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POTENTIAL HEALTH RISK OF HAZARDOUS WASTE INCINERATION

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Summary

Health risk estimates are presented for incineration of the principal organic hazardous constituents (POHCs) of waste streams. Preliminary results indicate that both the carcinogenic and the noncarcinogenic risks to populations living near incinerators are small. Further research is needed to confirm these results and to assess the human health risks from metals in waste streams and products of combustion formed during incineration.

1. Introduction

Annual production of synthetic organic chemicals in the United States quadrupled during the period 1960–1980. Production of these organic chemicals results in generation of more than 2.6×10^8 metric tons of hazardous chemical waste each year [1], with only 10% being disposed of in an environmentally safe manner [2]. In recent years, incineration has emerged as a potential alternative to hazardous waste disposal methods such as landfill, ocean dumping, and deep-well injection. Currently, there are at least 284 hazardous waste incinerators in the United States burning an estimated 5.5×10^6 metric tons of hazardous waste annually [3]. As hazardous waste streams are incinerated, most of the principal hazardous organic constituents (POHCs) are thermally destroyed or removed from the waste stream in bottom ash. Typical ranges for destruction and removal efficiency (DRE) are 99.0–99.9999%. In this paper, we survey recent estimates [4,5] of human inhalation exposure and health risk resulting from POHCs emitted during incineration of hazardous wastes.

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TABLE 2.1

Ten most prevalent constituents of hazardous waste streams[a]

Constituent	Amount incinerated (metric tons/year)
Methanol	133,200
Acetonitrile	58,600
Toluene	56,600
Ethanol	55,100
Amyl acetate	54,900
Acetone	51,500
Xylene	49,500
Methyl ethyl ketone	42,500
Adipic acid	36,100
Ethyl acetate	32,600

[a]From Ref. [6].

2. Composition of hazardous waste streams

The EPA has conducted a survey of the composition of hazardous waste streams currently being incinerated [6]. A total of 237 different constituents have been identified as present in one or more of the 413 hazardous waste streams reviewed. Table 2.1 lists the ten most prevalent constituents of hazardous waste streams currently being incinerated.

It was beyond the scope of our risk assessment studies [3,4] to assess the health risk associated with incineration of all 413 hazardous waste streams reviewed. Instead it was decided to select one generic waste stream containing carcinogenic organic chemicals, and one generic waste stream containing toxic, but noncarcinogenic chemicals. These waste streams and their average heats of combustion (Btu/lb) are: (1) pesticide-related chemicals (3,021 Btu/lb), and (2) phenol/acetone distillation chemicals (15,850 Btu/lb). Representative chemicals from each waste stream selected for analysis were: (1) chloroform, ethylene dichloride, hexachlorobutadiene, and 1,1,2,2-tetrachloroethane and (2) phenol, toluene, pyridine, phthalic anhydride, and methyl styrene.

2.1 Stack emission

The rate of release (mass per unit time) of specific chemicals in stack emissions is controlled by three facility variables: waste throughput, chemical concentration in the waste stream, and DRE. Waste throughput in an incineration facility is determined by the percent contribution of the waste to the total waste stream after supplementary addition of No. 2 fuel oil to insure combustibility. It is assumed that it is not necessary to add supplementary fuel oil if the waste has a Btu content greater than 10,000 Btu/lb, as is the case with the

TABLE 2.2

Waste and fuel oil throughputs for three incinerator sizes

Incinerator	Waste (grams/year)	
	Pesticide-related	Phenol/acetone distillation
1×10^6 Btu/h	1.84×10^8	3.53×10^8
10×10^6 Btu/h	1.84×10^9	3.53×10^9
150×10^6 Btu/h	2.76×10^{10}	5.29×10^{10}
	Fuel oil (grams/year)	
1×10^6 Btu/h	2.82×10^8	0
10×10^6 Btu/h	2.82×10^9	0
150×10^6 Btu/h	4.23×10^{10}	0

phenol/acetone distillation waste. A summary of both waste and supplementary fuel oil throughput is listed in Table 2.2 for three sizes of liquid injection (LI) incinerators. Predicted annual stack emission rates (grams/year) for each chemical assuming 99.99% DRE are given in Table 2.3.

