Methods For Addressing Public Health Concerns At Municipal Solid Waste Landfills

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Abstract: Municipal solid waste (MSW) landfills are the dominant waste disposal method in the U.S., receiving roughly 56 percent of the MSW generated in the country. Although regulatory programs have been implemented to minimize potential community health risks from MSW landfills, these facilities are often the subject of public health-related complaints. This paper describes available methods for addressing public health concerns at MSW landfills, including epidemiological studies, risk assessments, environmental monitoring, biomonitoring, and public health assessments. Advantages and disadvantages of the methods are discussed, including scientific reliability, and their ability to address landfill-specific health concerns. Case studies and literature results of epidemiological analyses, risk assessments and public health assessments conducted at MSW landfills are also presented.

Keywords: landfill; solid waste; risk assessment; epidemiology; landfill gas; biomonitoring

Introduction

Public health concerns occur often among communities located near municipal solid waste (MSW) landfills, even though currently permitted landfills are broadly regulated and routinely inspected by public health and environmental agencies. The types of health effects mentioned by communities include cancer risks, respiratory illnesses, and a variety of non-cancer effects. Releases to air and impacts on air quality tend to be the most common concern at modern landfills, even those equipped with landfill gas (LFG) treatment systems.

This paper describes different types of studies that can be conducted to address community concerns about potential landfill air impacts. The focus of this paper is on currently-permitted MSW landfills that accept non-hazardous solid waste. These types of landfills differ substantially, with respect to waste disposal history, engineering design, and daily operations, from hazardous waste sites that were once landfills (e.g., Superfund sites), old unregulated waste disposal sites (e.g., historically referred to as “dumps), and even currently permitted hazardous waste landfills.

Epidemiological Studies

Epidemiological studies evaluate the distribution or pattern of disease and its association with possible sources of exposure to an agent that could potentially cause the disease. With respect to landfills, the goal of an epidemiological study is to help determine whether there is a difference in disease between people with different exposures related to the site or sites under study and a control population. Epidemiological studies cannot determine whether any specific facility is the cause of reported results. These studies are most useful for determining whether further research is needed and, if so, what type of follow-up studies would be most informative.

Epidemiological Study Methodology

Epidemiological studies related to landfills can be generally divided into two groups, single site studies and multi-site studies (Redfearn and Roberts 2002, Dolk 2002). Single-site studies often have very limited statistical power due to low population densities, and thus small sample size, around many landfills. While multi-site studies benefit from larger sample sizes, they are often limited due to a lack of detailed site-specific information such as waste disposal history, environmental exposures, and other local pollution sources. Multi-site studies also tend to include mixtures of different types of sites, such as hazardous waste sites or old landfill facilities that were largely unregulated, which makes their conclusions inapplicable to currently permitted MSW landfills. Study methods used in both single-site and multi-site studies include geographical, case-control, and cohort studies. Most epidemiological investigations related to landfills have been geographical studies which compare disease rates (e.g., incidence, mortality) among people living near sites compared to the general population or people not living near landfill sites. The reliability of epidemiological studies depends largely on the accuracy of two key inputs, an estimate or measurement of disease, and an estimate or measurement of exposure, and also the possible effect of confounding factors.

Disease data in epidemiological studies can be compiled from registries that track reported medical information. By relying on actual health data, epidemiological studies can be more credible to a concerned community than risk assessments, which focus on the more abstract probability of disease. Disease registries are commonly maintained by state or national agencies for cancer incidence and mortality, and for some types of non-cancer health conditions, such as asthma and adverse birth outcomes. Uncertainties in health registries can, however, limit the reliability of epidemiological study results (Irvine and Burns 2001).

Disease information may also be obtained from personal health surveys. Health surveys are more time consuming and expensive to conduct than evaluations which rely on disease registries, and recall and reporting bias can significantly limit their accuracy. Redfearn and Roberts (2002) note that increased risks found in a number of landfill studies that relied on self-reported health effects may have resulted from recall and reporting bias rather than effects from chemical releases. People who are concerned about a landfill, or perceive that exposure or health effects are occurring, will be more likely to respond positively to survey questions, particularly questions that deal with common and often subjective health effects, such as headache or nausea (Dolk 2002). The potential for bias can be minimized through rigorous survey design, interviewer training, validation of collected participant information, and careful analysis of survey results.

