Hazard Ranking System Issue Analysis: Carcinogenic Risk Analysis of the Air Pathway Target Distance Limit

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June 1987

MTR-86W140

SPONSOR:
U.S. Environmental Protection Agency
CONTRACT NO.:
EPA-68-01-7054

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ABSTRACT

This report presents an analysis of the target distance limit employed in the EPA Hazard Ranking System (HRS) air pathway. The target distance limit is defined as the maximum distance used in determining the target population in the air pathway.

The report presents estimates of the general level of cancer risk arising from air emissions from uncontrolled waste sites and examines the implications of the analysis for the targets category of the HRS air pathway. The principal conclusions reached in the analysis are: (1) simple risk analysis techniques can be fruitfully employed in HRS issue analyses, although their use in assessing actual site risks based on the data developed during site inspections is unwarranted, (2) the uncertainty associated with the results is high and generalizations must be made with caution, (3) cancer risks to individuals living beyond 4 miles from the boundary of a site from long-term exposures to air emissions from most uncontrolled waste sites are probably very low (as are their risks from chronic exposures to non-carcinogenic contaminants with safe exposure thresholds), (4) risks from these effects to individuals living beyond 1/4 from the boundary of a site are also probably low, (5) risks to individuals residing with 1/4 mile of site boundaries are difficult to assess using techniques such as are employed here and are probably higher than indicated in this study, and (6) particulate emissions from large sites may pose a higher, potentially unacceptable, cancer risk than is indicated by this analysis.

The major implications for the HRS air pathway are as follows: (1) the target distance limit cannot be definitively set based on the results of this analysis, further analysis of sub-chronic risks must be undertaken before a revision of the four-mile limit is made, (2) cancer risk should not be emphasized in the HRS air pathway, and (3) differential cancer risks between sites can best be reflected in the toxicity and waste quantity components of the HRS waste characteristics category.

Suggested Keywords: Superfund, Hazard ranking, Hazardous waste, Air emissions.

ACKNOWLEDGMENT

The author would like to acknowledge the participation of Michael Dusetzina of the United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Mr. Dusetzina exercised the Human Exposure Model and produced the data on which the analysis is based. This study would not have been possible without his participation and assistance.

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1.0 INTRODUCTION

1.1 Background

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) (PL 96-510) requires the President to identify national priorities for remedial action among releases or threatened releases of hazardous substances. These releases are to be identified based on criteria promulgated in the National Contingency Plan (NCP). On July 16, 1982, EPA promulgated the Hazard Ranking System (HRS) as Appendix A to the NCP (40 CFR 300; 47 FR 31180). The HRS comprises the criteria required under CERCLA and is used by EPA to estimate the relative potential hazard posed by releases or threatened releases of hazardous substances.

The HRS is a means for applying uniform technical judgment regarding the potential hazards presented by a release relative to other releases. The HRS is used in identifying releases as national priorities for further investigation and possible remedial action by assigning numerical values (according to prescribed guidelines) to factors that characterize the potential of any given release to cause harm. The values are manipulated mathematically to yield a single score that is designed to indicate the potential hazard posed by each release relative to other releases. This score is one of the criteria used by EPA in determining whether the release should be placed on the National Priorities List (NPL).

During the original NCP rulemaking process and the subsequent application of the HRS to specific releases, a number of technical issues have been raised regarding the HRS. These issues concern the desire for modifications to the HRS to further improve its capability to estimate the relative potential hazard of releases. The issues include:

- Review of other existing ranking systems suitable for ranking hazardous waste sites for the NPL.
- Feasibility of considering ground water flow direction and distance, as well as defining "aquifer of concern," in determining potentially affected targets.
- Development of a human food chain exposure evaluation methodology.
- Development of a potential for air release factor category in the HRS air pathway.
- Review of the adequacy of the target distance specified in the air pathway.
- Feasibility of considering the accumulation of hazardous substances in indoor environments.
- Feasibility of developing factors to account for environmental attenuation of hazardous substances in ground and surface water.
- Feasibility of developing a more discriminating toxicity factor.
- Refinement of the definition of "significance" as it relates to observed releases.
- Suitability of the current HRS default value for an unknown waste quantity.
- Feasibility of determining and using hazardous substance concentration data.

- Feasibility of evaluating waste quantity on a hazardous constituent basis.
- Review of the adequacy of the target distance specified in the surface water pathway.
- Development of a sensitive environment evaluation methodology.
- Feasibility of revising the containment factors to increase discrimination among facilities.
- Review of the potential for future changes in laboratory detection limits to affect the types of sites considered for the NPL.

Each technical issue is the subject of one or more separate but related reports. These reports, although providing background, analysis, conclusions and recommendations regarding the technical issue, will not directly affect the HRS. Rather, these reports will be used by an EPA working group that will assess and integrate the results and prepare recommendations to EPA management regarding future changes to the HRS. Any changes will then be proposed in Federal notice and comment rulemaking as formal changes to the NCP. The following section describes the specific issue that is the subject of this report.

1.2 Issue Description

Several issues relevant to the HRS air pathway have been raised by Congress and by public comments on the NPL and NPL rulemaking actions. An analysis of these issues and options for revising the HRS air pathway developed as a result of the analysis are presented in a separate report (Wolfinger, 1986). That separate report

focuses on revising the air pathway to reflect the potential of sites to emit air contaminants in the absence of observed air releases. An additional issue was identified in the course of that analysis regarding whether the target distance limit in the air pathway should be revised. The target distance limit is defined as the maximum distance used in determining the target population for the HRS air pathway. Currently, the air pathway target distance limit is set at four miles.

This issue arises because current knowledge of atmospheric residence times for common waste contaminants (generally 3 to 70 days; Cupitt, 1980) indicates that these contaminants may remain in the atmosphere for relatively long periods of time and hence may be transported over long distances.* Given these residence times, transport distances would easily exceed the four miles currently employed as the HRS air pathway target distance limit. As a result, the number of people potentially at risk from site emissions could be much greater than would be indicated using a four-mile limit. However, the concentrations to which people living far from the site would be exposed would, on average, be very low due to dilution. Hence, the risk associated with exposures at long distances could be low, possibly negligible. Nonetheless, if the contaminants released

*The estimates of atmospheric residence time provided reflect the effects of atmospheric physio-chemical processes such as photochemical oxidation and deposition on contaminant concentrations. As such, residence time reflects the fraction of emitted contaminant emissions remaining in the atmosphere, not the contaminant concentration.

from the site do not have safe exposure thresholds (for example, carcinogens) even a low exposure would induce some non-zero risk of adverse effects from the exposure.

Individual risks, such as the probability that an exposed individual will develop cancer, will decline with distance as exposure concentrations decline due to dilution. In contrast, other risk measures, such as overall cancer incidence in the exposed population, can increase with distance if population increases faster with distance than average concentrations decline. Thus, the counteracting effects of population increase with distance and contaminant concentration decline with distance, in determining risk, may or may not result in significant risks at distances greater than four miles. Therefore, given a definition of an acceptable risk,* dilution and population growth counteract to determine the point at which the incremental risk from any specific waste site becomes acceptable. The point at which risk generally becomes acceptable could be used to determine the air pathway target distance limit.

1.3 Purpose and Organization of Report

The principal purpose of this report is to investigate the general level of carcinogenic risk associated with air releases from

*The establishment of an acceptable risk level for air emissions from uncontrolled waste sites is beyond the scope of this paper. Such a decision is most properly an EPA policy decision that takes into account public perceptions of acceptability, as well as the costs and benefits associated with the risk.

uncontrolled waste sites and to determine whether a change is warranted in the target distance limit in the air pathway. In particular, the study is intended to determine whether a modification to the current HRS target distance limit of four miles is warranted, based on the potential for carcinogenic effects to arise from air emissions from uncontrolled waste sites in exposed populations residing beyond four miles from the site. The study also examines the potential for carcinogenic effects in exposed populations residing within four miles of the site.

Additionally, the study is intended to provide information that can be used to address other questions concerning the HRS air pathway. These questions include the definition of risk measures to be employed in the air pathway, the determination of the relative weight of carcinogenic effects in assessing toxicity in the air pathway and the determination of the relative importance of air pathway exposures in determining overall site risks in comparison to ground water and surface water exposures.

The body of the report is organized in four chapters. Chapter 2 presents an overview of the approach used to analyze the target distance limit. The results of the analysis are presented in Chapter 3. Chapter 4 discusses the limitations in the approach and their implications for the analysis. Chapter 5 presents the conclusions of the analysis and discusses their implications for any modification of the HRS air pathway.

2.0 APPROACH

The approach employed in analyzing the air pathway target distance limit was to determine the distances from uncontrolled waste sites (i.e., CERCLA sites) at which incremental cancer risks (i.e., risks above the "normal" background level) from air emissions would be deemed acceptable. These distances might then be used in determining the target distance limit, given a definition of acceptable risk. This determination was made using incremental lifetime (70-year) cancer risk estimates produced by the EPA Office of Air Quality Planning and Standards Human Exposure Model (HEM)* for 25 selected** final and proposed National Priorities List sites. The availability and ease of use of this model, as well as its constraints, determined to a large degree the type of analysis conducted.

2.1 Focus of the Study

The focus of the target distance analysis is on the incremental risk, at increasing distances, of carcinogenic effects arising from long-term, sustained exposures (i.e., chronic) to atmospheric contaminants arising from emissions from uncontrolled (and thus generally inactive) waste sites. The analysis assumes that any concentration, no matter how small, induces some risk of developing cancer to individuals in the exposed population (i.e., there is no

*Further information on HEM can be found in Battye et al., 1985.
**Details of the selection process are provided in Section 2.5.

threshold for carcinogenic effects). As indicated by Haemisegger et al. (1985), the no-threshold assumption for carcinogenic effects has strong support in the scientific community. Further, as indicated in Battye et al., 1985, EPA has reviewed the literature regarding the carcinogenicity of volatile organic contaminants potentially emitted from hazardous waste treatment, storage, and disposal facilities and found no compelling scientific reason to abandon the no-threshold assumption.

The primary reasons for this focus on carcinogenic effects was the availability of both the HEM and supporting data on carcinogenic potency* for several contaminants of interest and the importance of the no-threshold assumption in analyzing risks at long distances from the site, as discussed below. Although HEM could be modified for use in other types of analysis (for example, non-carcinogenic risk from chronic exposures), resource and data constraints precluded modifying HEM or employing another model such as the Industrial Source Complex Model (ISC).** The no-threshold assumption is important because of its conservatism. The lack of a threshold implies that any dose, no matter how small, will result in some risk to an exposed individual. The alternate assumption, that

*For purposes of this analysis, carcinogenic potency is defined as the probability that an exposed individual will develop cancer arising from a sustained exposure to 1 ug/m^3 of contaminant for a 70-year period.

**For further information on the Industrial Source Complex Short-term and Long-term models, the reader is referred to United States Environmental Protection Agency, 1986a.

a "no-effect" threshold exists implies that individuals exposed to doses smaller than the threshold experience no risk. Dilution in the atmosphere will probably reduce ambient concentrations below any threshold as the distances increase from the emission point. Nonetheless, population increases with distance will probably result in significant increases in the number of people exposed at most sites. Thus, the no-threshold assumption will generally result in higher estimates of risk than the assumption of a "no-effect" threshold. From this perspective, the no-threshold assumption is desirable.

This focus on carcinogenic effects was deemed reasonable for two reasons. First, EPA focused on cancer as the effect of interest in its scoping study of the air toxics problem in the United States (Haemisegger et al., 1985). The reasons for EPA's focus include the importance of cancer as a cause of death in the United States, the existence of several, ubiquitous, carcinogenic air pollutants (e.g., benzene, arsenic and vinyl chloride), the ability to quantify carcinogenic risk, and the degree of concern, on the part of the public, about the link between environmental pollution and cancer. This emphasis on cancer does not imply that EPA is not concerned with other types of human health or environment effects either arising from long-term or short-term exposures.

Second, available data do not indicate that gaseous or particulate contaminant concentrations sufficient to induce acute

effects are generally achieved off-site from inactive facilities.* Since, CERCLA is intended to address off-site risk from air releases and not risk to on-site workers [CERCLA Sec. 101(9) and 101(20)(A)], the exclusion of risk of acute effects from the analysis is warranted.