TABLE 2.3

Emission rates of incinerated chemicals (99.99% DRE)

Chemical	Amount in stream (%)	Emission rate (grams/year)					
		Incinerator size $\times10^6$ Btu/h					
		1		10		150	
		Stack	Fugitive	Stack	Fugitive	Stack	Fugitive
Pesticide-related							
Chloroform	6.1	1.12×10^3	1.60×10^4	1.12×10^4	4.10×10^4	1.68×10^5	5.56×10^4
Ethylene dichloride	19.0	3.50×10^3	1.82×10^4	3.50×10^4	4.74×10^4	5.23×10^5	6.30×10^4
Hexachloro-butadiene	9.2	1.69×10^3	1.07×10^2	1.69×10^4	1.69×10^2	2.54×10^5	3.73×10^2
1,1,2,2-tetra-chloroethane	2.4	4.42×10^2	2.14×10^2	4.42×10^3	5.58×10^2	6.62×10^4	7.43×10^2
Phenol/acetone distillation							
Toluene	11	3.91×10^3	6.77×10^3	3.91×10^4	1.80×10^4	5.87×10^5	3.49×10^4
Pyridine	0.7	2.68×10^2	3.64×10^2	2.68×10^3	9.69×10^2	4.01×10^4	1.83×10^3
Phthalic anhydride	0.006	2.05×10^{-1}	3.60×10^{-3}	2.05	1.49×10^{-2}	3.09×10^1	2.80×10^{-2}
Methyl styrene	10.6	3.72×10^3	1.05×10^3	3.72×10^4	2.79×10^3	5.55×10^5	5.25×10^3

TABLE 2.4

Percent contribution of fugitive emissions to total emissions of chloroform at a liquid injection incinerator

% DRE	Contribution (%)		
	LI-1	LI-10	LI-150
99.99	93.5	78.8	24.8
99.90	58.8	27.1	3.2
99.00	12.5	3.6	0.3

2.2 Fugitive emissions

Fugitive emissions consist of releases from the tanks, pumps, valves, flanges, and connections located in the receiving, storage, and feed areas of the incinerator. Our fugitive emission estimates were derived using emission factors from a study of fugitive emissions at petroleum refineries [7]. Table 2.3 lists total fugitive emission rates for each chemical considered in our study. For smaller incinerators operating at 99.99% DRE, it is apparent that fugitive emissions contribute significantly to total emissions. For large incinerators, fugitive emissions are a relatively unimportant contributor to total emissions for all DREs studied. Table 2.4 lists the percent contribution of fugitive emissions to total emissions of chloroform, the most volatile chemical in our study.

3. Exposure assessment

3.1 Atmospheric transport models

Annual-average ground-level air concentrations of representative chemical pollutants were estimated using IEM, an automated inhalation exposure methodology [8]. This methodology employs a slightly modified version of the Industrial Source Complex Long Term Model (ISCLTM), which is a Gaussian-plume model developed for the EPA [9].

IEM was applied within a 100-km radius around the incinerator facility. Although Gaussian-plume models are generally utilized for distances of 20–50 km around a site, this type of dispersion model has been validated for flat terrain out to 150 km predicting annual-average air concentrations to within a factor of three of those measured [10]. Exposure and risk due to long-range transport (greater than 100 km) were not estimated.

IEM input parameters include model plant descriptors, pollutant behavior variables, and region-specific meteorological data. Stack parameters employed are summarized for the three incinerators in Table 3.1. Region-specific meteorological data were obtained from Stability Array (STAR) data tapes [11] and from a compendium of weather statistics [12]. The STAR data were organized into six Pasguill stability categories (A through F) and six wind speed

TABLE 3.1

Stack parameters for three incinerator sizes

	Size × 10^6 Btu/h		
	1	10	150
Height (m)	15.24	30.48	30.48
Exit gas temperature (K)	355	355	355
Exit gas velocity (m/s)	1.10	11.10	41.1
Diameter (m)	0.61	0.61	1.22
Generic gas emission rate (g/s)	1.0	1.0	1.0

classes with average winds speeds of 0.75, 2.5, 4.3, 6.8, 9.5, and 12.5 m/s. The remaining meteorological parameters were obtained or derived from Ruffner [12]. For the principal site they include an average air temperature of 280.2 K and six mixing layer heights: 1819.5, 1213.0, 1213.0, 1024.3, 458.0, and 10000.0 meters for categories A through F, respectively. Mixing layer heights were assumed equal for all wind speed classes within each stability category.