Classification of exposure is a critical and challenging part of epidemiological studies related to landfills. Exposure hierarchies can indicate how well exposure data in an epidemiological study reflect actual exposure levels, with increasing uncertainty, reduced accuracy, and more limited interpretation occurring at lower levels of the hierarchy (Chrostowski 1994, Dolk 2002, NRC 1991). At the top of the hierarchy are quantified personal measurements followed next by measured environmental concentrations representative of landfill-specific impacts (rather than prevailing background conditions). These data are, however, generally not available due to high cost, lack of sensitive or validated test methods, invasiveness of human tissue and body fluid sampling and inability to distinguish landfill-specific impacts from prevailing environmental conditions. Lower on the hierarchy are modeled levels of environmental concentrations which can be calculated using air dispersion models, and last, use of geographic surrogates to define exposure levels (e.g., distance from a landfill, census tract, zip code).

Most published epidemiological studies related to landfills have characterized exposure by proxy based on distance from, or geographical areas surrounding, landfills (Dolk 2002, Roberts and Redfearn 2002). These exposure measures do not take into account exposures related to occupation and personal behaviors, site-specific landfill operations, or climatic conditions that affect dispersion of landfill-related releases. Use of distance metrics increases the likelihood of misclassification of exposure, which in turn, limits the ability of epidemiological studies to detect differences in disease status among populations (Harrison 2003). Geographic information systems (GIS) offer promise of enhancing exposure characterization in epidemiological studies although even these methods are limited by uncertainties of low case numbers, confounding, and possible data quality errors (Elliott and Wartenberg 2004, James et al. 2004, Nuckols et al. 2004).

Confounding variables can significantly affect the results of epidemiological studies. A confounding variable is both a risk factor for the disease and associated with the exposure being evaluated. Confounders in landfill-related epidemiological studies include pre-existing health conditions, socioeconomic status, the availability of health care and social services, personal behavior patterns such as smoking, occupational exposures, and the presence of local pollution sources (DEFRA 2004, Dolk 2002). Dolk (2002) notes that investment in better exposure assessment in epidemiological studies may be more important than more detailed evaluation and control of confounders.

Epidemiological studies cannot identify cause and effect relationships. An association between a health endpoint and a measure of exposure does not indicate that the health endpoint was caused by the evaluated exposure. Although this is a well-known characteristic of epidemiological studies, their results are often misinterpreted, especially in the press or by community activists, as proof of an effect. A causal link between a landfill and adverse health effects must be supported by rigorously designed epidemiological studies, consistency among different epidemiological studies regarding the types and significance of health effects, a theoretical basis for the purported health effect with respect to both the biological mechanism and the presence of an exposure pathway exists, and a realistic basis to support the effects such as actual field measurements.

Epidemiological Study Results

Redfearn and Roberts (2002) reviewed the results of 13 single-site epidemiological studies related to seven landfills and four multiple-site landfill studies. They noted that most of the single-site studies focused on large, old landfills operated prior to current regulatory regimes or landfills that received hazardous or liquid chemical wastes. The multi-site studies focused on mixtures of different types of landfills, including old hazardous waste landfills that were not capped or lined. They concluded that the study results were inconsistent with respect to specific types of health effects and that more studies reported no associations than positive associations. They also concluded that the studies do not provide convincing, rigorous evidence for an association between landfills and adverse birth outcomes. More recent studies of congenital anomalies and cancer (Palmer et al. 2005, Dummer et al. 2003, Irvine 2003, Jarup et al. 2002, Morris et al. 2003) have similarly shown that residential proximity to a landfill is not consistently associated with increased risks.

ATSDR (2001) reviewed a number of studies that evaluated adverse health effects among people living near old or mixed types of landfills in Canada, the U.S. and Europe. ATSDR concluded that, although each study found some increases in some health effects, overall the data were inconclusive due to study limitations described by the study researchers (e.g., lack of detailed exposure information and the possible impacts of confounding factors). ATSDR noted that the study authors thought a singe-site study is unlikely to be able to answer whether landfill gases are adversely affecting the health of a community.

