks [29 days]. The intake [*I*] in units of mass or volume of contaminated media per day is determined from tables of standard values of intake [3], and converted to units of volume of contaminated air per day. Note that the average air intake for a male guinea pig [hamster] is 0.06 liter per minute [1]. The average male guinea pig body weight [*W*] is 0.125 kilograms [1]. Similar to methylene chloride, to account for interspecies and intraspecies variability, the literature recommends use of a safety factor, *F*. For phenol, there appears to be a wide range of response sensitivity between species [guinea pigs to rats, monkeys, rabbits, etc.], therefore, F_1 is assumed to be a value of ten [3]. The potential for intraspecies variation in human sensitivity is represented by F_2 with a recommended value of one [since there is no human data regarding human variation in sensitivity. A F_3 safety factor element of ten can be applied if the LOAEL is derived from a short-term study [as in this case]. Thus, the safety factor [*F*] is 100.

The lifespan [*L*] is the lifetime of the experimental species [guinea pig] expressed in days. The equivalent human dose [*D*] can be calculated from the animal study. As with methylene chloride, the equivalent human dose is a function of the LOAEL, contaminated air intake, exposure duration, weight of the animal species, lifespan of the experimental species, human lifetime [75 years], human body weight [70 kilograms], and a safety factor. The equivalent human dose for phenol is 275,000 milligrams.

The risk factor [*R*] is defined as the excess risk per unit of dose [derived from the lowest available experimental equivalent human dose-response point]. IRIS tabulates the risk factor for specific chemicals and exposure routes [oral, inhalation, etc.]. IRIS documents a risk factor of 1.50E-5, which will be used the following risk assessment calculations [3].

For determining the maximum dose to an individual in the general population, the maximum phenol concentration is used. From the literature [7], the maximum phenol exposure to the general population is 40 PPB [0.154 mg per m^3]. Similar to the methylene chloride concentrations in Figure 1, the maximum phenol dose for the general population occurs along the fenceline north of the facility in the upper right quadrant of Figure 1. The general population risk group dose of 45,530 mg is well under the equivalent human dose of 275,000 mg from the animal study. The maximum dose calculation for an individual in the general population is repeated for each of the receptor locations and illustrated in Figure 8. From the literature [7], the maximum phenol dose for the individual worker is approximately 130 PPB. Like the methylene chloride calculations, the worker risk group dose of 78,188 mg is well under the value of the lowest effective dose of 275,000 mg from the animal study. The maximum dose calculation for

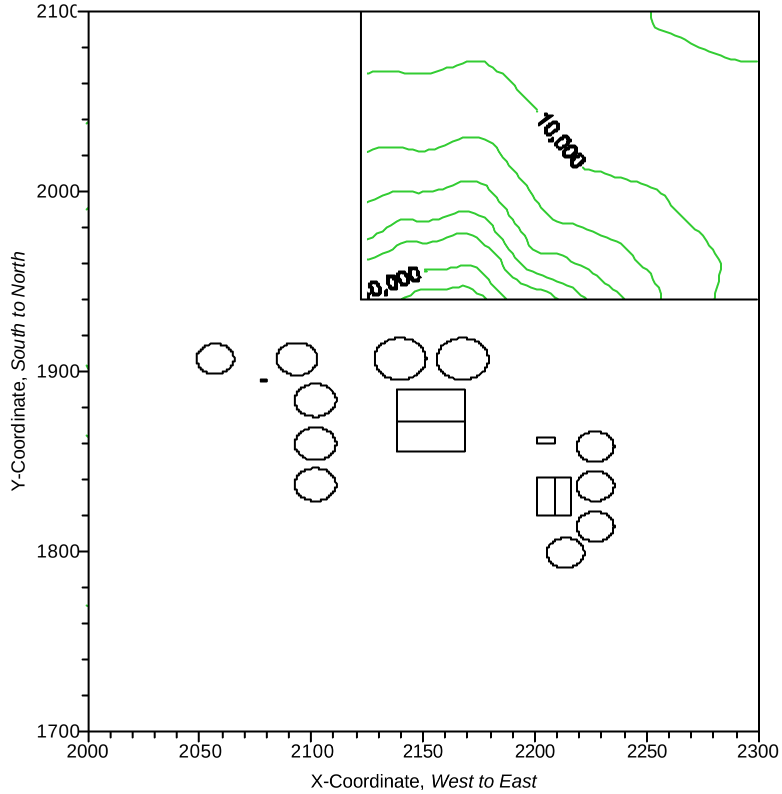

Figure 8. Equivalent phenol human dose for individuals in the general population, mg