3.2 Population exposure

Population exposures were estimated based on population distributions reported in the 1980 Census. A hypothetical waste incineration site (S-1) in the northern Midwest was chosen as the primary site for analysis. Two additional sites in heavily populated areas were chosen to investigate the effect of

TABLE 3.2

Cumulative population at three incinerator sites

Distance (km)	S-1	S-2	S-3
0.200	0	0	5
0.375	0	0	33
0.625	0	203	77
0.875	0	1,465	138
2.000	203	21,798	597
3.000	949	59,833	1,457
4.000	2,378	103,785	3,322
5.000	4,053	136,709	10,838
6.000	6,039	350,865	34,197
10.000	7,437	579,196	104,495
20.000	76,576	1,888,865	679,796
40.000	126,614	5,214,028	3,630,222
60.000	263,097	6,973,872	4,980,861
80.000	349,969	7,586,057	5,990,682
100.000	448,187	8,202,805	7,389,283

TABLE 3.3

Source contributions to population exposure for an LI-10 incinerator at the S-1 Site (99.99% DRE)

Pollutant	Total value (person $\mu g/m^3$)	Percent of total emissions from	
		Stack	Fugitive
Chloroform	7.13	14.9	85.2
Ethylene dichloride	10.2	32.3	67.7
Hexachlorobutadiene	1.61	98.5	1.5
1,1,2,2-tetrachloroethane	4.96×10^{-1}	83.6	16.4
Phenol	6.61×10^{-4}	97.8	2.2
Toluene	6.30	58.4	41.6
Pyridine	3.93×10^{-1}	64.1	35.9
Phthalic anhydride	1.95×10^{-4}	98.9	1.1
Methyl styrene	3.90	89.6	10.4

population size and distribution on human inhalation exposure and health risk. Population concentrations were determined in 160 sector segments (ten concentric circles divided by sixteen radial vectors) for each site. Cumulative population distributions for all three sites are given in Table 3.2.

3.2.1 Primary site

Population exposure (person $\mu g/m^3$) at the primary site are presented in Table 3.3 for an LI-10 incinerator with 99.99% DRE. The percent contribution of stack and expected fugitive emissions to total collective exposure for each of the chemical constituents of the waste classes considered are also given. Note that the percent contribution of fugitive emissions to total collective exposure varies widely, with the highest contribution coming from the more volatile chemicals.

3.2.2 Supplementary sites

Population exposure to chloroform (person $\mu g/m^3$) released from an LI-10 at the two supplementary sites is compared with chloroform exposure at the primary site in Table 3.4. Although total population size and distribution vary between the three sites (see Table 3.1), average exposure at all three sites is very similar (1.6×10^{-5}, 3.6×10^{-5}, and 1.7×10^{-5} $\mu g/m^3$, respectively). Thus, at least for the sites we considered, total population size and distribution around an incinerator site have little impact on the average individual exposure within 100 km. However, population distribution will affect the location of the maximally exposed individual. Table 3.5 gives the largest annual average exposure ($\mu g/m^3$) to chloroform in a populated sector segment at each of the three sites. Maximum exposure to fugitive emissions also occurred in these sector seg-

TABLE 3.4

Cumulative population exposure (person $\mu g/m^3$) to chloroform at the three incineration sites

Distance (km)	S-1	S-2	S-3
0.200	0	0	1.74×10^{-1}
0.375	0	0	6.10×10^{-1}
0.625	0	6.61×10^{-1}	9.36×10^{-1}
0.875	0	3.00	1.20
2.000	2.05×10^{-1}	3.11	1.87
3.000	5.72×10^{-1}	5.35×10^{1}	2.33
4.000	1.02	6.70×10^{1}	3.08
5.000	1.41	7.42×10^{1}	4.61
6.000	1.75	1.06×10^{2}	7.52
10.000	1.82	1.28×10^{2}	1.36×10^{1}
20.000	4.99	1.92×10^{2}	3.57×10^{1}
40.000	5.73	2.70×10^{2}	9.74×10^{1}
60.000	6.55	2.90×10^{2}	1.11×10^{2}
80.000	6.90	2.92×10^{2}	1.18×10^{2}
100.000	7.12	2.96×10^{2}	1.23×10^{2}

TABLE 3.5

Maximum annual average individual exposure ($\mu g/m^3$) to chloroform at three incineration sites

Source	Site S-1	Site S-2	Site S-3
Stack	1.17×10^{-4}	2.05×10^{-4}	3.05×10^{-4}
Fugitive	1.39×10^{-3}	3.45×10^{-3}	4.38×10^{-2}
Total	1.51×10^{-3}	3.65×10^{-3}	4.41×10^{-2}

ments. It can be seen that exposure from total emissions differs by up to a factor of 30, depending on the distance the nearest individual lives from the incinerator site (1500, 675, or 200 m for the sites S-1, S-2, and S-3, respectively). The impact of stack emissions on maximum individual exposure does not vary significantly from site to site, differing only by a factor of 2.6 (see Table 3.3).