A comprehensive review of the health effects of waste management conducted in the U.K. concluded that the association between birth defects and proximity to landfill sites shown in some studies does not demonstrate a causal relationship. The U.K. study noted that the size of the birth defect increase is much smaller than other factors that influence the likelihood of birth defects, and the numerical results cannot be used reliably. The report suggested that further studies be performed to identify non-waste related factors that may influence this association (DEFRA 2004).

Risk Assessment

Health risk assessments are also often used to evaluate community health concerns related to landfills. Health risk assessments for landfills calculate the chance of health problems occurring as a result of exposure to landfill-related releases, but they do not measure actual health effects in the community. Risk assessments generally incorporate health-protective assumptions, or margins of safety, to ensure that the calculated risks will not be underestimated.

Risk Assessment Methodology

Risk assessments methods have been widely published and applied by regulatory and research agencies (USEPA 1989, 1992), however, only a few guidance documents have been prepared specifically for operating or proposed MSW landfills (UKEA 2000, 2004a). These risk assessment methods rely on a several step process that consists of hazard identification, exposure assessment and risk characterization.

Hazard identification is the step in which compounds that may be present at a landfill are identified, research on the potential health problems associated with these compounds is reviewed, and data on how much of the compound it would take to cause potential health effects (called “dose-response assessment”) is compiled. Dose-response information is compiled from regulatory agency and research institution databases or scientific publications. In the U.S., the dose-response criteria include cancer slope factors (to calculate additional lifetime cancer risks) and reference doses or reference concentrations (to evaluate non-cancer health effects). Dose-response criteria are not readily available for some landfill compounds and, in these instances, risk assessments often use health-based benchmark levels to assess risks.

The exposure assessment determines whether, and how much, people might be exposed to compounds present at a landfill. In this step, the potential releases from a landfill, and pathways of transport from the source to areas where people might be exposed, are identified and evaluated. A landfill risk assessment focusing on landfill gas and dust uses a variety of site-specific landfill measurements and mathematical models to calculate potential air concentrations and exposures in a landfill's vicinity. As is the case with epidemiologic studies, risk assessments often are limited by exposure uncertainties. These uncertainties may be reduced by incorporating detailed site-specific data, using refined methods for determining landfill gas emission rates and for dispersion modeling (USEPA 2004, Bogner et al. 1997, Morcet et al. 2003, Pierce and Stege 2001, UKEA 2004b), and calibrating models using site-specific ambient monitoring results (RWDI 1994, 1999).

Risk characterization is the step in which potential risks to the population associated with exposure to the compounds present at the landfill are assessed. This step combines information on exposure and toxicity to calculate the chance that adverse health effects might occur. Types of risks typically evaluated include chronic cancer risks and the chance that chronic or acute non-cancer health effects may occur under specified exposure conditions.

<u>Risk Assessment Results</u>

Redfearn and Roberts (2002) used a risk assessment methodology to examine the theoretical basis that landfill gas releases were sufficient to lead to the health effects often of concern to communities around landfills. They concluded that landfill gas emissions were not high enough to represent a theoretical basis for adverse health effects, especially at the distances evaluated in epidemiological studies. They found that the amount of dilution of emissions in air between a landfill source and off-site receptors would reduce levels below health-based criteria with a substantial margin of safety. They also stressed that systematic measurement of community exposures near landfill sites is needed to improve both risk assessment and epidemiological studies of landfills.

Risk assessments for proposed MSW landfill expansion projects in Canada evaluated potential long-term and short-term health risks through a number of exposure pathways. These assessments evaluated human health risks associated with landfill gas releases from the landfill surface and a flare, and particulate matter released due to landfill activities. Risks were calculated for 17 landfill gas compounds, particulate matter, and 6 combustion gases. The risk results were below regulatory target levels, except for some of the modeled daily particulate matter concentrations which, on occasion, exceeded regulatory guideline levels at maximum receptor locations (Cantox 2004a, 2004b).