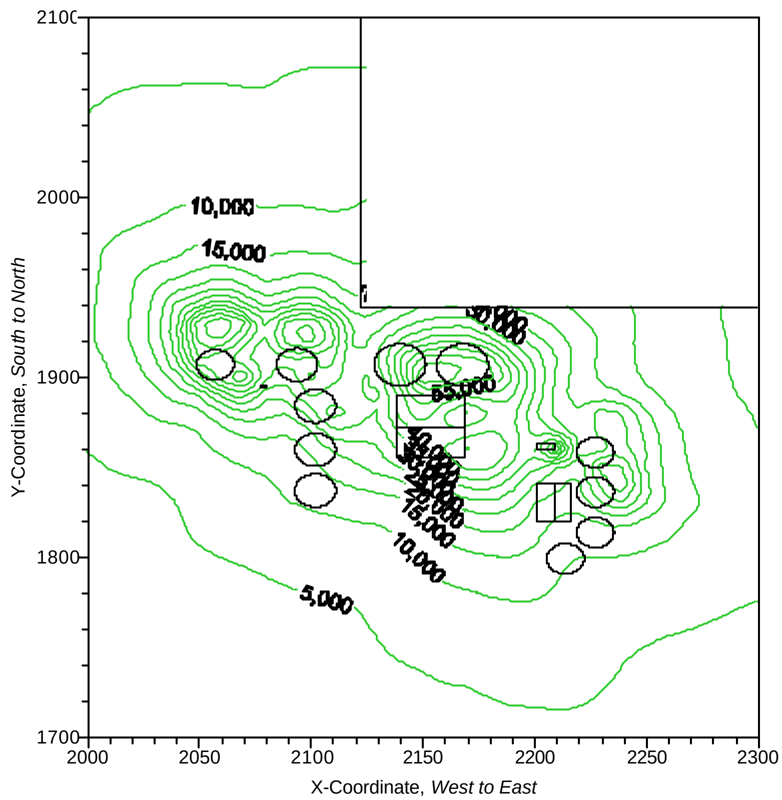

Figure 9. Equivalent phenol human dose for individual workers, mg

an individual worker is repeated for each of the receptor locations and illustrated in Figure 9.

Maximum individual excess risk [P_e] for the general population and workers are determined similar to the methylene chloride example. The calculation for the maximum individual excess risk for the general population and worker subgroup is repeated for each of the receptor locations and illustrated in Figures 10 and 11.

An important part of risk analysis is the estimation of the number of cases, which may be generated by a certain scenario of exposure [1]. Risk groups of primary concern are the general population and subsets of the general population such as worker groups. The average number of excess cases generated per year of exposure can be calculated. The computation determining the number of excess cases [phenol] for the general population for a given year is repeated for each of the receptor locations and illustrated in Figure 12. Similar to the methylene chloride example, quantify the excess cases [*EC*] and average number of excess cases generated per year for the worker subgroup, where *N* is defined as the number within the affected population subgroup. The computation determining the number of excess cases for the worker group is repeated for each of the receptor locations and illustrated in Figure 12 and on a per year basis, Figure 13.

The loss of life expectancy [$LLE = individual\ \ lifetime\ risk \cdot average\ remaining\ lifetime$] is the life [days or years] lost due to a particular exposure or activity. For example, smoking will shorten the average male smoker's life by 6.2 years. Any risk factor to which a person is exposed can affect that person's life expectancy, the decrease or increase in life expectancy is estimated to be 0.00056 years or under 5 hours. Like the methylene chloride case study, there appears to be little impact to the health of the general population and IWTF workforce to the exposure concentrations predicted by the computer models.

CONCLUSIONS

The following conclusions can be drawn from this discussion and analysis. The coupled model can be used to provide situational information on individual chemical exposures to conduct a site-specific health risk assessment for chemical depainting agents [phenol and methylene chloride] at an industrial wastewater treatment facility. An Agency for Toxic Substances and Disease Registry Study concluded that exposure to current ambient air emission from the industrial wastewater treatment plant does not pose a public health concern [11]. This is in agreement with the conclusion from the risk assessment portion of this effort. The risk assessment results concluded that current phenol and methylene chloride exposure concentrations are not of public health concern. For both phenol and methylene chloride, the equivalent human doses experienced by both the surrounding general population and worker groups were well under the dosages found to pose health concerns in laboratory animal experiments. The estimated lose of life expectancy was on the order of hours, which is considered trivial when compared to other health impacts, *i.e.*, smoking, etc. Note that the estimated ground-level chemical concentrations were a worst-case concentration over a 24-hour period. Average concentrations will be lower and generate an even less health risk.