4. Health effects assessment

Chemicals studied in the present assessment were classified as either carcinogens or noncarcinogens, and separate measures of toxicity were developed for these two classes. Carcinogenic toxicity is estimated in terms of lifetime excess cancer risk, while noncarcinogenic toxicity is estimated by acceptable daily intake (ADI) and threshold limit values (TLV). Toxicity data are taken from two health effects documents for hazardous organic compounds [13,14].

TABLE 4.1

Health risk estimators for chemicals in two generic wastes

Pollutant	Health risk estimator		
	Excess risk[a] $(mg/kg/d)^{-1}$	ADI[b] (mg/d)	TLV[c] (mg/m^3)
Chloroform	7.0×10^{-2}	8.8	50
Ethylene dichloride	3.7×10^{-2}	NA[d]	40
Hexachlorobutadiene	7.75×10^{-2}	1.4×10^{-1}	NA
1,1,2,2-tetrachloroethane	2.0×10^{-2}	NA	35
Phenol	1.99×10^{-2}	7.0×10^{-1}	19
Toluene	NA	2.0×10	3.75×10^{2}
Pyridine	NA	2.0×10^{-2}	15
Phthalic anhydride	NA	2.1	6
Methyl styrene	NA	17	4.80×10^{2}

[a]Excess risk of developing cancer after a lifetime exposure [13,14].
[b]Acceptable daily intake or verified references doses [15].
[c]Threshold limit value is the time-weighted concentration for an 8-hour workday and 40-hour workweek to be used as a guide in the control of health hazards [16].
[d]Not available.

Health effects data for compounds considered in this assessment are summarized in Table 4.1. The estimate of excess human lifetime risk to cancer was used for all compounds in the pesticide-related waste. The ADI value [15] was used for all compounds in the phenol/acetone distillation waste. For phthalic anhydride and methyl styrene the TLV [16] was used to convert to ADI (see Section 4.2).

4.1 Carcinogenic toxicity

Potency factors for chemical carcinogens were derived by the EPA from available human epidemiological data and from animal studies when necessary. Excess lifetime risk factors for carcinogens are interpreted as the probability that an individual will develop cancer after an exposure (for 70 years) to the chemical resulting in a dose of 1 mg/d for each kilogram body weight.

The EPA estimates of excess risk are purposefully conservative. The excess risk represents the upper 95% confidence limit of the largest possible slope of a linear dose–response curve consistent with empirical human or animal data. Thus, the true, or expected risk, associated with a chemical is smaller than this maximum risk with 95% confidence. These conservative assumptions concerning the EPA excess risk estimates should be kept in mind when interpreting the results of the present risk assessment.

4.1.1 Sample calculation for carcinogenic risk

The estimate of carcinogenic risk associated with a hazardous waste stream is obtained by multiplying the population exposure (person $\mu g/m^3$) by a con-

TABLE 4.2

Expected number of excess cancers over 70 years from incineration of pesticide-related waste at a liquid injection incinerator (for a population of 0.45×10^6)

% DRE	LI-1	LI-10	LI-150
99.99	5.3×10^{-5}	1.8×10^{-4}	7.2×10^{-4}
99.90	1.3×10^{-4}	7.7×10^{-4}	7.3×10^{-3}
99.00	9.2×10^{-4}	5.4×10^{-3}	7.1×10^{-2}

version factor which takes into account average weight and breathing rate to yield population dose (person mg/kg/d). This in turn is multiplied by the excess cancer risk factor developed by the EPA. For example, for a population exposure of 1×10^6 person $\mu g/m^3$ and an excess cancer risk factor of 1×10^{-2} $(mg/kg/d)^{-1}$ the calculation is as follows:

Excess cancers over 70 years in the exposed population =

$$(1\times10^6 \text{ person } \mu g/m^3)\left[\frac{22.8\ m^3}{\text{person d}}\right]\left[\frac{1\ mg}{1000\ \mu g}\right]\left[\frac{1\text{ person}}{70\ kg}\right]$$

$$(0.5)\left[\frac{1\times10^{-2}\text{ cancers}}{mg/kg/d}\right] = 1.63$$

The 0.5 in the above calculation represents the amount of chemical assumed to be absorbed and retained upon inhalation. The 22.8 m^3/d represents the Reference Man breathing rate [17].