Finally, the assessment of sub-chronic effects (i.e., those arising from exposures of 10 to 90 days duration) is severely limited due to deficiencies in models relating site emissions to levels of sub-chronic effects and deficiencies in the data necessary to employ such models. Study limitations precluded the acquisition and modification of a medium-term (e.g., monthly) dispersion model (such as the ISC) or modification of HEM to create such as an assessment model. Moreover, regardless of the availability of applicable dispersion models, the assessment of sub-chronic effects would be severely handicapped by the lack of data on sub-chronic

*However, a large body of evidence indicates that waste sites can pose an acute risk to individuals working on the site as a result of inhaling emitted contaminants. This evidence includes the case histories of individuals who have died or become ill from breathing vapors released from waste sites (e.g., hydrogen sulfide). Such evidence is further supported by some of the available monitoring data. For example, on-site ambient concentrations of trichloroethylene have been detected at three times the threshold limit value at the Kin-Buc Landfill (United States Environmental Protection Agency, 1982). The potential for exposure to concentrations that might result in acute effects is further evident in the emphasis placed in EPA manuals on monitoring air concentrations to ensure investigator safety during site and remedial investigations (United States Environmental Protection Agency, 1984a and 1985).

effect thresholds for most contaminants of concern and the lack of human exposure models relating concentrations to severity of effect (e.g., number of people experiencing the effect). Similar data and exposure model limitations limit the analysis of chronic, non-carcinogenic effects as well.

2.2 Simplifying Assumptions

Given the limited focus of the study and the resource constraints, several simplifying assumptions were made during the study including:

- Uniform, constant emission rate
- Linear dose-response function with a uniform slope (potency value)
- Site-specific, but otherwise homogenous, unchanging population
- Simple climatological dispersion model
- No transformation or deposition of contaminants
- Use of Stability Array (STAR) meteorological data
- Sustainability of annual average concentrations

This section describes these assumptions. The effect of these assumptions on the study conclusions is discussed in the Chapter 4.

The first set of assumptions made in the study concern the contaminant emission rates and characteristics. These assumptions are among the most critical in terms of their affect on the validity of the study conclusions. The study assumes a uniform, constant emission rate of 100 kilograms per year with a carcinogenic potency

of 10^{-5} m^3/ug* for all sites regardless of the size or other characteristics of the sites. The analysis did not attempt to account for differences between the sites studied in terms of the rates of contaminant releases (e.g., either daily variations or variations in average annual emission rates) or the nature of the contaminants that are released. Thus, the analysis tacitly assumes that there are no significant effects of short-term deviations from average doses on long-term cancer incidence.

A uniform annual emission rate was selected since it is not possible to calculate site-specific annual emission rates within the constraints of this project. The calculation of site-specific annual emission rates would require the use of different emission estimation equations for each site depending on the type of emissions sources present on the site (e.g., surface impoundments). There are no emission estimation procedures currently available that are specifically applicable to uncontrolled waste sites and there are questions about the applicability of the existing active site emission rate equations to uncontrolled waste sites (Wolfinger, 1986).

Moreover, these emission rate equations usually address instantaneous or short-term emission rates. Their extension to

*This potency is the probability of developing cancer resulting from a continuous lifetime exposure to 1 ug/m^3 of contaminant. It is equivalent to a conventional potency of 0.035 mg/kg/d under the assumptions used in this study. These assumptions are discussed later in this section.

annual emissions would involve integrating emissions estimates for numerous different site-specific meteorological conditions to form a long-term average rate. Such a procedure would be further complicated by the fact that many sites have numerous emission sources of differing types. Finally, data are lacking for many of the factors included in these emissions estimation equations (e.g., age of the site and waste constituent concentrations). Further information on available methods for estimating site-specific emission rates can be found in Breton et al., 1983 and 1984.

The emission rate of 100 kilograms per year was chosen for several reasons. First, it is not an unreasonable value given the range of estimates provided in the literature. An overview of the available information on emission rates is presented in Table 2-1. These estimates reflect numerous different assumptions about site conditions. More complete information is presented in Appendix A. The table also provides the 100 kilogram per year equivalent to the emission rate expressed in the units used by the respective authors. For example, assuming a site of area 10,000 m^2, 100 kilograms per year is equivalent to 0.32 $ug/m^2/s$. This value can be compared with the values of 0.4 to 18.4 $ug/m^2/s$ reported in Hwang, 1985.

Inferring long-term emission rates from the values in this table should be viewed with caution since the authors cited do not indicate whether they believe the rates presented can be sustained for a period of one year. In fact, it is unlikely that many of the cited

TABLE 2-1

SELECTED INFORMATION ON WASTES SITE EMISSION RATES

Source (units) Contaminant	Emission Rate Landfill	Surface Impoundment	Landtreatment	Contaminated Soil	100 Kg/yr Equivalent
Hwang, 1985 ($ug/m^2/s$)					
Toluene	1.48	18.4	4.7		0.32
1,1,1-Trichloroethane		15.3			0.32
Methylene Chloride	0.4				0.32
Tetrachloroethylene	0.76				0.32
Benzene			1.1		0.32
Chlorobenzene			2.4		0.32
Baker, 1985 (g/s)					
Vinyl Chloride	0.02-0.28				0.003
Shen, 1981, (ug/s)					
Aroclor 1242	8-184				3171
Shen, 1982b (ug/s)					
Aroclor 1242	35-5680				3171
Springer, Thibodeaux and Chatrathi, 1983 ($mg/m^2/d$)					
Aroclor 1248					
as liquid	0.08-2.65				27.4
in sludge	0.30-0.91				27.4

TABLE 2-1 (Concluded)

Source (units) Contaminant	Emission Rate				100 Kg/yr Equivalent
	Landfill	Surface Impoundment	Landtreatment	Contaminated Soil	
Thibodeaux, 1981 ($g/m^2/d$)					
Benzene	89-563				0.027
Chloroform	340-1820				0.027
Vinyl Chloride	826-3650				0.027
Aroclor 1248	0.001 - 0.01				0.027
Shen, 1982a (g/s)					
Benzene		5.5			0.003
Thibodeaux et al., 1982 (kg/d)					
Benzene		0.1-0.38			0.274
Toluene		1.2-0.48			0.274
Total Hydrocarbons		2.6-5.2			0.274
1,1-Dichloroethane		9.0-0.11			0.274
Total Chlorinated Hydrocarbons		50.0-1.1			0.274
Caravanos and Shen, 1984 (g/min)					
Benzene				0.7- 4.5	0.190
Carbon Tetrachloride				1.4-11.1	0.190
Trichloroethylene				0.8- 7.9	0.190

rates could be sustained for such a period of time, much less the 70-year lifetime assessed in this study. As indicated by this table, the variation in reported emissions estimates is high and is a major source of uncertainty in the results of the analysis.

In the opinion of the author, the uncertainties inherent in carcinogenic risk assessments indicate that only order of magnitude (or greater) differences in risk estimates are important in analyzing the air pathway target distance limit (see Sections 4.1 and 4.2). Thus, given the values cited in Table 2-1, the set of reasonable values for a sustained rate would be limited to the values 0.1, 1.0, 10, 100 and 1000 kilograms per year. The value of 1000 kilograms per year, equivalent to 70 metric tons emitted over the period of the analysis, was deemed to be too high. Available information on the quantities of contaminants in NPL sites indicate that the values of 0.1 and 1.0 kilograms per year are probably too low. This leaves 10 and 100 kilograms per year as choices for the analysis.

The study also assumes that a linear, no-threshold dose-response function is appropriate for the contaminants in question at the expected concentrations. The use of such a model for low-dose risk characterization is generally accepted, given that there is no conclusive evidence indicating that a different model is preferable. Table 2-2 presents a fairly comprehensive list of potency factors for airborne carcinogens for use in such a model.

TABLE 2-2

CARCINOGENIC POTENCY FACTORS
$(ug/m^3)^{-1}$

Chemical	Factor	Reference
Acrylamide	1.7×10^{-5}	3
Acrylonitrile	6.9×10^{-5}	1
	6.8×10^{-5}	3
Allyl Chloride	5.5×10^{-8}	3
Asbestos	1.0×10^{-5}	3
Arsenic	1.4×10^{-2}*	1
Benzene	7.4×10^{-6}	1
	6.9×10^{-6}	2,3
Benzidene	6.6×10^{-2}	1
Benzo(a)pyrene	1.7×10^{-3}	1
	3.3×10^{-3}	3
Benzyl Chloride	1.2×10^{-5}	3
Beryllium	1.4×10^{-3}	1
	4.0×10^{-4}	3
Bis(chloromethyl) ether	0.93**	1
1,3 Butadiene	4.6×10^{-7}	3
Cadmium	1.7×10^{-3}	1
	2.3×10^{-3}	3
Carbon Tetrachloride	1.5×10^{-5}	2,3
Chloroform	1.0×10^{-5}	3
Chromium	1.2×10^{-2}	1,3
1,1 Dichloroethylene	3.3×10^{-4}	1
1,2 Dichloroethane	1.0×10^{-5}	1
	2.6×10^{-5}	3
	7.0×10^{-6}	2

*Potency factor is in units of cc/fiber.

**This value corresponds to the probability (p) that an individual exposed to 1 ug/m^3 of bis(chloromethyl) ether continuously for 70 years will develop cancer, assuming $p = 1 - \exp(-pf \times d)$, where pf is the potency factor and d is the dose arising from a continuous exposure of 1 ug/m^3. The linear model assumed in this study does not apply to this contaminant at this level of exposure. As of NPL Update 5 (51 FR 21099, 10 June 1986), this contaminant has not been identified at any NPL site during a site inspection.

TABLE 2-2 (Continued)

Chemical	Factor	Reference
Dichloromethane (Methylene Chloride)	4.1×10^{-6}	1
	1.8×10^{-7}	2,3
Diethanolamine	1.1×10^{-7}	3
Dimethylnitrosamine	5.4×10^{-3}	3
Dioctyl Phthalate	1.3×10^{-7}	3
Ethyl Acetate	5.0×10^{-7}	3
Ethylene	2.7×10^{-6}	3
Epichlorohydrin	2.2×10^{-7}	3
Ethylene Dibromide	5.1×10^{-4}	3
Ethylene Oxide	1.0×10^{-4}	1
	3.6×10^{-4}	2,3
Formaldehyde	6.1×10^{-6}	2,3
Melamine	4.1×10^{-7}	3
Methyl Chloride	1.4×10^{-7}	3
4,4 Methylene Dianiline	2.1×10^{-5}	3
Nickel	3.4×10^{-4}	1
	3.3×10^{-4}	3
Nitrobenzene	1.2×10^{-7}	3
Nitrosomorpholine	2.5×10^{-5}	3
Pentachlorophenol	3.9×10^{-7}	3
Perchloroethylene	4.9×10^{-7}	1
	1.7×10^{-6}	2,3
Polychlorinated Biphenyls	1.2×10^{-3}	3
Polynuclear Aromatic Hydrocarbons	1.7×10^{-3}	1
Propylene Dichloride	7.2×10^{-7}	3
4, 4, 150 Propyliene Diphenol	1.4×10^{-6}	3
Propylene Oxide	1.2×10^{-4}	3
Styrene	2.9×10^{-7}	3
Terephthalic Acid	1.8×10^{-8}	3
Titanium Oxide	5.6×10^{-7}	3
Trichloroethylene	1.3×10^{-6}	1
	4.1×10^{-6}	2,3
Vinyl Chloride	7.1×10^{-6}	1
	2.6×10^{-6}	3
Vinylidene Chloride	4.2×10^{-5}	3

TABLE 2-2 (Concluded)

Reference

1 - Adapted from United States Environmental Protection Agency, Superfund Public Health Evaluation Manual, (EPA 540/1-86/060, OSWER Directive 9285.4-1), United States Environmental Protection Agency, Washington, DC, October 1986b.

2 - Battye, William et al., Preliminary Source Assessment for Hazardous Waste Air Emissions from Treatment, Storage and Disposal Facilities (TSDFs), (Draft Final Report), GCA Corporation, Bedford, MA, February 1985.

3 - Haemisegger, Elaine et al., The Air Toxics Problem in the United States: An Analysis of Cancer for Selected Pollutants, (EPA-450/1-85-001), United States Environmental Protection Agency, Washington, DC, May 1985.

Most, but not all, of these substances have been identified at uncontrolled waste sites. Potency values in the references cited were given either in units of m^3/ug (Battye et al., 1985 and Haemisegger et al., 1985) or were adapted from values expressed in units of $(mg/kg/d)^{-1}$ (United States Environmental Protection Agency, 1986b). In the latter case, the values were converted assuming a continuous 70-year exposure, an inhalation rate of 20 m^3 per day, and a body weight of 70 kilograms. These assumptions are those recommended in the referenced report. In all cases, these potency values reflect inhalation potency according to the references.

As can be seen from this list, the value chosen (10^{-5} m^3/ug) is a reasonable "mid-range" value, particularly given that some uncontrolled waste sites do not contain carcinogens.* A uniform value was applied since data are lacking on the carcinogenic potency factors for many contaminants commonly found in uncontrolled waste sites (even suspected carcinogens such as tetrachloroethane) and because of difficulties in identifying the contaminants available for migration into the air on a site-specific basis.