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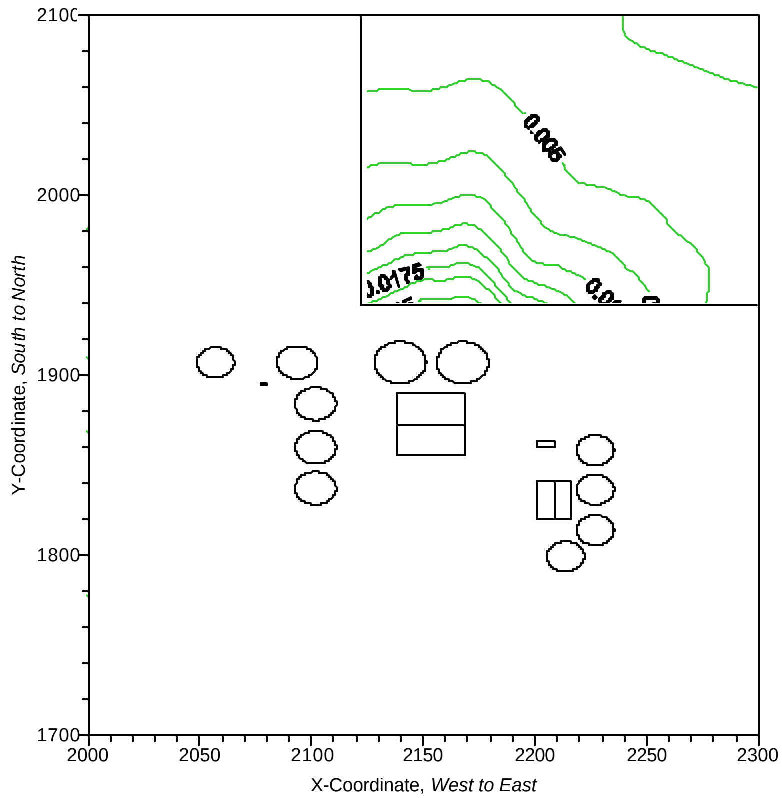