4.1.2 Pesticide-related waste

Estimates of the excess number of cancers over 70 years associated with incinerating the pesticide-related waste stream at site S-1 are given in Table 4.2. These estimates represent the summation of the expected number of excess cancer risk from each of the four pesticide-related chemicals. At the proposed EPA standard of 99.99% DRE, the expected number of excess cancers over 70 years is less than 1.6×10^{-3} for all incinerator sizes. As can be seen, excess cancer risk is fairly independent of incinerator size at a DRE of 99.99% and is dependent on incinerator size for a DRE of 99.00%.

4.2 Noncarcinogenic toxicity

Measures of toxicity for noncarcinogenic chemicals are usually expressed in terms of ADIs or TLVs [15,16]. An ADI is defined as that daily intake (mg/d) which will result in no observed adverse acute or chronic effects. TLVs have been developed for an occupational setting, and represent time-weighted average air concentrations (mg/m^3) to which nearly all workers may be repeatedly

TABLE 4.3

Average daily intake from phenol/acetone distillation wastes released by hazardous waste incinerators (presented as a fraction of ADI)

	ADI (mg/d)	Incineration facility (99.99% DRE)		
		LI-1	LI-10	LI-150
Toluene	20	2.8×10^{-10}	1.2×10^{-9}	8.5×10^{-9}
Pyridine	0.02	1.1×10^{-7}	1.9×10^{-9}	1.4×10^{-8}
Phthalic anhydride	2.1	3.2×10^{-13}	2.4×10^{-12}	2.5×10^{-11}
Methyl styrene	171	9.3×10^{-11}	5.8×10^{-10}	5.7×10^{-9}

exposed, day after day, 40 h/week, without adverse effect. TLVs are based on rather general evidence of toxicity, including information from industrial experience, human and animal studies, and similarity to other chemicals.

TLVs may be converted to ADI values by the following formula [18]:

$$\text{ADI (mg/d)} = \frac{\text{TLV (mg/m}^3) \times 10\ (\text{m}^3/\text{d}) \times 0.5 \times 5\,(\text{d})/7\,(\text{d})}{10}$$

where 10 m^3/d = volume of air breathed during an 8-h work day; 0.5 = the amount of chemical assumed to be absorbed and retained during inhalation [18]; and 10 = a safety factor to account for sensitive individuals in the population.

4.2.1 Sample calculation for noncarcinogenic risk

The estimate of average individual risk for a noncarcinogen (as measured as a fraction of the ADI) is obtained by comparing daily intake of the chemical with the ADI. If the estimated daily intake is less than the ADI, there should be no adverse effects from continuous exposure to the chemical. As an example, consider an individual exposed to an average concentration of 1 $\mu g/m^3$ of a chemical with an ADI of 0.1 mg/d. The daily intake as a fraction of ADI is computed as follows:

$$1\ \mu\text{g/m}^3 \times 22.8\ \frac{\text{m}^3}{\text{d}} \times \frac{1\ \text{mg}}{1000\ \mu\text{g}} \times 0.5 \times \frac{1}{0.1\ \text{mg/d}} = 0.11$$

Thus, under the above conditions, an individual would be receiving 11% of the ADI, and no adverse health effects would be expected, provided the individual has no other sources of exposure to this chemical and is not simultaneously exposed to significant doses of other chemicals.

4.2.2 Phenol/acetone distillation waste

None of our five selected constituents of the phenol/acetone distillation wastes are known carcinogens. We therefore used the ADI as a measure of non-

carcinogenic risk. Estimates of average daily intake of these constituents as measured as a fraction of the ADI are listed in Table 4.3. These estimates account for both stack and fugitive emissions.

5. Conclusions

We have surveyed recent upper bound estimates of health risk from POHC emitted during incineration of two representative hazardous waste streams. Both the carcinogenic and the noncarcinogenic risk from incineration of these waste streams are small. Further research is needed to show that these results are representative of other hazardous waste streams. In addition, research is needed in two other areas. First, whenever POHCs are incinerated, a number of products of incomplete combustion (PIC) can be formed and released to the atmosphere. Second, during incineration up to 35% of metals in a hazardous waste stream can be emitted to the atmosphere. At present the potential health risks from these two sources of exposure are unknown, but there are indications that metal emissions may pose significant risks under certain conditions. However, if risks from PICs and metals can be controlled, incineration of hazardous waste may be a viable alternative, at least from a health risk perspective, to land-disposal of hazardous waste.

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