The values of 100 kilograms per year and 10^{-5} m^3/ug are less critical than they might seem because of the structure and assumptions of a linear, no-threshold dose response model such as is used in HEM. Viewed as a set of equations, the model is linear in

*In terms of this study, contaminants that are not carcinogens can be viewed as having a carcinogenic potency of zero.

both the emission rate and the potency. This implies that an order of magnitude increase in either one (or in the product of the two) will induce a proportional increase in the estimates of risk. Thus, the results from the model when an emissions rate of 10 kilograms per year and a potency of 10^{-5} m^3/ug are assumed are one-tenth the results when an emission rate of 100 kilograms per year and a potency of 10^{-5} m^3/ug are assumed.

The second set of assumptions concern the type and demographic characteristics of the populations assessed in the study. The study employed actual population data for 25 uncontrolled waste sites. The data used are taken from the 1980 Census and manipulated in the HEM population allocation module discussed below. However, the study addresses only individuals residing on or near the sites (i.e., within 60 miles) and assumes that the individuals are exposed to average annual contaminant concentrations based on their place of residence (as determined by their Census enumeration district and the HEM population allocation module). The study does not address non-resident individuals, such as workers, who might be exposed to site emissions either routinely or on a one-time basis.

The study also assumes that the exposed populations are demographically homogenous and identical. As a result, the analysis does not address the additional risk posed to sensitive populations. This assumption permits a simple conversion of potency in terms of $(mg/kg/d)^{-1}$ to potency in terms of m^3/ug as discussed

previously. The study does not address differences between individuals (such as age, sex, or smoking habits) that might affect their exposure levels, their contaminant intake and retention rates, or the characteristics of their response to contaminant doses. The study also does not account for any differences in the population characteristics that might be associated with different sites. These assumptions permit the use of a single potency factor for all individuals exposed to emissions from a site. The assumption, coupled with the assumption that contaminant emission rates and characteristics are identical for all sites, permits the use of a single potency factor throughout the study. These assumptions are necessitated both by considerations of simplicity and by gaps in the available data on dose-response relationships.

Further, the study assumes that the population does not change over time. Population growth and other demographic changes over time are not considered in the analysis.

The third assumption concerns the applicability of the dispersion model used to estimate exposure concentrations. The study ignores certain site-specific characteristics that might affect exposure concentrations, such as terrain. This assumption permits the use of the simple Gaussian plume model employed in HEM. The study also assumes tacitly in using such a dispersion model that wind speed, direction, and stability vary only over time, not over distance. These parameters are assumed to be spatially invariant

within the transport distances studied. The temporal frequency distribution of these parameters varies, however, between sites.

The fourth simplifying assumption is that the contaminants are neither transformed nor deposited during transport within the distances studied. This assumption is reasonable for gaseous contaminants given the data available on atmospheric residence times. The assumption is less reasonable for particulates. However, it is necessary since HEM does not account for deposition.

The fifth assumption made concerns the meteorological data applicable to the sites. Since no site-specific meteorological data of sufficient duration and quality for use in the analysis were available for uncontrolled waste sites, the study assumed that the meteorological data from the closest weather station that collected Stability Array (STAR) data were applicable to the sites. The impact of this assumption on site selection is discussed later. Moreover, the study assumes that these data are applicable to the 70-year period of the study.

The sixth assumption made is that the average annual concentrations estimated by HEM are sustained for the 70-year period of the study. This assumption derives from the assumptions that the emission rate is constant and the meteorological characteristics are fixed for the 70-year study period.

Finally, the study assumes that the emissions arise from the center of the sites.

2.3 Measures of Risk

Three generic measures of risk, defined below, were analyzed: MEI risk, AEI risk and population incidence. Although these measures are most commonly used in assessing cancer risks, their use is not restricted to cancer analyses. For the purposes of assessing cancer risks, MEI risk is defined as the lifetime probability that a maximally exposed individual (MEI) will develop cancer. MEI risk is dimensionless, since it is strictly a probability. However, MEI risk is frequently expressed in terms of the expected number of cancer cases per unit of maximally exposed population (e.g., 1 case per 100 people).

Maximally exposed individuals are those individuals, in the exposed population, that are expected to be exposed to the highest ambient concentration (and thus receive the highest dose) of the contaminant in question from the source in question. Contrary to intuition, the maximally exposed individual is not necessarily the individual living closest to the site. Local atmospheric patterns and site-specific emission patterns may cause an individual who lives farther from the site to be exposed to a higher long-term average concentration, receive a higher dose, and be at greater risk (all other factors being equal).

The average exposed individual risk (AEI risk) of developing cancer is defined here as the average lifetime probability that an individual in the exposed population will develop cancer. As in the

case of MEI risk, AEI risk is dimensionless. AEI risk is also frequently expressed as a cancer rate (i.e., expected number of cancer cases per unit of exposed population). For example, the AEI risk from a site might be expressed as 1 case per 100,000 people, corresponding to a probability of 10^{-5}. In terms of the estimates produced by HEM, AEI risk is the sum, over all applicable receptor locations,* of the product of the population at the receptor location, the concentration at the receptor location, and the potency of the contaminant, all divided by the total applicable population (i.e., the product of the potency and the population-weighted average of the ambient concentrations).

Population incidence is defined as the number of incremental cancer cases expected in the exposed population over a 70-year period. Population incidence is frequently divided by 70 to yield an "annual" incidence for convenience of comparison. Thus, unlike MEI risk and AEI risk, population incidence is not a rate or probability. It is expressed as the expected increase in the number of cases in the exposed population. For example, assume a site has an exposed population of 10,000 and an AEI risk of 0.001 (1 in 1000). Also assume a second site has an exposed population of 1000 and an AEI risk of 0.01 (1 in 100). The second site has an AEI risk 10 times higher than the first site, yet the expected incremental cancer incidence in

*A receptor location in HEM is a point in space at which individuals (receptors) are exposed to ambient contaminant concentrations.

the exposed populations for both sites are the same, 10 cases. Similarly, two sites may have the same AEI risk, but have different population incidences due to differences in the size of the exposed population. Thus, although population incidence and AEI risk are related, they present different perspectives on the risk of cancer from contaminant releases from a site.

MEI risk and population incidence are used in numerous EPA analyses including Clean Air Act Section 112 analyses of National Emission Standards for Hazardous Air Pollutants, Clean Air Act Section 108 and 109 analyses for National Ambient Air Quality Standards, and Toxic Substances Control Act Section 4(f) regulatory analyses. EPA has also suggested the use of MEI risk and population incidence as primary risk measures in the recent proposal of a regulatory program for land disposal prohibitions under the authorities in the Resource Conservation and Recovery Act (51 FR 1635, 14 January 1986). AEI risk is currently not considered directly in EPA analyses.

EPA has not set an acceptable risk level to be used uniformly. Generally, MEI risks above 10^{-4} have been considered unacceptable, while risks below 10^{-8} have been considered acceptable (Thomas, 1984). The acceptability of MEI risks between 10^{-4} and 10^{-8} is assessed on a case-by-case basis incorporating, for example, considerations of the size of the exposed population. The Superfund Public Health Evaluation Manual also indicates that remedial actions

under CERCLA should be designed to reduce risk levels to within this range (United States Environmental Protection Agency, 1986b). Further, as indicated in Travis et al., 1987, EPA has suggested a de minimis MEI risk level of 10^{-5} to 10^{-4} for small populations and 10^{-7} to 10^{-6} for large populations. These authors also indicate that in the context of occupational decisions, the Federal government has always acted to reduce MEI risks when it exceeds about 4×10^{-3} in small populations or about 3×10^{-4} in large populations (e.g., the entire population of the United States). Further, according to the authors' analysis, the Federal government has never acted when MEI risks were below 10^{-4} for small populations, or 10^{-6} for large populations. EPA has not set acceptable levels for AEI risk.

Outputs from HEM can be used to estimate all three of these risk measures, as discussed below.

2.4 Overview of the EPA Human Exposure Model

The EPA Human Exposure Model (HEM) is a straightforward exposure model that relates emissions of contaminants from a source to the exposure and risk at receptor locations at varying distances from the site. These estimates are developed in three basic steps. First, annual average contaminant concentrations are estimated at each receptor location using a long-term dispersion model. Second, the population allocation component of the model estimates the number of people at each receptor location. The concentration and population estimates are then used in the third step to calculate exposure/risk

estimates. Figure 2-1 illustrates the sequence of calculations in the model. The following sections describe the model in greater detail.

2.4.1 The Receptor Grid

HEM uses a circular receptor grid in estimating concentrations and exposure. The model assumes a virtual point source (i.e., an emission source of essentially zero radius) located at the center of a collection of concentric rings. The radius of each ring is specified by the user. The current analysis employed rings of the following radii:

- 1/4 miles
- 1/2 miles
- 1 mile
- 2 miles
- 3 miles
- 4 miles
- 10 miles
- 15 miles
- 25 miles
- 50 miles
- 60 miles

The receptor grid is formed by the intersection of these rings with 16 wind direction radial lines drawn from the point source. These radials are 22.5 degrees apart. An example of an HEM receptor grid is illustrated in Figure 2-2.

2.4.2 The HEM Dispersion Module

The dispersion model employed within the HEM dispersion module is a simplified climatological, steady-state Gaussian plume model* designed to estimate long-term arithmetic average pollutant concentrations at user-specified receptor locations. The HEM

*Further information on Gaussian plume models can be found in Hanna, Briggs, and Hosker, 1982.