Risk assessments for two operating MSW landfills in Pennsylvania evaluated inhalation exposures to several dozen landfill gas compounds and inhalable particulate matter. These assessments evaluated chronic long-term and acute short-term noncancer human health effects and cancer risks for the LFG compounds. PM concentrations were evaluated by comparison with regulatory standards and criteria, along with background local ambient air data. The risk assessment results were below target risk levels and available benchmark concentrations, and it was concluded that landfill gas and dust from the landfills did not pose a health hazard to surrounding communities (CPF 2003, 2005).

Two risk assessments for landfills in California evaluated inhalation exposures to landfill gas emissions from surfaces and control devices. These assessments addressed 43 volatile organic LFG compounds, 6 sulfur-containing compounds, hydrogen chloride and mercury using mathematical models to calculate emissions and air dispersion. The reports concluded that chronic non-cancer and cancer risks were lower than target risk levels. One study included an acute risk evaluation and found that acute exposure levels were below target levels. The studies also evaluated diesel emissions and concluded that no mitigation measures were recommended other than already required by existing and future state and federal regulation (SCS 2001, 2002).

A risk assessment conducted for the Seneca Meadows Landfill in NY involved flux chamber sampling at 32 on-site surface locations, air dispersion modeling, and collection of ambient air samples on site and off site during community-reported odor events. The study evaluated roughly 80 volatile organic and sulfur compounds and found that off-site ambient concentrations attributable to the landfill were below short-term and annual NY guideline levels. The off-site ambient air samples were concluded to be attributable to regional conditions, not the landfill (Emcon 1998).

Environmental Monitoring

Monitoring can help address public concerns by indicating whether a landfill is having a measurable impact on the surrounding environment. ATSDR (2001) recommend that ambient air monitoring data can be compared to available health-based screening values as a first step in evaluating whether landfill gas emissions may pose risks to a surrounding community.

Ambient air monitoring provides direct measurements of chemical compounds in the air. As a result, monitoring data is often more understandable and credible to surrounding communities compared to mathematically modeled concentrations. ATSDR provides a guide for ambient air monitoring at landfills that is useful for determining whether such data will be helpful in addressing landfill-specific impacts (ATSDR 2001). Important factors identified in this guide include selection of chemicals for monitoring, choice of sampling methods, consideration of meteorological data, selection of monitoring locations, identification of sampling schedules, and review of data quality. A good first step in any landfill air sampling program is to develop a monitoring protocol that addresses each of the factors discussed in ATSDR's guide.

A common difficulty in monitoring programs is developing an approach that allows differentiation of landfill-related impacts from background concentrations and concentrations associated with other local or regional pollution sources. Moreover, off-site air concentrations associated with a modern landfill equipped with LFG controls are likely to be below typical detection limits. Ambient air monitoring also generally requires greater cost and time to conduct than modeling, particularly if multiple sampling events and many landfill-related compounds are being addressed.

Public Health Assessments

Public health assessments (PHAs) are conducted by ATSDR, state health departments and owners and operators for a variety of facilities and sites across the U.S. PHAs for operating landfills are typically conducted in response to local community petitions or requests by local officials. ATSDR defines a PHA as a study that examines the relationship between actual exposures to compounds in the environment and subsequent signs of disease and illness and evaluates health effects specifically with regard to site-specific exposure situations (ATSDR 1999). ATSDR states that its PHA approach relies not only on the components of risk assessment but also the principles of biomedical judgment, risk management, and risk communication (De Rosa et al. 1998). At the conclusion of each PHA, ATSDR makes a determination of health hazard using five categories (urgent public health hazard, public health hazard, indeterminate public health hazard, no apparent public health hazard, or no public health hazard), and often provides recommendations for public health protection and additional study. PHAs conducted by ATSDR or state health departments may be more credible to communities than other study methods because they are conducted by an independent third party rather than by the facility owner or the regulatory agency for the site.