Figure 10. Maximum individual risk for phenol in the general population

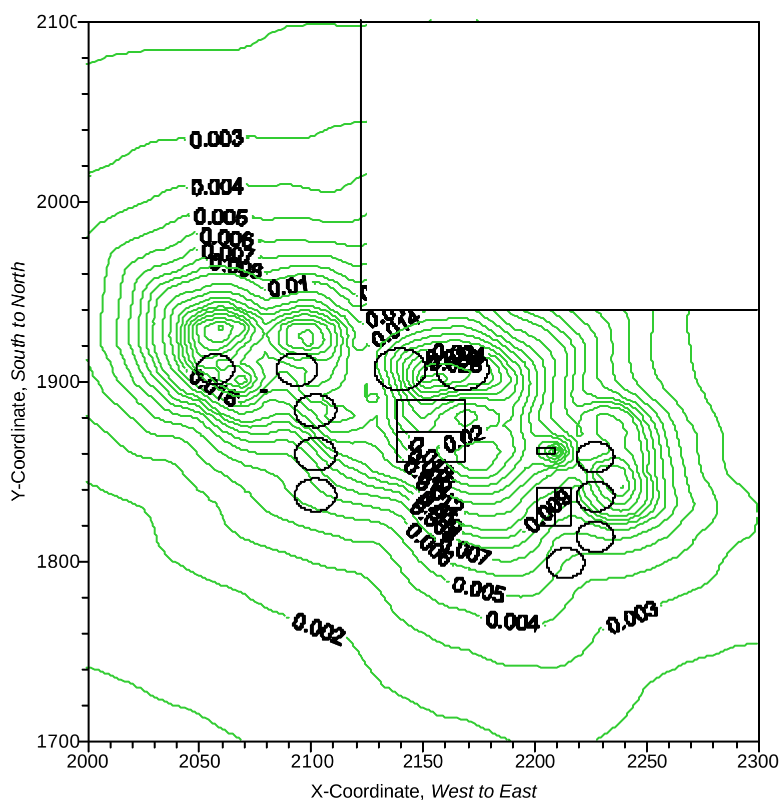

Figure 11. Maximum individual risk for phenol in workers

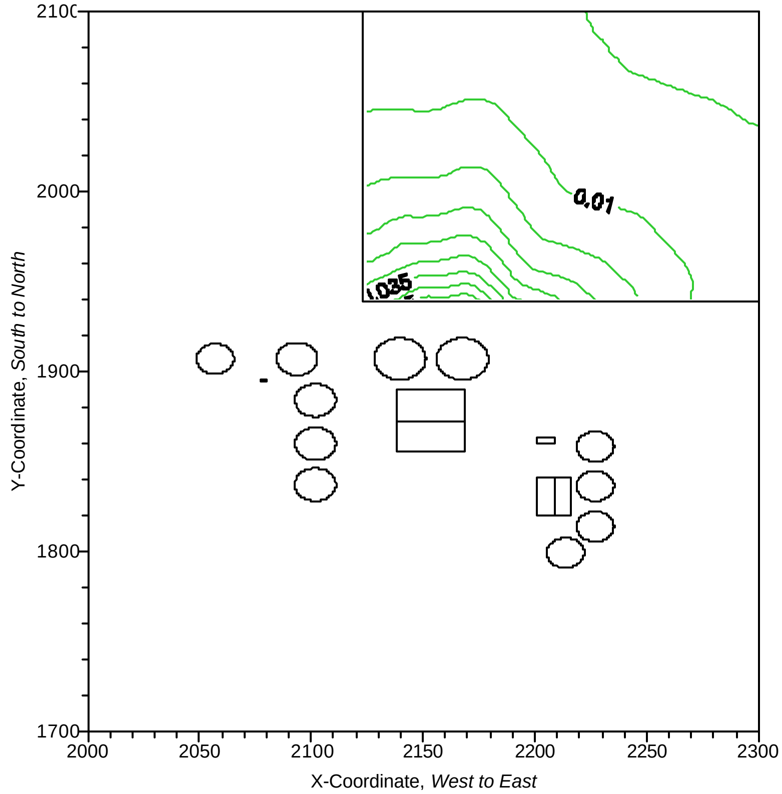

Figure 12. Maximum number of excess cases per year for phenol for the general population

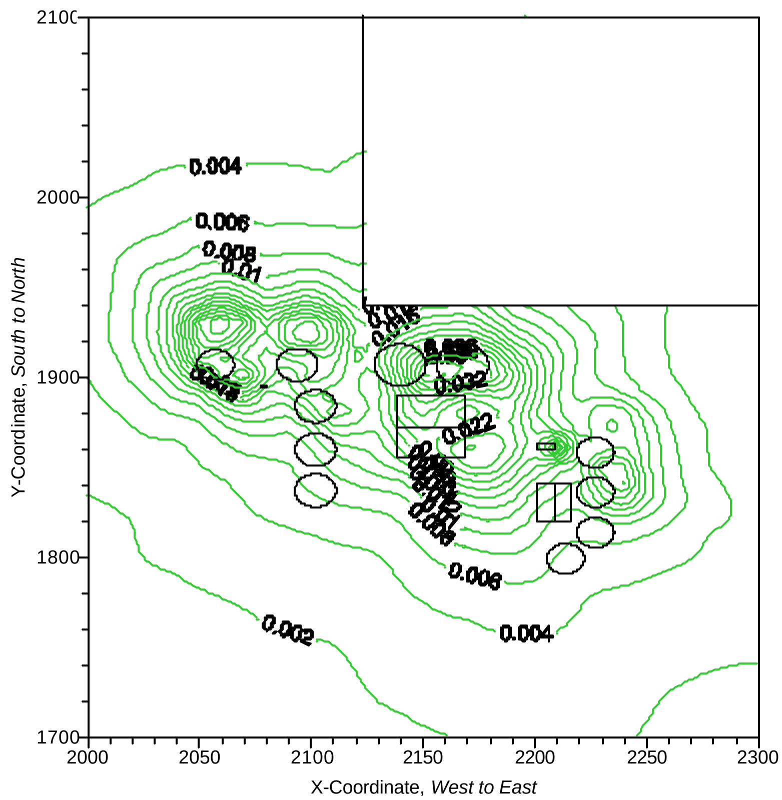

Figure 13. Maximum number of excess cases per year for phenol for workers