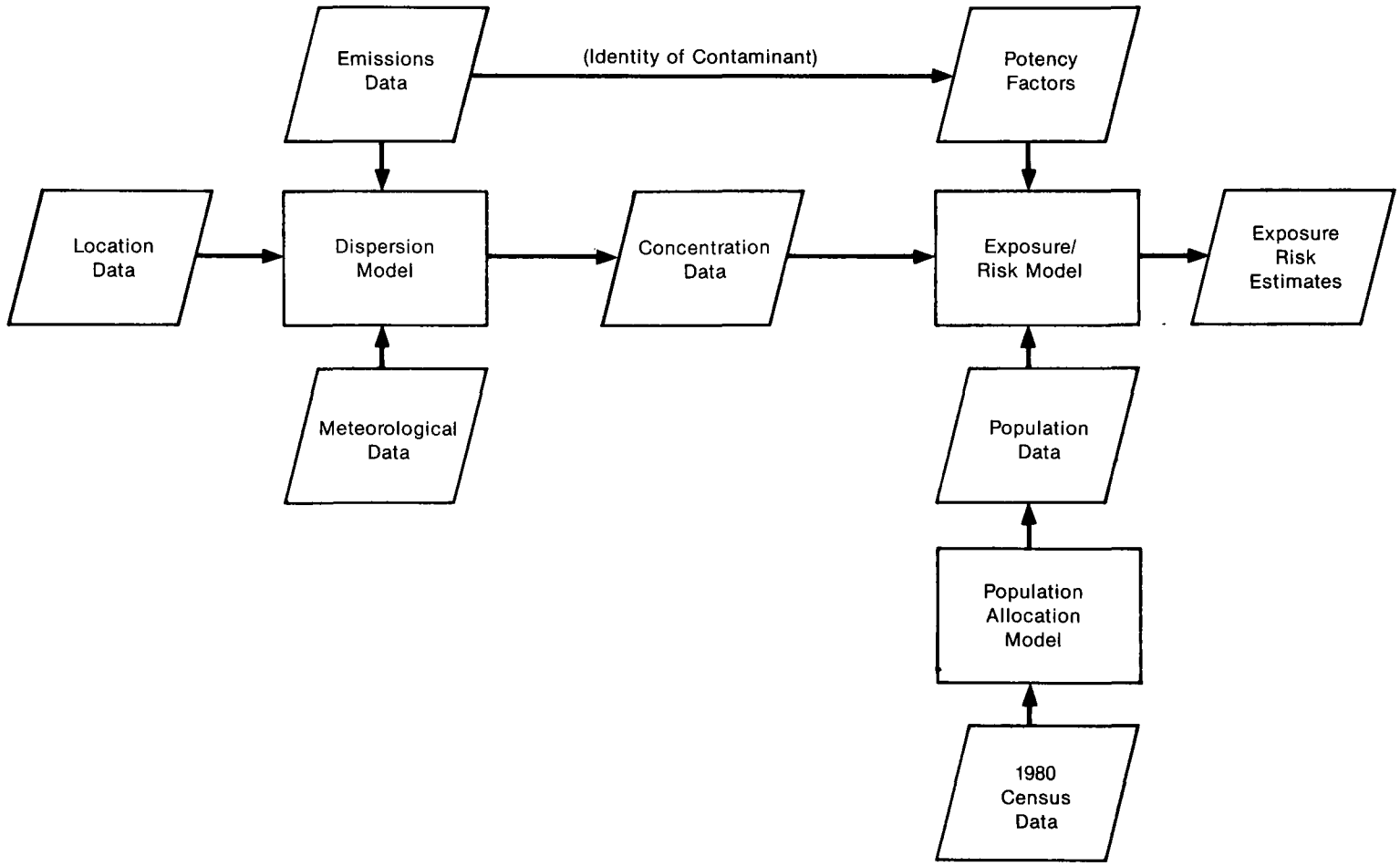

FIGURE 2-1
BASIC HUMAN EXPOSURE MODEL (HEM) STRUCTURE

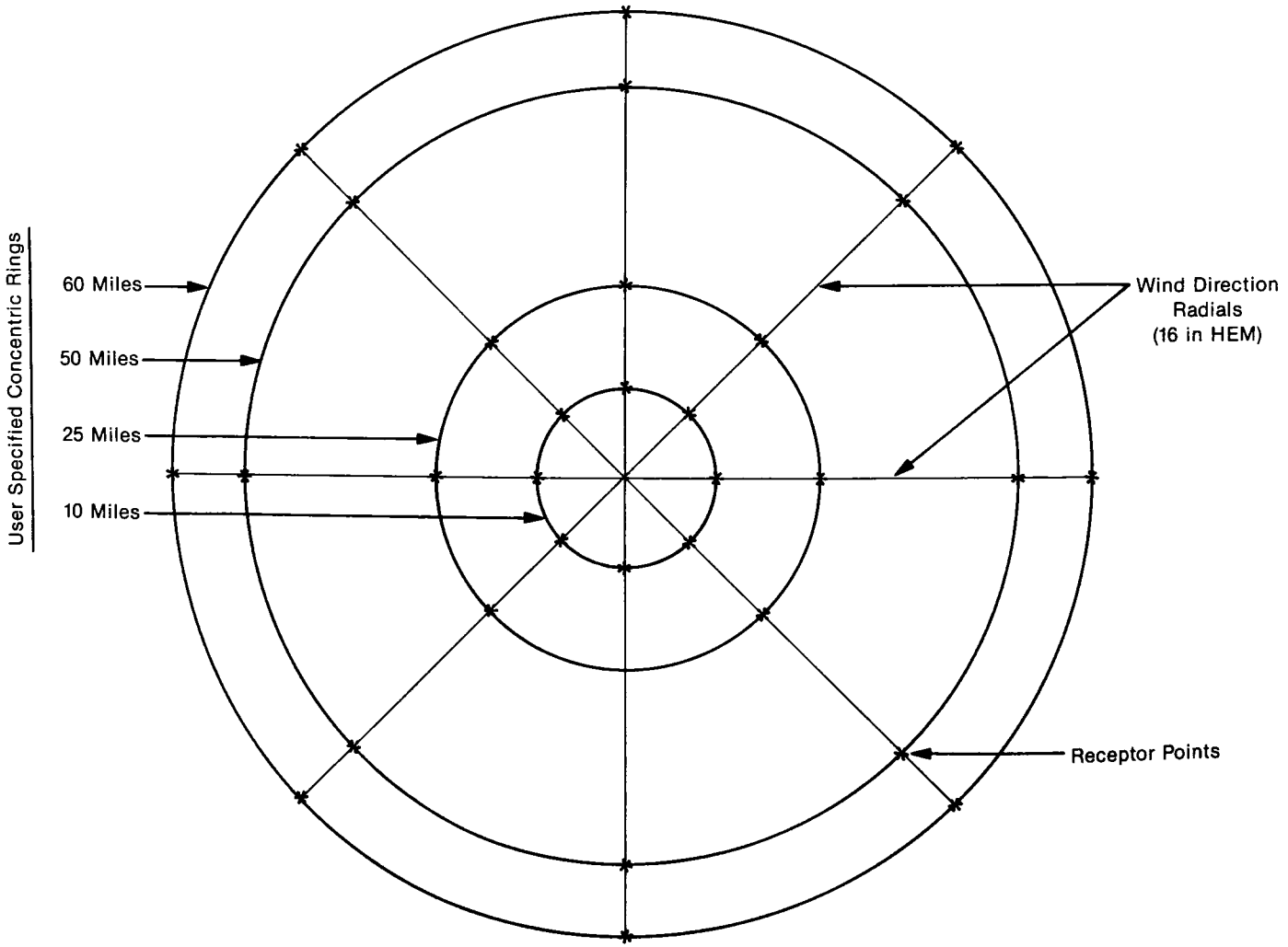

FIGURE 2-2
HEM RECEPTOR GRID

dispersion model estimates the annual average ambient concentrations of a pollutant at each receptor location arising from constant emissions at the center of the receptor grid. The model can account for chemical transformation but not for deposition of the pollutants. However, as discussed previously, the analysis assumes that contaminants neither transform nor deposit within the area of concern. Alternately, the model can be viewed as assuming that all deposited materials are immediately resuspended.

An annual total emissions rate (kilograms per year) is required as input to the dispersion model. The model calculates the equivalent emissions rate in units of kilograms per second. The model assumes the emissions rate is constant throughout the year regardless of site-specific conditions, including meteorological conditions. This assumption is possibly a weakness in the model when analyzing waste site emissions. The rate of emissions from waste sites is sensitive, for example, to changes in temperature, pressure and other meteorological variables. Thus, the assumption that emission rates are constant may result in an overestimate (or underestimate) of the concentrations associated with any set of meteorological conditions. The potentially non-linear relationship between emission rates and meteorological conditions indicates that these errors may not average out.

The dispersion model employs the Stability Array (STAR) data from the closest weather station (usually an airport) as

meteorological input. These data are available from the National Climatic Center in Ashville, North Carolina. The STAR data include wind speed, wind direction and atmospheric stability class information. The model manipulates these data to create a joint wind speed/velocity/stability class frequency distribution. This distribution, generally reflecting five years of data, is assumed to be the same in all years of the analysis.

The airborne contaminant concentration at each receptor location is calculated using the Gaussian dispersion model under the meteorological conditions that define each class in the frequency distribution. The annual average concentration at each receptor location is calculated as the average of the calculated receptor location concentrations, weighted by the frequency.

2.4.3 The Population Allocation Module

The number of people allocated to each receptor location is determined in the population allocation module. As discussed previously, no attempt was made to supplement the estimates produced by the population allocation module with additional, site specific information such as the locations of residences near the sites.

This module is an adaptation of the RADII5 computer program developed by the Bureau of the Census (Moon, 1985 and Dusetzina, 1985). RADII5 employs the 1980 Census data to determine the number of people living within a given distance of a user-specified location. The location is given in terms of latitude/longitude

coordinates. This location data requirement affected the choice of sites selected for the target distance analysis, as discussed below.

The module uses two different allocation procedures to allocate people to receptor locations, depending on the distance from the site. One procedure is used for receptor locations within about 2.2 miles (3.5 kilometers) of the site, while a different procedure is used for receptor locations lying beyond about 2.2 miles. Different procedures are required due to the size of the grid cells within about 2.2 miles, which in many cases are smaller than the Census enumeration districts used to determine population in the RADII5 program. An allocation procedure is employed to distribute a portion of the population in each enumeration district to each receptor location within the district. Due to this limitation in the allocation procedure, the risk estimates produced by HEM under the study assumptions are suspect for distance below about 2.2 miles.

A different problem, however, pertains for longer distances. This problems arises whenever the enumeration districts do not wholly fall within the rings specified in the analysis. In such cases, people residing within one ring may be allocated to the next, more distant ring due to the assumptions in the allocation procedure. This problem declines in importance as distance increases because differences in ambient contaminant concentrations between rings level off.

2.4.4 The Exposure/Risk Module

The preceding modules produce estimates of (1) the annual average contaminant concentration at each receptor location and (2) the population at each receptor location. The exposure/risk module calculates the incremental lifetime risk of developing cancer for the population located at each receptor location, as a result of continuous exposure to the calculated contaminant concentrations. These calculations use the above concentration estimates and a cancer potency factor in a linear model. The model assumes that the probability of an individual developing cancer is the product of the potency factor and the concentration to which the individual is exposed. The expected number of cases in the exposed population is simply the sum of the probabilities that each individual in the exposed population will develop cancer.

The contaminant-specific potency factor is defined as the lifetime probability that an individual would develop cancer from inhaling air containing an average concentration of 1 ug/m^3 of the contaminant continuously for his lifetime. These potency factors are usually calculated from q_1^* potency values* assuming that each individual weighs seventy kilograms and breathes 20 cubic meters of air per day, as discussed previously. Generally the q_1^* potency factors are determined as the upper limit of the 95 percent confidence interval on the linear term in a multi-stage

*Further information on q_1^* values can be found in Office of Technology Assessment, 1981.

probability model* of cancer effects versus dose. The data used to develop these models is generally based on studies of cancer in animals. As stated previously, the study assumes that the potency factor applies to all exposed individuals regardless of age, sex, or other demographic or health characteristics.

2.4.5 HEM Output

HEM produces estimates for several risk-related variables that can be used in calculating risk measures. The principal HEM variables used in the target distance analysis are:

- Maximum contaminant concentration to which someone is exposed.
- Number of people exposed to this maximum concentration.
- Minimum contaminant concentration to which at least one individual is exposed.
- Number of people exposed to at least this minimum concentration.
- Population incidence (i.e. the sum, over all receptor locations, of the product of the average annual concentration at the location, the population at the location, and the potency factor).

Values for additional variables are also available from HEM but are not relevant to this analysis.

HEM produces estimates of each of these variables, for each waste site, as a function of the distances specified. Within HEM, differences in site estimates reflect differences in assumptions of emission rates, emission potency factors, atmospheric conditions and

*Further information on such effects models can be found in Office of Technology Assessment, 1981.

demographic characteristics. The model is linear in the first two factors, but not in the latter two factors. For example, a 10 percent decrease in the emission rate will result in a 10 percent decrease in all concentration and exposure variables but will not affect the population variable. However, this analysis assumes fixed values for the emission rate and potency factor. Thus, in this study, differences in risk estimates between sites reflect differences in site-specific meteorology and population characteristics only.

2.5 Site Selection

An analysis of several sites is needed to ensure that the results reasonably reflect the range of site meteorological and demographic conditions encountered at uncontrolled waste sites. However, the data requirements of the HEM, together with project resource constraints, restricted the choice of sites suitable for analysis. HEM requires that the latitude/longitude of the site be provided as input within an accuracy of one second. Further, the limited availability of site-specific meteorological data requires that the site can be associated with a weather station collecting STAR data. As a result of these considerations, 25 sites were randomly selected for analysis from the December 1985 list of final and proposed NPL sites subject to these data requirements. Because of these restrictions, the geographic distribution of sites selected may not be truly representative of the universe of uncontrolled waste

sites. The distribution is somewhat biased towards the industrial Midwest, an area of generally higher-than-average population density. The implications of this bias for the analysis are discussed in Section 4.5.

2.6 Analysis Framework

The HEM was used to provide estimates of contaminant concentration, exposure, and population at various distances from the center of the 25 selected sites. These outputs were converted, as necessary, to yield estimates of MEI risk, AEI risk and population incidence for each site. Since MEI risk is defined as the maximum risk to any individual in the exposed population, a single estimate of MEI risk is made for each site. MEI risk varies among sites, as does the distance from the site to the closest receptor location associated with a maximally exposed individual. This distance is a potentially important determinant of the MEI risk and is a potentially significant determinant of the air pathway target distance limit. The target distance analysis includes both an analysis of MEI risk and an analysis of the distance to the closest maximally exposed individual.

Two analyses of AEI risk are presented in this report. The first addresses the probability that an average-exposed individual living within a circle of specified radius about the center of the site will develop cancer as a result of emission from the site. For example, estimates are presented on the average risk to individuals

living within 25 miles of the site. The second incremental analysis examines the AEI risk to populations living between specified radii, e.g., the average risk to an individual living between 25 and 50 miles from the center of the site. This analysis is presented for six such areas:

- 0- 4 miles
- 4-10 miles
- 10-15 miles
- 15-25 miles
- 25-50 miles
- 50-60 miles

An incremental AEI risk analysis for areas within 4 miles (e.g., 1-2 miles) was not presented due to uncertainties in the population allocation procedures employed within about 2.2 miles of the sites (see Sections 2.4.3 and 4.4).

This dual approach was taken to examine the possibility of setting the air pathway target distance limit based on either the distance at which AEI risk would be acceptable or, alternately, the smallest distance from the site beyond which the average risk to an exposed individual living in this area would be acceptable.

The expected number of incremental cancer cases arising from exposure to site emissions in the exposed population (i.e., population incidence) is examined for six concentric zones centered at the center of the site. This analysis was performed to determine first, if a significant number of cases could be expected in the exposed population. If this proved to be so, the analysis would examine the feasibility of setting the air pathway target distance

limit based on the distance at which most (or all) of the expected number of incremental cases would be accounted for.