ATSDR conducted a PHA at the Fresh Kills Landfill in New York City (ATSDR 2000) and found that contaminants in the groundwater, surface water, sediment, and fish and shellfish near the Fresh Kills Landfill, and chemicals emitted from the Fresh Kills Landfill posed no apparent public health hazard. The agency provided a variety of recommendations including continued communications with local communities, future air monitoring, and monitoring and control of landfill gas emissions. A PHA for the Hartford, Connecticut MSW landfill focused on hydrogen sulfide emissions (ATSDR 1998a). ATSDR concluded that hydrogen sulfide at the Hartford Landfill was not likely to trigger a pre-existing asthmatic condition, or cause any overt toxic reaction. The agency recommended no further sampling for hydrogen sulfide but continued community education regarding health issues. The PHA for Mercer County Landfill in Pennsylvania examined epidemiological data on cancer and birth defects, and concluded there were no excess health problems in the area that could be related to the site (ATSDR 1998b). A study for the Four Hills Landfill in New Hampshire concluded that there was no apparent public health hazard due to some volatile organic compounds in landfill gas, that air data for hydrogen sulfide was inadequate for reaching conclusions, and that adverse pregnancy outcomes could not be evaluated due to inconsistent scientific information on this topic (ATSDR 2003a). ATSDR reached different conclusions in two PHAs for construction and demolition debris (C&D) landfills, which differ substantially from MSW landfills in the types of wastes received. ATSDR concluded that one of the C&D landfills presented no apparent health hazard while the other presented an urgent public health hazard (ATSDR 2003b, 1998c).

Biomonitoring

One approach that has been mentioned for addressing landfill-related public health concerns is biomonitoring which involves the analysis of human tissues or excreta for evidence of exposure to chemical substances. Biomonitoring is appealing because it can provide a measurement of internal exposure although it may not indicate whether there may be a health effect. An emerging area in biomonitoring involves use of biomarkers that can indicate environmental exposure by measuring cellular or biochemical variations in biological samples that may correlate to a clinical effect (Chrostowski 1994, Jarup et al. 2000, Kamrin 2004).

The use of biomonitoring for site-specific assessments is relatively new and has not been widely used. Although biomonitoring data have been collected from the general population (CDC 2005) and at some hazardous waste sites, site-specific investigations related to current MSW landfills do not appear to have been conducted. There are a number of important reasons why biomonitoring is rarely applied in a site-specific setting. In order for biomonitoring or a biomarker to be useful in a site-specific study, it must be associated with an exposure relevant to the specific site and also linked to a health effect. Meeting these criteria is challenging, especially since biomarkers specific to MSW landfills and which are not also confounded by other factors are difficult to identify. Even if biomonitoring indicates that an exposure has occurred, the results are not likely to be both traceable to a specific site and/or clearly linked to a health effect under study. Other limitations of biomonitoring include the lack of validated and standardized measurement methods for some biomarkers, lack of population baseline levels for many chemicals and target measurements, and the time, cost and complications associated with collecting biological samples from people (Jarup et al. 2000, Kamrin 2004).

Tarkowski et al. (2000) note that monitoring for biomarkers of exposure for hazardous waste sites are only available for a limited number of substances and should only be used where there are clear indications of exposures. They recommend that biomarkers only be used after validating their use in a risk assessment process that establishes a relationship between a site, exposure and health outcome. Jarup et al. (2000), in summarizing biological monitoring possibilities for hazardous waste sites, explains that biomarkers must be validated before application in the risk assessment process to establish the relationship between the biomarker, exposure and the health outcome.

Conclusions

There is no single strategy that can be forwarded to address all public health concerns related to a landfill. The selection of study approach for a landfill, and its level of refinement, depends on a number of factors, including site-specific landfill conditions, the public health concerns raised by a local community, and the likelihood that a study method will be able to scientifically address the community's concern. In some cases, a screening-level public health assessment following the ATSDR methodology may be adequate to address public health questions raised by a community. In other cases, a detailed risk assessment focusing on specific aspects of landfill operation may be required. A review of epidemiological information, or collection of environmental sampling information, may also be helpful. In general, a weight-of-evidence approach based on all available information may be most appropriate for reaching conclusions regarding potential public health impacts related to a landfill.

References

Agency for Toxic Substances and Disease Registry (ATSDR) and Connecticut Department of Public Health. 1998a. Health Consultation: Hartford Landfill, Hartford, CT.

Agency for Toxic Substances and Disease Registry (ATSDR) and Pennsylvania Department of Health. 1998b. Health Consultation for the Tri County Landfill, Mercer County, PA.

Agency for Toxic Substances and Disease Registry (ATSDR). 1998c. Petitioned Health Consultation: Dry Bridge Road Landfill, RI.

Agency for Toxic Substances and Disease Registry (ATSDR). 1999. A Citizen's Guide to Risk Assessment and Public Health Assessments at Contaminated Sites. March 1999.

Agency for Toxic Substances and Disease Registry (ATSDR). 2000. Petitioned Public Health Assessment - Conclusions and Recommendations, Fresh Kills Landfill, Staten Island, Richmond County, NY.

Agency for Toxic Substances and Disease Registry (ATSDR). 2001. Landfill Gas Primer: An Overview for Environmental Health Professionals.

Agency for Toxic Substances and Disease Registry (ATSDR) and New Hampshire Department of Health and Human Services. 2003a. Health Consultation: Four Hills Landfill, Nashua, NH.

Agency for Toxic Substances and Disease Registry (ATSDR). 2003b. ATSDR Exposure Investigation Finds Urgent Public Health Hazard from Hydrogen Sulfide in Warren Township, OH.

Bogner, J., Spokas, K., Niemann, M., Niemann, L. and Baker, J. 1997. Emissions of non-methane organic compounds at an Illinois (USA) landfill site: Preliminary field measurements. Proceedings Sardinia 97, Sixth International Landfill Symposium, Cagliari, Italy.

Cantox. 2004a. Human Health Risk Assessment of the Proposed Richmond Landfill Expansion. Mississauga, Ontario.

Cantox. 2004b. Human Health Risk Assessment of the Proposed Warwick Landfill Expansion. Environmental, Mississauga, Ontario.

Centers for Disease Control (CDC). 2005. Third National Report on Human Exposure to Environmental Chemicals. Atlanta, GA.

Chrostowski, P.C. 1994. Exposure assessment principles. In Patrick, D.E. (ed.). Handbook of Toxic Air Pollution. New York: Van Nostrand Reinhold Co., Inc.

CPF Associates, Inc. and EarthRes Group, Inc. 2003. Human Health Risk Assessment for the Grand Central Sanitary Landfill, Plainfield Township, Northampton County, PA.

CPF Associates Inc. 2005. Human Health Risk Assessment for Alliance Sanitary Landfill, Inc., PA.

Department for Environment, Food and Rural Affairs (DEFRA), Enviros and the University of Birmingham. 2004. Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes. May 2004. www.defra.gov.uk/environment/waste.

De Rosa, C.T., Pohl, H.R., Williams, M., Ademoyero, A.A., Chou, C-H., and Jones, D.E. 1998. Public Health Implications of Environmental Exposures. Environ. Health Perspect. 106:369-378.

Dolk, H. 2002. Methodological issues related to epidemiological assessment of health risks of waste management. In Environmental and Health Impact of Solid Waste Management Activities. Hester, R.E. and Harrison, R.M., Eds. Royal Society of Chemistry: Cambridge, UK.

Dummer, T.J., Dickinson, H.O. and Parker, L. 2003. Adverse pregnancy outcomes near landfill sites in Cumbria, northwest England, 1950-1993. Arch. Environ. Health 58(11):692-698.

Elliott, P. and Wartenberg, D. 2004. Spatial epidemiology: Current approaches and future challenges. Environ. Health Perspect. 112:998-1006.

Emcon. 1998. Landfill Gas Sampling / Risk Evaluation and Ambient Sampling Program. Seneca Meadows Landfill, Seneca Falls, NY. Grand Island, NY. June.

Harrison, R.M. 2003. Hazardous waste landfill sites and congenital anomalies: Where do we go from here? Occup. Environ. Med. 60(2):79080.

Irvine, H. and Burns, H. 2001. Risk of adverse birth outcomes near landfill sites. BMJ 323:1365.

Irvine, H. 2003. Landfill sites: Is the risk of adverse birth outcomes really different in Scotland? Scottish Med. J. 48:102-104.

James, L., Matthews, I. and Nix, B. 2004. Spatial contouring of risk: A tool for environmental epidemiology. Epi. 15(3):287-292.