Four descriptive statistics are presented for each of the risk variables discussed above: average among sites, variation among sites, minimum of all sites, and maximum of all sites. The following chapter discusses the risk estimates produced during the study.

3.0 CARCINOGENIC RISK ESTIMATES

This chapter presents the estimates of carcinogenic risk from releases of airborne contaminants from uncontrolled waste sites. Results are presented for three risk variables: risk to the maximally exposed individual (MEI risk), average risk to exposed individuals (AEI risk), and expected lifetime incidence of increased cancer in the exposed population (population incidence). In addition, results of an analysis to determine the distance to the maximally exposed individual are also presented.

3.1 MEI Risk

In HEM, the risk to the maximally exposed individual at a site is equal to the product of the maximum exposure concentration and the potency factor (expressed in units of m^3/ug equivalents). The maximum exposure concentration is the highest estimated concentration at a receptor location with at least one individual. Thus, the MEI risk at a site is determined by both population distribution and meteorology.

The maximum exposure concentration is equal to the highest estimated concentration only if someone is living at the associated receptor location. Otherwise, the maximum exposure concentration is less than the highest estimated concentration. Similarly, the maximum exposure concentration does not necessarily occur at the closest receptor location because of meteorological considerations. Nor does it necessarily occur in the first ring around the site.

Furthermore, the maximum exposure concentration does not necessarily occur at the closest receptor location that has an individual. Meteorological conditions (e.g., prevailing winds) may result in a higher average concentration occurring at a location further from the site along a different radial.

Estimated MEI risks for the 25 sites examined ranged from 4×10^{-9} to 1×10^{-6} (see Table 3-1). The average was estimated at 5×10^{-7}. This indicates that the chance that the maximally exposed individual will develop cancer during his lifetime as a result of continuous exposure to emissions from the site is about 1 in 2 million on average. Inter-site variation, as reflected in the standard deviation of the site-specific estimates about the average, was about one-half the average, indicating only a small degree of site-to-site variation in MEI risk. Actual site-to-site variation in MEI risk, due to actual variations in emission rates and waste composition, may be higher than indicated. No analysis was performed to determine the relative roles of meteorology and population distribution in determining these differences.

Table 3-1 also presents information on the distance to the maximally exposed individual and on the risk to that individual. The table indicates that at no site examined did the MEI live within 1/4 mile of the estimated center of the site. The result is potentially misleading since some of the sites are larger than 1/4 mile in radius, while distance in this analysis is measured from the

TABLE 3-1

SUMMARY STATISTICS OF MAXIMALLY EXPOSED INDIVIDUAL (MEI) RISK

Distance Ring (miles)	Number of Sites	MEI Risks (10^{-7}) Average	Range
0-1/4	0	NA	NA
1/4-1/2	8	5	3 - 7
1/2-1	8	7	4 - 11
1-2	8	3	1 - 10
2-3	1	0.04	0.04
greater than 3	0	NA	NA

NA - Not applicable.

center of the site. Further, as stated previously, this study does not address workers at the site, only individuals residing on or near the site. Thus, at some of the sites, no one lives within 1/4 mile of the site center since they would then also be living on the site. However, at three sites, individuals were identified as living within 1/4 mile of the site but, in each case, the risk to these individuals was lower than the MEI risks. This illustrates that distance alone does not determine the MEI risk. Meteorology and geographic population distribution are important determinants as well.*

At eight of the sites examined, the MEI lived between 1/4 and 1/2 mile of the site. The risks to these maximally exposed individuals ranged between 3×10^{-7} and 7×10^{-7} with an average of 5×10^{-7}. At eight other sites, the MEI lived between 1/2 and 1 mile of the site. Contrary to intuition, the range of risks for these individuals ranged from 4×10^{-7} to 11×10^{-7} and averaged about 7×10^{-7}, a slight <u>increase</u> over the 1/4 to 1/2 mile ring. Both the range of the risks and the average risks declined for the eight sites at which the MEI lived between 1 and 2 miles of the site. At only one site did the MEI live beyond 2 miles from the site. The MEI risk at this latter site was 4×10^{-9} (the minimum estimated).

*An additional important determinant of MEI risk, actual location of residence, is not considered in this study since people are assigned to receptor locations, not actual residence locations.

The table indicates that a target distance limit of three miles in the air pathway would account for the MEI at most sites. The analysis indicates that the probability that the MEI at a final or proposed NPL site would be beyond three miles is small. The bias in the site selection procedure discussed previously, however, indicates that the distance to the maximally exposed individual at the selected sites may be an underestimate if compared to all final and proposed NPL sites. This possibility arises since, because of the location bias, individuals may live closer to the selected sites, on average, than to NPL sites in general (a corollary of the possible higher-than-average population density associated with the selected sites). However, a distance of three miles may not account for the maximally exposed individual at non-NPL sites again due to possible differences in population density (non-NPL sites may have lower average population densities than NPL sites, a possibility arising from the importance of population in determining air pathway scores in the current HRS).

3.2 Risk to the Average Exposed Individual

Table 3-2 presents the estimates of AEI risk to the population living within specified distances from the center of the site. Under the assumptions of the analysis, the risk is small at all distances examined, ranging, on average, from 1 chance in 100 million within 4 miles to about 1 chance in 1 billion within 60 miles. The risks, on average, to the population living closer

TABLE 3-2

SUMMARY STATISTICS OF RISK TO AVERAGE EXPOSED INDIVIDUALS (AEI RISK) LIVING WITHIN SPECIFIED DISTANCES

	Distance (miles)*					
Parameter	4	10	15	25	50	60
Average	1 E-8	5 E-9	3 E-9	2 E-9	1 E-9	9 E-10
Inter-site Variation**	1 E-8	4 E-9	3 E-9	2 E-9	1 E-9	1 E-9
Maximum	6 E-8	2 E-8	1 E-8	7 E-9	7 E-9	7 E-9
Minimum	2 E-9	1 E-9	6 E-10	3 E-10	2 E-10	1 E-10

*Measured from center of site.
**Defined as the standard deviation of the site-specific estimates about the average.

than 4 miles will be higher, although the average will never exceed the MEI risk. Thus, the AEI risk to the population living closer than 4 miles from the site will not exceed 5×10^{-7}, on average.

The site-to-site variation in AEI risk is moderate. Inter-site variation was about 10^{-8} at 4 miles, declining steadily to 10^{-9} at 60 miles. However, the inter-site variation was approximately equal to the average AEI risk at all distances. The maximum AEI risks range from about 6×10^{-8} at 4 miles to about 7×10^{-9} at 25 to 60 miles. The minimum AEI risks range from about 2×10^{-9} at 4 miles to about 1×10^{-10} at 60 miles.

Table 3-3 presents the estimates of the AEI risk to the population living beyond 4 miles of the site. As stated above, AEI risk is small even within a distance of 4 miles and declines with further distance. This is highlighted by the decline in average risks to individuals living further from the site. The chance that an average exposed individual would develop cancer as a result of the emissions from a site average about 1 chance in 1 billion for the population living between 4 and 10 miles from the site. AEI risk declines to about 1 chance in 10 billion for the population living between 50 and 60 miles of a site.

There is small site-to-site variation in these estimates as well. The inter-site variation was 6×10^{-10} between 4 and 10 miles and declined steadily to 6×10^{-11} between 50 and 60 miles. The relative variation was fairly constant at 50 percent. Estimated

TABLE 3-3

SUMMARY STATISTICS OF RISK TO AVERAGE EXPOSED INDIVIDUALS (AEI RISK) LIVING WITHIN SPECIFIED DISTANCE RANGES

	Distance (miles)				
Parameter	4-10	10-15	15-25	25-50	50-60
Average	1 E-9	7 E-10	4 E-10	2 E-10	1 E-10
Inter-site Variation*	6 E-10	3 E-10	2 E-10	9 E-11	6 E-11
Maximum	4 E-9	1 E-9	8 E-10	5 E-10	3 E-10
Minimum	7 E-10	3 E-10	2 E-10	8 E-11	5 E-11
Number of Sites**	24	24	24	24	24

*Defined as the standard deviation of the site-specific estimates about the average.

**Model estimates indicated that no one lives beyond four miles of one of the sites. Hence, this site was excluded from this analysis.

AEI risks ranged from 2×10^{-9} to 6×10^{-8} within 4 miles of the site. In the area from 50 to 60 miles surrounding the site, estimated AEI risk ranged from 5×10^{-11} to 3×10^{-10}.

3.3 Population Incidence

Population incidence is defined as the number of incremental cancer cases that can be expected in the exposed population due to the emissions from the site in question over a period of 70 years. At each receptor location, the product of the population estimate, the concentration and the potency factor is calculated. The sum of the values for all receptors within a specified distance equals the population incidence within that distance.

Table 3-4 presents the summary statistics of population incidence for the sites examined in the analysis. As seen in the table, population incidence is very small at all distances. The model indicates that, on average, one can expect 7×10^{-4} additional cancer cases in the exposed population over a 70-year period within 4 miles of the site. The estimated population incidence increases to only about 2×10^{-3} cases in the exposed population, on average, within 60 miles of the site. As would be expected, population incidence continually increases with distance, although at a decreasing rate. This illustrates that, given an assumption that no safe exposure threshold exists, population incidence will increase as long as population increases, despite decreasing incremental exposure concentrations.

TABLE 3-4

SUMMARY STATISTICS OF POPULATION INCIDENCE*

Parameter	Distance (miles)					
	4	10	15	25	50	60
Average	7 E-4	1 E-3	1 E-3	2 E-3	2 E-3	2 E-3
Inter-site Variation**	8 E-4	8 E-4	1 E-3	2 E-3	2 E-3	3 E-3
Maximum	4 E-3	5 E-3	6 E-3	6 E-3	1 E-2	1 E-2
Minimum	3 E-5	8 E-5	1 E-4	2 E-4	2 E-4	2 E-4

*Expected number of incremental cancer cases in the exposed population.

**Defined as the standard deviation of the site-specific estimates about the average.

There is moderate site-to-site variation in the estimates of population incidence arising from differences in meteorology and population distribution at each distance. Inter-site variation increased from 8×10^{-4} at 4 miles to about 3×10^{-3} at 60 miles probably reflecting increasing site-to-site variation in population. Nonetheless, as in the case of AEI risk, the relative site-to-site variation was approximately equal to the population incidence at all distances. The maximum population incidence ranged from about 4×10^{-3} cases within 4 miles of the site to 1×10^{-2} cases within 60 miles of the site. The minimum incidence ranged from 3×10^{-5} within 4 miles to 2×10^{-4} within 60 miles.

These results indicate that incremental population incidence does not provide a reasonable basis for establishing a target distance limit in the HRS air pathway. Thus, an extension of the target distance limit beyond 4 miles, to account for increases in number of expected cancer cases in the general exposed population as distance increases, is not warranted. Further, the results together with the results of the analysis of AEI risk, indicate that cancer incidence in the general exposed population probably should not be reflected in the air pathway target category at all, since the absolute magnitude of the estimates are very small even in the worst case.

4.0 STUDY LIMITATIONS

Several important limitations affect the conclusions that can be drawn from the analysis. Most of these limitations are common to all assessments of the risk from releases of airborne carcinogens. These limitations can be classified into five groups: emissions rates, potency factors, study assumptions, HEM model structure, and site selection. The following sections discuss these groups of limitations and their implications.

4.1 Limitations in the Emission Rate Assumptions

This section discusses the limitations arising from the choice of the emission rate of 100 kilograms per year, as well as the limitations arising from the assumptions of constancy and uniformity. Some of these assumptions are common to all airborne carcinogen risk assessments (e.g., sustainability of emission rates, independence of meteorology and emission rate, and simplifications arising from difficulties in estimating emission rates). Other limitations arise from unique aspects of this analysis (e.g., uniformity in emission rates).

The analysis assumes that a constant emission rate of 100 kilograms per year applies uniformly to all of the sites studied. The value of 100 kilograms per year was chosen after a review of the limited body of information available on waste site emission rates. Much of this information applies to active waste disposal sites or is based on idealized models that do not reflect conditions common

to uncontrolled waste sites. Few data are available on emission rates for uncontrolled waste sites. However, even given the limited coverage of the available information, it is clear that the site-to-site variation in short-term emission rates is large (see Appendix A). For example, estimated instantaneous emission rates of benzene from landfills range between 0.047 $ng/cm^2/sec$ and 2106 $ng/cm^2/sec$ in different studies. (One hundred kilograms per year is equivalent to about 0.032 $ng/cm^2/sec$ for a 10,000 m^2 landfill.) Further, available models indicate particulate emission rates could exceed 100 kilograms per year in locations that are both windy and dry. Given some of the contaminant concentrations found in soils of uncontrolled waste sites (on the order of 1 part in 100), emission rates for particulate carcinogenic contaminants might reasonably exceed 100 kg/yr as well.

As stated previously, the assumptions that the average concentration is sustained at each receptor location is derived from the assumption that the constant emission rate is sustained. It is doubtful that any but the largest sites could sustain a 100 kilogram per year emission rate for 70 years. However, little information is available on long-term site emission rates.

The study also assumes that the constant emission rate applies to all sites at all times. This assumption is not common in airborne carcinogenic risks assessments but rather arises from limitations in resources and scope of this study and the resulting

need for simplicity. This assumption ignores the wide variation between sites in emission rate, quantity, and composition due to differences in site characteristics such as waste characteristics, containment, soil type and meteorology. The constant emission rate also ignores the temporal variations in emission rates within a year and between years. Generally, as a site ages its emissions rate will decline as the quantity of contaminants remaining on the site declines.

Overall, the emission rate assumptions are probably conservative. The uniform emission rate of 100 kilograms per year for 70 years may be an overestimate of the "average" of all sites, particularly for sites containing volatile organics. It is less likely to be an underestimate. Long-term sustained rates for most sites will probably be lower, although short-term emissions at much higher equivalent rates are likely. The lack of data to confirm or dispute the emission rate assumptions implies a high degree of uncertainty in the risk estimates produced in the analysis. However, the net result is probably that the risk values will be somewhat elevated and their uncertainty high.

4.2 Limitations Associated with the Potency Factors

Several of the limitations associated with the potency factors are similar to the limitations in the emission rates. The limitations associated with basic potency factors are common to all risk assessments. The additional limitations associated with

translating potency factors in dose units (e.g., mg/kg/d) to potency factors in ambient units (e.g., m^3/ug) are unavoidable but, nonetheless, common to many airborne carcinogenic risk assessments.

The first important limitation arises from the use of a uniform potency factor of 10^{-5} m^3/ug (see Section 2.2). This limitation is not common but, as with the emission rate, arises from the need for simplicity in the analysis. An examination of the available data in Table 2-2 on potency factors (expressed in these units) indicates that this value is a reasonable mid-range value. It is, however, low when compared with potency factors for airborne, carcinogenic inorganics (e.g., 10^{-2} for arsenic). The overall range of "known" potency values (expressed in terms of m^3/ug) is about 10^{-8} to 1.0. However, many of the substances found at uncontrolled waste sites are not carcinogenic, e.g., iron. Thus, the carcinogenic potency of emissions from some uncontrolled waste sites may be as low as zero.

As in the case of the emission rate, the assumption that a uniform potency factor applies to all sites ignores site-to-site variation in waste composition. It is evident that the overall carcinogenic potency of the contaminants on one site may be orders of magnitude higher than those on another site due to differences in waste composition among sites. Further, the choice of a single potency value ignores synergistic or antagonistic interactions between the various contaminants present on a particular site and

between site contaminants and other contaminants in the environment in determining the overall emissions potency.

Similarly, the analysis does not account for the interaction of the exposure with other lifestyle-related risk factors, such as smoking, in determining the probability that an individual will develop cancer. Nor does the analysis account for any other synergistic or antagonistic interactions between the exposure to the contaminant and any other factor. The study assumes that the potency factor applies to each individual uniformly irrespective of the individual's age, sex or any other characteristic and thus, risks to sensitive populations are not specifically addressed as well. Many of these characteristics, particularly age, affect the probability that an individual will develop cancer from a given exposure during his lifetime.

There are further uncertainties associated with the basic q_1^* potency factor values that limit the usefulness of the model results. These uncertainties arise from limitations in the basic toxicology data underlying the potency factors, the validity of the use of models based on from animal data to in assessing human health risks, and the validity of the models used to infer low dose response relationships based on high dose response data. Battye et al. (1985) present a more detailed discussion of potency factors and their use in HEM. A more complete discussion of the overall limitations of potency factors can be found in Office of Technology Assessment, 1981 and National Research Council, 1983.

Finally, as discussed previously, the potency values used in this analysis were derived from q_1^* values using assumptions on the weight and daily respiratory rate of an exposed individual (assuming a homogenous population). These assumptions ignore the potential for some portion of some contaminants to be exhaled and thus not to be available to cause a harmful effect to the body system.

The overall effect of these considerations on the validity of the results of the target distance analysis is problematic. Overall, they indicate that a very high degree of uncertainty is introduced into those portions of the analysis sensitive to the actual risk values (e.g., MEI risk). Many of these uncertainties, however are also common to any cancer risk assessment.

4.3 Limitations Arising from Simplifying Assumptions

There are several limitations that arise from the simplifying assumptions made during the study in additional to those related to emission rates and potency. Again, many of these limitations are common to airborne carcinogenic risk assessments and arise from gaps in fundamental knowledge of atmospheric processes in general and site-specific conditions in particular.

First, the necessary simplifying assumptions required to use a the dispersion module of HEM are strictly true for many of the sites examined. These assumptions include spatial invariance of wind speed, wind direction, and atmospheric stability. Nonetheless,

these simplifying assumptions are commonly made in many air quality modeling analyses, even in employing approved air quality models in analyses supporting air emission permit processes. The question is whether the extent of the violation of assumptions in comparison to reality is sufficient to invalidate the use of the model. These assumptions have been accepted in other HEM analyses (e.g., Battye et al., 1985). However, it is imperative that the truth of the assumptions be considered in making judgments based on the modeling results.

HEM has not been reviewed by EPA as part of its formal model review process. It is thus difficult to delineate the limitations of the model overall. However, HEM's limitations include all of those generally applicable to any climatological dispersion model such as the Climatological Dispersion Model (CDM; Busse and Zimmerman, 1973 and Brubaker, Brown and Cirillo, 1977). According to the recommendations in the EPA Guideline on Air Quality Models (1986a), CDM is appropriate for use in the following situations:

- Point and area sources
- Urban areas
- Flat terrain
- Transport distances less than 50 kilometers
- Long-term average concentrations

Many of the sites analyzed in this study, however, are neither in urban areas nor are they surrounded by flat terrain. Further, the analysis was conducted for distances up to 100 kilometers. Despite

these recommendations, HEM is used by EPA in analyzing airborne carcinogenic risk at distances up to 100 kilometers (Dusetzina, 1986).

The target distance analysis implicitly assumes that the terrain around the site is flat for 60 miles; an assumption of questionable validity in many parts of the United States. The apparent conflict between these assumptions and the EPA recommendations does not necessarily invalidate the use of the model and the results of the analysis. It does indicate that the results should be viewed with caution.

Second, the assumption that the contaminant is neither transformed or deposited within the grid region may not be valid. As stated previously, it may be valid for many gaseous contaminants but it is unlikely to be valid for particulates. This assumption may result in an overestimation of risks in the cases of chemicals that transform into other, less potent chemicals or that deposit and do not resuspend. Alternately, underestimates of risks may result for chemicals that transform into other, more potent chemicals. Further, lack of consideration of deposition ignores the potential increase in unit risk associated with ingesting deposited material as compared with inhaling suspended material. Overall, it is difficult to determine whether HEM underestimates or overestimates risks due to these assumptions.

Third, the study assumptions that the distribution of meteorological conditions, developed from the past five years of applicable STAR data from the closest applicable weather station, remains the same for all years of the analysis is open to question. Given that five years of data determine the distribution, however, this assumption is probably reasonable. The related assumption that the meteorological conditions from the nearest weather station are sufficiently representative of site meteorology for use in this study is of greater, but otherwise indeterminate, concern.

Fourth, the study assumption that the concentrations are maintained at a constant level over the 70-year period is open to question. This is equivalent to assuming that the site sustains the user-specified emissions rate for the 70-year study period and that the distribution of meteorological conditions does not change from year to year. This is a common, worst-case assumption arising from the need to forecast long-term concentrations from shorter-term (e.g., annual) information. This assumption is conservative, however, as it is unlikely that emissions from a waste site will remain constant over time (and would probably decrease).

A fifth limitation arises from the study assumption that populations do not change over time. The study essentially assumes that the number of people living in the affected area does not change over time (i.e., it does not account for births, deaths or migration into or out of the region), nor does it account for

migration within the region. Essentially, the study assumes that the same people remain at their assigned grid locations indefinitely. However, given the limitations of local, long-term (e.g., 70 years) forecasting models and uncertainties in the effects of short-term exposures on long-term risk, these limitations may both be unavoidable. Further, they may be acceptable since, on balance, they would probably result in an overestimation of the risks from an particular site.

A sixth limitation comes from the assumption that the emissions arise from the center of the site. This assumption may result in underestimation of the risks posed to surrounding populations due to emissions arising from sources located near the site boundary. This limitation increases in importance as the size and number of sources on the site increase.

Finally, the study assumption that the dose-response relationship can be adequately reflected using a linear, no-threshold dose-response model is open to question. Numerous other models can be employed (e.g., Weibull and probit models). However, in general, the linear, no-threshold model produces higher risk estimates at the low concentrations indicated by the dispersion model and is thus considered to be suitably conservative.

4.4 Limitations of the HEM

The principal limitations that HEM places on the conclusions, independent of the study assumptions, arise from the dispersion model employed in HEM and the population allocation procedure.

As stated previously, the dispersion model used in HEM is a steady-state Gaussian plume model. These models in general have many strengths, as indicated by their widespread use in regulatory applications. However, models of this type have a number of weaknesses that arise from their simplifying assumptions. Smith (1980) presents a review of the strengths and weaknesses of these models. The most important weaknesses, from the perspective of this analysis, are the assumptions that the wind speed, direction and stability are uniform over the entire grid region and that the terrain in the grid region is flat. Additionally, concerns have been raised about the validity of the use of Gaussian plume models in uneven terrain at distances beyond 10 kilometers (American Meteorological Society, 1980).

The population allocation procedure used in HEM was discussed in Section 2.4.3. As noted in that section, the procedure has difficulties at distances less than about 2.2 miles. In site-specifc analyses, EPA supplements the population allocations produced by HEM with actual location information derived from USGS topographic maps. This procedure was not followed during this study. Thus, the study relies on the population allocation module results produced by HEM for short distance risk analyses.

4.5 Limitations in the Site Selection Process

As discussed previously, 25 sites were selected from a list of final and proposed NPL sites that met HEM data requirements.

Table 4-1 presents a comparison between the regional distribution of the selected sites and the distribution of final and proposed sites through NPL Update 5. Overall the comparison is good. The comparison shows complete agreement for three of the regions (III, VIII, and X). The comparison indicates a slight bias towards Regions I and VI and a larger bias towards Region V. The comparisons also indicate a bias away from Regions II, IV, VII, and IX. Overall, this comparison indicates that the distribution is moderately biased towards areas of generally higher population density with a higher degree of urbanization. This would indicate that the population density surrounding the selected sites will be greater, on average, than that of the NPL sites as a whole. The potential effects of this geographic bias can be determined. Due to the bias toward areas of higher urbanization and population density, it is likely that people would be living closer to the selected sites than to all final and proposed NPL sites, on average. Further, one might expect that more people would be living within a given distance of the selected sites than to all final and proposed NPL sites, on average. These considerations indicate that the analysis may somewhat (1) understate the average distance to the MEI, (2) overstate the average MEI and AEI risks and, (3) inflate the estimates of average population incidence at each distance. Overall the effect of these biases is likely to be minor in comparison to the uncertainties induced by the limitations discussed previously.

TABLE 4-1

COMPARISON OF GEOGRAPHIC DISTRIBUTION
OF SITES SELECTED FOR ANALYSIS

Distribution Region	Sample Distribution		Actual NPL* Percent
	Number	Percent	
I	2	8	6
II	4	16	19
III	3	12	12
IV	0	0	11
V	10	40	24
VI	2	8	6
VII	0	0	5
VIII	1	4	4
IX	2	8	9
X	1	4	4

*National Priorities List (proposed and final) sites as of NPL Update 5 (51 FR 21099, 10 June 1986).

An additional limitation arising from the site selection procedure derives from the use of only final and proposed NPL sites as the sampling population. The HRS is designed to assist in evaluating all uncontrolled waste sites, not just NPL sites. As such, the results presented may be biased if generalized to apply to all uncontrolled waste sites. The overall implications of this bias are unknown. However, the structure of the HRS is such that the presence or absence of people, and the number of people living near a site, is an important determinant of the site HRS score. Thus, final and proposed NPL sites will probably have more people living near them than all uncontrolled waste sites, on average. Therefore, the bias induced by employing only final and proposed NPL sites in the analysis probably amplifies the geographic biases discussed above.

4.6 Overall Implications for the Analysis

Table 4-2 summarizes the limitations of the target distance analysis. Each of these limitations increases the uncertainty in the final results differentially. The implications of the uncertainties and limitations discussed above for the validity and usefulness of the target distance analysis results are complex and difficult to assess.