Jarup, L., Laurent, C. and Tarkowski, S. 2000. Biological monitoring in studies of waste sites. Annex 5. In World Health Organization. 2000. Methods of Assessing Risk to Health From Exposure to Hazards Released From Waste Landfill Sites. EUR/00/5026461.

Jarup, L., Briggs, D., de Hoogh, C., Morris, S., Hurt, C., Lewin, A., Maitland, I., Richardson, S., Wakefield, J. and Elliott, P. 2002. Cancer risks in populations living near landfill sites in Great Britain. Br. J. of Cancer 86:1732-1736.

Kamrin, M.A. 2004. Biomonitoring Basics. Environmental Health Research Foundation. Manassas, VA. June.

Morcet, M., Aran, C., Bogner, J., Chanton, J., Spokas, K. and Hebe, I. 2003. Methane mass balance: A review of field results from three French landfill case studies. Proceedings of the Sardinia03 Ninth International Waste Management and Landfill Symposium. Sardinia, Italy.

Morris, S.E., Thomson, O.W., Jarup, L., de Hoogh, C., Briggs, D.J. and Elliott, P. 2003. No excess risk of adverse birth outcomes in populations living near special waste landfill sites in Scotland. Scottish Med. J. 48:105-107.

National Research Council (NRC). 1991. Environmental Epidemiology: Public Health and Hazardous Wastes. National Academy Press: Washington, DC.

Nuckols, J.R., Ward, M.H. and Jarup, L. 2004. Using geographic information systems for exposure assessment in environmental epidemiology studies. Environ. Health Perspect. 112:1007-1015.

Palmer, S.R., Dunstan, F.D.J., Fielder, H., Fone, D.L., Higgs, G. and Senior, M.L. 2005. Risk of congenital anomalies after the opening of landfill sites. Environ. Health Perspect. 113:1362-1365.

Pierce, J.L. and Stege, G.A. 2001. Characterization of landfill gas surface emissions at landfills with soil covers. SCS Engineers, Long Beach, CA. Waste Tech 2001, National Solid Waste Management Association, February 11-14, San Diego, CA.

Redfearn, A. and Roberts, D. 2002. Health effects and landfill sites. In Environmental and Health Impact of Solid Waste Management Activities. Hester, R.E. and Harrison, R.M., Eds. Royal Society of Chemistry: Cambridge, UK.

Rowan Williams Davies & Irwin Inc. (RWDI). 1994. Final Report on Calibration of Dispersion Modelling for Vinyl Chloride, Eastview Landfill Site, Guelph, Ontario.

Rowan Williams Davies & Irwin Inc. (RWDI). 1999. Vinyl Chloride Model Calibration and Impact Assessment at the BFI Ridge Landfill Site.

SCS Engineers. 2001. Human Health Risk Assessment and Air Quality Impact Analysis. Proposed Landfill Expansion, Fink Road Landfill. Stanislaus County, CA.

SCS Engineers. 2002. Air Quality Impact Analysis and Air Toxics Risk Assessment. Landfill Operational Emissions: Salinas Valley Solid Waste Authority Regional Landfill Project. Monterey County, CA.

Tarkowski, S., Jarup, L. and Laurent, C. 2000. Biological monitoring in waste landfill studies. Int. J. Occup. Med. & Environ. Health 13(4):345-360.

UK Environment Agency (UKEA). 2000. A Practical Guide to Environmental Risk Assessment for Waste Management Facilities. Guidance Note 25, Version 2. Prepared by Pollard, S., Purchase, D. and Herbert, S. November 8, 2000.

U.K. Environment Agency (UKEA). 2004a. Environment Agency Guidance on Assessment of Risks from Landfill Sites. External Consultation. May 2004.

U.K. Environment Agency (UKEA). 2004b. Guidance on Monitoring Landfill Gas Surface Emissions. LFTGN 07 Landfill Directive.

U.S. Environmental Protection Agency (USEPA). 1989. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual (Part A). EPA/540/1-89/002.

U.S. Environmental Protection Agency (USEPA). 1992. Guidelines for Exposure Assessment. Fed. Reg. 57:22888-22938.

USEPA. 2004. Measurement of Fugitive Emissions at a Region I Landfill. EPA-600/R-04-001.