In the opinion of the author, the uncertainties in the emission rate and potency assumptions are the most critical for the target distance analysis. These two factors have the greatest effect in

TABLE 4-2

SUMMARY OF STUDY LIMITATIONS

Source of Limitation	Limitation
Emission Rate	Chosen Emission Rate Uniform Rate Among Sites Constant Rate Over Time Sustainability for 70 Years
Potency Factors	Chosen Potency Factor Uniform Factor Among Sites Uniform Applicability to All Individuals Translation of Dose Factors to Exposure Factors Lack of Interactions
Simplifying Assumptions	Flat Terrain Urban Area 100 Kilometer Scale Uniform Meteorology No Pollutant Loss Source and Applicability of Meteorological Data Constant Exposure/Dose Homogenous Population Unchanging Population Exposure Location Linear Multi-stage Model
HEM	Gaussian Plume Model
Site Selection Process	Possible Regional Bias

determining the estimated risk from the site and hence the distance at which the risk becomes acceptable given a criterion for acceptability. There is considerable variation in the composition of waste deposited in uncontrolled waste sites and hence there should be considerable variation in the rate and potency of their actual emissions.* The conflict between this suspected variation and the simple assumptions used in the analysis underline the importance of these assumptions in the analysis.

The effect of both the limitations associated with the simplifying assumptions and the use of HEM on the validity of the study and its conclusions is more problematic. Some of the assumptions would result in overestimates (e.g., linear, dose-response model) while others would result in underestimates (homogenous population). Little information is available indicating the effects that these assumptions would have on risk estimates of this type. However, these uncertainties are common to many, if not all, airborne carcinogenic risk assessments. Lacking further information, the importance of these assumptions on the validity of the conclusions and the analysis remains a question of individual judgment.

*The actual variation in emission rates between sites is largely unknown due to a lack of monitoring data that can be used to estimate emission rates. Differences in emission potencies is amply evidenced by the wide variation in contaminants detected at sites.

The uncertainty in generalizing the results from the sample of 25 to the entire universe of sites arising from possible regional bias in the site selection procedure is probably small.

Overall, the limitations and uncertainties indicate that a high level of uncertainty should be ascribed to the results of the analysis. This is particularly true for the risk estimates. The study results probably overstate the risk posed by most sites. The degree of this overstatement is unknown. As a result, it is not clear that even an order of magnitude difference between the risk values represents a significant difference in terms of the actual risk posed by sites. This uncertainty is mitigated somewhat by the lack of certainty as to what constitutes an acceptable risk. EPA has not established uniform guidelines for acceptable risk that account for uncertainties in potency and exposure factors.

However, because of the structure of the model and its assumptions regarding population allocation, the analysis of the distance to the maximally exposed individual is less uncertain.

Despite these limitations, the author believes that this analysis can provide insight into the risks posed by most uncontrolled waste sites and could provide a reasonable basis for establishing, in part, the target distance limit in the HRS air pathway.*

*The sub-chronic risks posed by site should also be considered in setting the target distance limit.

5.0 CONCLUSIONS OF THE STUDY AND IMPLICATIONS FOR THE HRS AIR PATHWAY TARGET DISTANCE CATEGORY

The objective of this analysis in the context of the air pathway of the Hazard Ranking System is primarily to determine the target distance limit in terms of the distance beyond which emissions from uncontrolled waste sites would generally be deemed to pose an acceptable risk to the surrounding population. A secondary objective is to provide information useful in answering other questions relevant to the modification of the air pathway including:

- Definition of risk measures to be employed in the air pathway.
- Determination of the relative weight of carcinogenic effects in assessing toxicity.
- Determination of the relative importance of air pathway exposures in determining overall site risks.

This chapter presents the results of the analysis of these questions based on the risk estimates presented earlier.

5.1 Risks from Air Contaminant Releases from Waste Sites

Despite the limitations of the analysis, several general conclusions about the nature of cancer risk from uncontrolled waste sites can be drawn. First, both the estimated average individual risk and the incremental incidence of cancer in the exposed population arising from exposure to uncontrolled waste site emissions are likely to be small. The combined emission rate/potency factor would have to be increased by a factor of about 100 to induce one additional cancer in the exposed population in the worst case

examined (see Table 3-4). It must be stressed, however, that the study assumptions may result in underestimates of the risks to those individuals residing near the site.

Second, the analysis indicates that for most waste sites, the MEI risks will probably be less than those that have been considered acceptable by EPA or other Federal agencies in past instances (see, for example, Thomas, 1984 and Travis et al., 1987). However, an unacceptable MEI risk is possible for some sites, given (1) the uncertainties in the emission rates and in the ranges of potency factors, and (2) the possible underestimation of near site risks resulting from the assumptions of the study. The use of a potency factor of 10^{-2} (e.g., arsenic) for the worst case examined would result in an MEI risk of about 10^{-3}, which is greater than the generally acceptable range.

Third, an examination of the range of potency values, emission rates and the results of this analysis indicate that particulates rather than volatile organic gases <u>may</u> pose the greater cancer threat from releases into the air from uncontrolled waste sites. This preliminary conclusion is based on two observations. Potency factors for particulates (e.g., arsenic) appear to be higher, on average, than for volatile organics. Also, it is unlikely that a site would emit a critical amount of volatile organic contaminants for a sustained period of time (e.g., 100 kilograms per year for 70 years) although it may be possible that some large sites may emit

such a critical amount of contaminated particulates. Major uncertainties in this conclusion are (1) the potentially greater impact of deposition processes on particulates as compared with gases (which would result in potentially lower exposure concentrations for particulates), (2) the effect of contaminated particle re-entrainment on increasing total exposure, (3) the impact of transformation processes which could create more or less potent carcinogenic organic compounds in the ambient air,* and (4) the uncertainties in long-term emission rates.

A limited conclusion concerning non-cancer risks can also be made based on the results of this analysis. One can conclude that the risk of non-carcinogenic effects at distances beyond 4 miles would be negligible, at most sites, for the contaminants with known safe thresholds. This conclusion arises from the relationship between AEI and MEI risk and exposure concentrations. AEI risk is the product of the population-weighted average exposure concentration and the potency factor. Thus, the average exposure concentration (in units of ug/m^3) is 10^5 times the AEI risk. Using this fact and the results from Table 3-3, the average annual concentration to which the average individual would be exposed at distances beyond 4 miles would be well below 1 nanogram per cubic meter, at all of the sites examined. At distances beyond 10 miles

*For example, benzo(a)pyrene, a common hydrocarbon transformation product, has an estimated carcinogenic potency of 1.7×10^{-3}.

the average annual concentration at the worst site examined is estimated to be less than or equal to about 0.1 nanograms per cubic meter. Further, a comparison of the estimates for AEI risk and MEI risk for distances less than 4 miles indicates that the MEI risk is generally between 10 and 100 times the AEI risk. Extrapolating this relationship to distances greater than 4 miles indicates that the highest average annual exposure concentration is below 100 nanograms per cubic meter at all such sites. This concentration is below all of the safe exposure thresholds* listed in United States Environmental Protection Agency, 1986b for chronic inhalation exposures. Thus, it is reasonable to conclude that it is unlikely that safe exposure thresholds for chronic effects would be exceeded at distances beyond four miles from most waste sites.

The analysis does not provide information on the potential magnitude or geographic extent of health effects caused by sub-chronic exposures or from chronic non-carcinogenic exposures to contaminants that lack safe exposure thresholds.

*Using the acceptable daily intake for chronic inhalation effects as the safe threshold concentration, and assuming the relationship between dose and exposure concentration discussed previously, the lowest safe threshold concentration for chronic effects listed in United States Environmental Protection Agency, 1986b is about 180 nanograms per cubic meter (based on an ADI for inhalation of 5.1×10^{-5} milligrams per kilogram per day for inorganic mercury compounds).

5.2 Implications for the HRS Air Pathway Targets Category

The results of the analysis have major implications for the structure of the HRS air pathway targets category. First, the results indicate that cancer risk should not be emphasized in the HRS air pathway except possibly for near-site residents. Rather, despite the lack of knowledge about non-carcinogenic risk, it is probably reasonable to emphasize non-cancer effects in the air pathway pending the results of study of such risks. Such analyses to delineate the non-cancer risks arising from uncontrolled waste site air emissions should be undertaken and modifications to the HRS (e.g., target distance limits) developed as warranted.

This conclusion does not imply that cancer risk should be excluded from the HRS. The results of the analysis indicate that cancer risk from some sites may be unacceptable depending on the characteristics of the waste contaminants on the sites and their emission rates. The results of the analysis indicate, however, that the only potentially significant variation between between cancer risks from sites arises from possible differences in site contaminant emission rates and potencies. Thus, emissions rates and potencies provide the bulk of the discrimination between sites in terms of long-term cancer risk. Both of these factors can be reflected best in the HRS waste characteristics category. Emissions rates are in fact currently reflected, albeit indirectly, in the waste quantity factor. The carcinogenic potency of the compounds at

the site, and hence the probable potency of emissions, can be reflected in the toxicity factor. A method for reflecting carcinogenic potency is discussed in DeSesso et al., 1986. It is not unreasonable to conclude, therefore, that cancer risk in the air pathway is best reflected via the waste characteristics category and that no cancer risk evaluation table need be developed in the targets category. This conclusion emphasizes the importance of revising the waste characteristics category to better reflect cancer risk and emission rates as discussed in DeSesso et al., 1986 and Wolfinger, 1986.

Second, the results indicate that if cancer risk were to be reflected in the targets category, then MEI risk should be the principal cancer risk measure employed in the air pathway targets category. However, the results of the analysis indicate that for most sites, MEI risk would be considered acceptable by EPA (using the guidance given in Thomas, 1984). Hence, the relative weight given to MEI risk in the air pathway targets category, in comparison to non-cancer risk measures, should be small.

Further, the analysis indicates that the overall population incidence of cancer and the risk of developing cancer to average exposed individuals are not of concern at most sites and should not be reflected in the HRS target distance limit and population target evaluation tables. Again, this conclusion is subject to the uncertainty in near-site estimates.

The results also have implications for the structure of any MEI cancer risk evaluation table, if such a table were to be included in the air pathway targets category. The magnitude of site-to-site variation in MEI risk indicates that, assuming uniform potency factors and emission rates, MEI risk does not differ significantly between sites whenever the MEI lives within two miles of the site. Also, the MEI risks that occur at two miles and beyond are probably inconsequential (e.g., less than 10^{-8}). Further, current EPA policy on MEI cancer risk de-emphasizes the number of maximally exposed individuals in favor of the magnitude of the risk to each MEI. Thus, the structure of an MEI cancer risk evaluation table, if developed, should de-emphasize the number of MEIs in favor of their probable exposure. This would indicate that an MEI risk target evaluation table should be based on the distance to the nearest MEI with a maximum value assigned whenever the MEI lives within two miles and a minimum value (or zero) assigned whenever the MEI lives further than three miles.

The best method of identifying the locations of maximally exposed individuals, and hence estimating the distance to the closest MEI, is to employ a dispersion model to estimate concentrations at receptor locations corresponding to actual residences (based, for example, on aerial photographs). The use of such models is currently beyond the current scope of site inspections and HRS evaluation. However, given information on the

latitude and longitude of a site, the cost of employing HEM to determine the distance to the MEI would be negligible, assuming EPA made the model available.*

Alternately, the MEI cancer risk evaluation table could be based on a surrogate for this distance, such as the distance to the nearest residence. The use of this particular surrogate measure would probably not provide sufficient discrimination among the sites as probably few sites lack a residence within two miles.

Finally, the analysis provides little indication of the air pathway target distance limit that should be employed for evaluating non-cancer risks or for evaluating combined cancer and non-cancer risks. Thus, the question of the target distance limit to be used in the HRS air pathway is not resolved by this analysis. As stated earlier, studies of non-carcinogenic risks are needed to establish the target distance limit completely.

*The estimated cost is about two dollars per site in computer costs and well less than two hours per site analyst time (Dusetzina, 1986).

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APPENDIX A

SELECTED INFORMATION ON EMISSION RATES

Little data are available on contaminant emission rates for uncontrolled waste sites. This appendix presents a compilation of selected information on waste disposal site emission rates. This information is presented to show the wide variation in emission rates under differing assumptions and conditions. It is intended to provide a context for the emission rate assumptions used in the target distance analysis. This information is an amalgam of sampling studies, laboratory simulation studies, and simple analyses using emission rate equations that have been conducted by others.

Two characteristics of the information presented are important when comparing emission rates. First, tne variation in the data is large. The emission rate data range over eight orders of magnitude between contaminants, source types and studies (10^{-5} to 10^{3} equivalent $ng/cm^2/s$). Benzene emission rates, for example, vary over six orders of magnitude between studies. Second, all of the available information relate only to relatively short-term emission rates, at most one day in duration. None of the studies examined addressed long term emissions sustainable for a period of 70 years, the assumption required in the target distance analysis.

Table A-1 presents conversion factors for use in comparing rates in different units. Tables A-2 through A-10 present the emission estimates and other supporting information.

TABLE A-1

CONVERSION FACTORS

One Kilogram Per Year is Equivalent to:	
1,000	Grams per year
0.1142	Grams per hour
3.17×10^{-5}	Grams per second
31.71	Micrograms per sec
3.17×10^{-3}	Micrograms per m^2 per sec*
3.17×10^{-4}	Nanograms per cm^2 per sec*

*Assumes source size is 10,000 m^2.

TABLE A-2

LANDFILL STUDY 1

Source:	Shen, Thomas T., "Estimating Hazardous Air Emissions from Disposal Sites," Pollution Engineering, Vol. 13, No. 8, August 1981, pp. 31-34.
Source Type:	Landfill
Estimation Approach:	Calculations; simplified emission rate estimation equation
Assumptions:	Aroclor soil concentration = 5,000 ppm Wind speed = 4 m/s Size = 40m x 40m Cover depth = 10cm Cover porosity = 0.4
Emission Estimates:	Aroclor 1242 emission rate uncovered 184 ug/s covered 8 ug/s

TABLE A-3

LANDFILL STUDY 2

Source: Springer, Charles, Louis J. Thibodeaux and Shrikrisna Chatrathi, "Simulation Study of the Volatilization of Polychlorinated Biphenyls from Landfill Sites," Environment and Solid Wastes Characterization, Treatment and Disposal, Francis, C. W. and S. E. Auerbach, eds., Proceedings of the Fourth Life Sciences Symposium, Environment and Solid Wastes, Held in Gatlinburg, TN, on October 4-8, 1981, Butterworth Publishers, Woburn, MA, 1983, pp. 209-222.

Source Type: Landfill

Estimation Approach: Simulation study employing emission estimation equations

Assumptions: Liquid Aroclor 1248
- Cell porosity = 0.2
- Cell depth = 3.0 meters
- Cell density = 2.0 g/cm^3
- Aroclor 1248 partial pressure = 1.3 E-6 atm.

Aroclor 1248 in sludge
- Cell porosity = 0.2
- Cell depth = 10.0 meters
- Aroclor 1248 partial pressure = 5.3 E-7 atm.

Emission Estimates:

Cap Parameters		Liquid Aroclor 1248	
		Gas Rate	Flux
Porosity	Depth (m)	($cm^3/g/s$)	($mg/m^2/d$)
0.1	3.0	3 E-7	2.42
0.1	3.0	2 E-7	1.6
0.1	3.0	1 E-7	0.8
0.1	3.0	3 E-7	2.42
0.1	1.0	3 E-7	2.46
0.1	0.5	3 E-7	2.51
0.1	3.0	3 E-7	2.42
0.2	3.0	3 E-7	2.65
0.08	3.0	3 E-7	2.40
0.06	3.0	3 E-7	2.31

TABLE A-3 (Concluded)

Emission Estimates: (Concluded)

Cap Parameters		Liquid Aroclor 1248	
		Gas Rate	Flux
Porosity	Depth (m)	($cm^3/g/s$)	($mg/m^2/d$)
0.06	1.0	3 E-7	2.36
0.06	0.5	3 E-7	2.39
0.1	3.0	0.0	0.08
0.08	3.0	0.0	0.05
0.2	3.0	0.0	0.33
0.1	3.0	0.0	0.08
0.1	1.0	0.0	0.24
0.1	0.5	0.0	0.45

Cap Parameters		Aroclor 1248 in sludge	
		Gas Rate	Flux
Porosity	Depth (m)	($cm^3/g/s$)	($mg/m^2/d$)
0.1	1.0	5 E-8	0.53
0.08	1.0	5 E-8	0.30
0.2	1.0	5 E-8	0.91
0.1	1.0	5 E-8	0.53
0.1	0.5	5 E-8	0.62
0.1	2.5	5 E-8	0.48

TABLE A-4

LANDFILL STUDY 3

Source: Thibodeaux, Louis J., "Estimating The Air Emissions of Chemicals from Hazardous Waste Landfills," Journal of Hazardous Materials, Vol. 4, 1981, pp. 235-244.

Source Type: Landfill

Estimation Approach: Calculations using emission estimation equations

Assumptions:
Temperature = 25 degrees C
Wind speed = 8.2 mi/h
Friction velocity = 0.5 m/s
Cover porosity = 0.51
Tortuosity = 1.71
Size = 100m x 100m
Cover depth = 1m
Gas velocity = 1.63 E-3 cm/s
Contaminant concentration in air spaces (g/m^3)
- Benzene = 399.3
- Chloroform = 1282
- Vinyl Chloride = 2556
- Aroclor 1248 = 7.76 E-3

Emissions Estimates:

Chemical	Emissions Rate ($g/m^2/d$) Without Gas Generation	With Gas Generation
Benzene	89.4	563
Chloroform	340	1820
Vinyl Chloride	826	3650
Aroclor 1248	9.5×10^{-4}	109×10^{-4}

TABLE A-5

LANDFILL STUDY 4

Source: Shen, Thomas T., "Air Quality Assessment for Land Disposal of Industrial Wastes," Environmental Management, Vol. 6, No. 4, 1982, pp. 297-305.

Source Type: Landfill

Estimation Approach: Calculations using emission estimation equations

Assumptions: Location: Caputo Landfill, New York
Aroclor 1242 soil concentration = 5,000 ppm
Cover depth = 50.8 cm
Cover layers; manure, paper mill sludge and topsoil

Emission Estimates: Aroclor 1242 emission rate
before cover 5678 ug/s
after cover 34.6 ug/s

TABLE A-6

LANDFILL STUDY 5

Source: Baker, Lynton W., An Evaluation of Screening Models for Assessing Toxic Air Pollution Downwind of Hazardous Waste Landfills, Masters Thesis, Office of Graduate Studies and Research, San Jose State University, San Jose, CA, May 1985.

Source Type: Landfill

Estimation Approach: Calculations using emission emission equations under different atmospheric conditions

Assumptions: Location: BKK Landfill, California
Temperature = 20 - 30 degrees C
Size = 583 acres, 228 acres containing wastes
Exposed area = $0.31 \times 10^8 - 2.6 \times 10^8$ cm^2
Cover depth = 10 ft
Cover porosity = 0.2

Emission Estimates:

		Vinyl Chloride Emission Rate (g/s) Atmospheric Conditions		
Date	Site	Hillside Drainage	Sea Breeze	Valley Drainage
3/84	A	0.197	0.126	
	B	0.023		0.141
8/84	A	0.279	0.179	
	B	0.033		0.199

TABLE A-7

LANDFILL STUDY 6

Source: Hwang, Seong T., "Model Prediction of Volatile Emissions," Environmental Progress, Vol. 4, No. 2, May 1985, pp. 141-144.

Source Type: Landfill, Evaporation Pond, and Land Treatment Facility

Estimation Approach: Measurements and calculations

Assumptions:

Parameters	Landfill	Pond	Land Treatment
Wind Speed (mph)	11-19	4-5	7-10
Size			
Surface area (ft^2)	231,000	5400	10 (acres)
Depth (ft)	34	7.5	
Waste Composition*			
Toluene	0.749	1.05	1.22 E-2
1,1,1-Trichloroethane		2.53	
Methylene Chloride	0.276		
Tetrachloroethylene	0.456		
Benzene			6.25 E-3
Chlorobenzene			1.04 E-3

Emission Estimates:

Parameters	Rates ($ug/m^2/s$) Landfill	Pond	Land Treatment**
Toluene			
measured	1.48	18.4	4.7
predicted	0.93	13.5	11
1,1,1-Trichloroethane			
measured		15.3	
predicted		15.2	
Methylene Chloride			
measured	0.4		
predicted	4.04		

*Units: Landfill, ug/g; Pond, ug/ml; Land Treatment, g/cm^3.
**Application rate 3.5 gr/cm^2, emission rate estimated at 70 hours after waste application.

TABLE A-7 (Concluded)

Emission Estimates: (Concluded)	Parameters	Rates ($ug/m^2/s$) Landfill	Pond	Land Treatment*
	Tetrachloroethylene			
	measured	0.76		
	predicted	0.32		
	Benzene			
	measured			1.1
	predicted			7
	Chlorobenzene			
	measured			2.4
	predicted			6

*Application rate 3.5 gr/cm^2, emission rate estimated at 70 hours after waste application.

TABLE A-8

SURFACE IMPOUNDMENT STUDY 1

Source:	Shen, Thomas T., "Estimation of Organic Compound Emissions from Waste Lagoons," Journal of the Air Pollution Control Association, Vol. 32, No.1, January 1982, pp. 79-82.
Source Type:	Surface Impoundment
Estimation Approach:	Calculations; simplified emission rate estimation equation
Assumptions:	Temperature = 20 - 30 degrees C Lagoon Size = 25m x 40m x 3.5m Benzene concentration in lagoon = 100 mg/l Wind speed = 3 m/s
Emission Estimates:	Peak Short Term Benzene Emissions Rate = 5.5 g/s

TABLE A-9

SURFACE IMPOUNDMENT STUDY 2

Source: Thibodeaux, Louis J. et al., "Air Emission Monitoring of Hazardous Waste Sites," Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, Held on November 29-December 1, 1982 in Washington, DC, Hazardous Materials Control Research Institute, Silver Spring, MD, 1982, pp. 70-75.

Source Type: Surface Impoundments

Estimation Approach: Back-calculation of emission rates from ambient data using concentration profile technique

Assumptions:

Pond 1,2

Size = 85 meter x 253 meter with a 1.2 - 1.5 meter berm
Eight surface aerators
Surface area = 21,600 m^2
Volume = 68,400 m^3
Depth = 3.2 meters
Wind speed = 151 - 360 cm/s
Contaminant concentrations in waste (ug/l):

Benzene	0.31 ± 0.31
Toluene	4.1 ± 4.7
Total Hydrocarbons	8.4 ± 2.8
1,1-Dichloroethane	34 ± 7.7
Total Chlorinated Hydrocarbons	207 ± 37

Pond 6

No surface aerators
Surface area = 4650 m^2
Volume = 4630 m^3
Depth = 1 meter
Wind speed = 159 - 325 cm/s
Contaminant concentrations in waste (ug/l):

Benzene	16 ± 9.5
Toluene	43 ± 3.0
Total Hydrocarbons	125
1,1-Dichloroethane	22 ± 19
Total Chlorinated Hydrocarbons	267

TABLE A-9 (Concluded)

Emission Rate: Contaminant	Calculated Flux ($ng/cm^2/s$)	Measured Flux* ($ng/cm^2/s$)	Rate (kg/d)
Pond 1,2			
Benzene	+0.0051	-0.29 - +0.06	0.095
Toluene	+0.062	-0.038 - +0.015	1.2
Total Hydrocarbons	+0.14	-1.0 - +1.1	2.6
1,1-Dichloroethane	+0.48	-0.022 - +0.04	9.0
Total Chlorinated Hydrocarbons	+2.7	-0.33 - +0.15	50.0
Pond 6			
Benzene	+0.047	0.095	0.38**
Toluene	+0.12	0.014	0.48
Total Hydrocarbons	+0.37	1.3	5.2**
1,1-Dichloroethane	+0.058	0.028	0.11**
Total Chlorinated Hydrocarbons	+0.064	0.28	1.1**

*Negative flux values indicate migration of the contaminant out of the air and into the pond.

**Based on measured rates. All others based on calculated rates.

TABLE A-10

CONTAMINATED SOIL STUDY 1

Source: Caravanos, Jack and Thomas T. Shen, "The Effect of Wind Speed on the Emission Rates of Volatile Chemicals from Open Hazardous Waste Dump Sites," Proceedings of the Fifth National Conference on Management of Uncontrolled Hazardous Waste Sites, Held on November 7-9, 1984 in Washington, DC, Hazardous Materials Control Research Institute, Silver Spring, MD, 1984, pp. 68-71.

Source Type: Contaminated soil

Estimation Approach: Laboratory experiment employing saturated soil in steel evaporation pans

Assumptions:

	Clay	Sand	Topsoil
Soil porosity (%)	48	32	51
Soil density (g/ml)	1.34	1.59	0.96

Emission Estimates:

Contaminant	Wind Speed (mph)	Emission Rate (g/min) Clay	Sand	Topsoil
Benzene	0.5	0.9	0.9	0.7
	2.5	2.2	2.2	2.3
	5.0	4.5	3.7	4.6
Carbon Tetrachloride	0.5	1.5	1.7	1.4
	2.5	4.2	4.0	4.8
	5.0	9.5	7.3	11.1
Trichloro-ethylene	0.5	0.9	0.8	0.8
	2.5	2.7	2.6	3.1
	5.0	6.0	5.3	7.9