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Cleanup of Former MGP Sites: Community Exposure, Responsible Party Liability, and Optical Remote Sensing

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ABSTRACT

Roughly 3,000 abandoned manufactured gas plant (MGP) sites currently exist in the United States. While the risk to the surrounding population from exposure to gaseous contaminants generated during a properly engineered site cleanup is typically negligible, community perception can often be an entirely different matter. In a highly publicized Illinois court case, a jury awarded more than $3 million to four families for effects suffered from exposure to air emissions generated during the cleanup of a nearby former MGP site, despite the fact that a direct link with the site was never established.

This paper discusses how optical remote sensing (ORS) can be used to conclusively demonstrate compliance with pre-established, health-based action levels for gaseous contaminants associated with the cleanup of former MGP sites. Because contaminant information is collected along the entire downwind site boundary, the plume cannot migrate offsite undetected.

Advantages of the ORS-based cross-sector-averaging technique over traditional point-source monitoring approaches are discussed. These include minimization of liability to parties responsible for the site cleanups, data quality, documentation of action-level compliance, and public perception.

INTRODUCTION

From the mid-1880s through the early 1950s, manufactured gas plants (MGPs) were widely used for generating gas to meet heating and lighting needs in cities and towns throughout the United States. Methane and hydrogen were produced from the heating of coal and other ingredients in large brick ovens, and were stored in on-site tanks. With the discovery of large deposits of natural gas in the 1950s and the advent of natural gas pipelines, however, MGPs were rapidly abandoned. Today, the coal tars, light oils, and inorganic wastes typically found in the soil and groundwater around these plants are an environmental and public health concern. Some estimates place the number of MGP sites still awaiting cleanup in this country at 3,000 or more.

A properly engineered MGP site cleanup proceeds in a systematic fashion which minimizes the amount of contaminated soil exposed to the air at any given time. This, together with the fact that the duration of soil-disturbance activities rarely exceeds several weeks, ensures that the associated health risk from exposure to harmful gaseous contaminants to the surrounding population is negligible in most cases. However, the *perception* of risk by affected communities during such cleanups can be great, and this can often translate into a substantial liability to the responsible party.

Such liability is well illustrated in the highly publicized 1998 Taylorville, Illinois case. A jury ordered Central Illinois Public Service Company (now AmerenCIPS) to pay $3.2 million to the families of four children who contracted neuroblastoma, a rare childhood cancer, allegedly from exposure to airborne emissions during the cleanup of a nearby MGP site. In February 2002, the Illinois Supreme Court affirmed the earlier Appellate Court ruling pursuant to an unsuccessful appeal by AmerenCIPS. This case has particular significance in that the jury awards were upheld in spite of the fact that a direct link between the cancer cases and air emissions from this site was never established. From a liability perspective, the lesson of course is that even though the health risks from exposure to gaseous contaminants for a given MGP site cleanup may indeed be negligible, it becomes necessary to conclusively *demonstrate* such insignificance.

Optical remote sensing (ORS) is ideally suited to demonstrate offsite, action-level compliance associated with gaseous contaminants which emanate from the cleanup of former MGP sites. Several ORS technologies exist, but open-path Fourier-transform infrared (FTIR) and ultraviolet (UV) spectroscopy are those most often employed owing to their ability to speciate complex mixtures of hydrocarbons. Concentration information for a wide range of contaminants is continuously collected, in real time, along an entire downwind site boundary. In this manner, a contaminant plume generated from soil-disturbance activities cannot leave the site property undetected, and it becomes much easier to conclusively demonstrate action-level compliance.

Presented below are relevant background information, the cross-sector-averaging technique as a preferred method for demonstrating action-level compliance, advantages of the technique over other approaches employing point-monitoring, and conclusions. Discussion on the analytical aspects of open-path FTIR and UV spectroscopy is not included, as many excellent papers exist on this subject. The interested reader is referred to a particularly comprehensive ORS technology review by Grant and Kagann. [1]

BACKGROUND

Typically, the assessment of offsite air exposure to the downwind community during MGP site cleanups is based on the collection of time-averaged measurement data (usually 24 hours) from air monitors or samplers positioned at the corners of the site perimeter. If the measured concentrations fall below pre-established, health-based action levels, the assumption is that the downwind community is protected and the cleanup proceeds.

Despite its popularity, this approach produces data of uncertain quality at best and is, in general, poorly suited for conclusively demonstrating action-level compliance during such cleanups. This is because the array of downwind monitors is not nearly dense enough to satisfactorily accommodate the combination of continual fluctuations in wind direction and variations in emission rates which occur over space and time. Spatial variations in emissions occur because the excavation location is always changing, and temporal variations occur due to the existence of "hot spots" owing to contaminant heterogeneity. Because of these inherent limitations in representativeness, such data cannot meet the stringent criteria of technical defensibility and legal admissibility required to conclusively demonstrate non-exposure in litigatory proceedings.

ORS offers a straightforward and highly cost-effective alternative to the above point-monitoring approach, and affords the opportunity for conclusive demonstration of action-level compliance. The issue of spatial representativeness is solved by the generation of path-integrated data, in which contaminants of concern are analyzed along the entire downwind, crossplume beam path (up to 100 meters or more in length). The issue of temporal representativeness is solved by the continual collection of appropriately time-averaged data, typically between 5 and 15 minutes.

ORS has been used to support remediation decisions for Superfund sites in a variety of ways. Each of these generally involves conservative estimation of a site-disturbance emission rate which is used as a source term to an appropriate air dispersion model. Downwind community exposure is assessed based on the predicted emissions for the receptor network of concern.

Discussed below is the concept of path-integrated concentration data, followed by overviews of three ORS-based, emission-estimation techniques employed in Superfund site remediations.

Path-Integrated Data

Gaseous concentrations are generally reported in units of mass of contaminant per volume of gas, such as micrograms per cubic meter (ug/m^3), or volume of contaminant per volume of gas, such as parts per billion (ppbv) or parts per million (ppmv). Path-integrated concentrations, however, are usually reported in units of parts-per-million-meters (ppm-m). It is often desirable to convert path-integrated concentrations (ppm-m) to units of milligrams per cubic meter times meter (mg/m^3 x m), or mg/m^2, in order to avoid consideration of the compound's molecular weight.

For an open-path FTIR or UV spectrometer, the total contaminant burden is measured within the approximate cylinder defined by the finite cross-sections of the light beam at each end and the length of the beam itself. This burden is then normalized to a pathlength of 1 meter. If, for example, a path-integrated concentration of 30 ppm-m is reported, no information concerning the contaminant distribution within the beam can be directly inferred, and the instrument response would be identical whether there was a uniform concentration of 30 ppmv over a distance of 1 meter, 3 ppmv over a distance of 10 meters, or 30 ppbv over a distance of 1 kilometer.

It is immediately evident that the integrated concentration reported is directly proportional to the total pathlength for a given uniform contaminant concentration. It also follows that for a site from which contaminants are emanating in a plume of narrow width (e.g., 10 meters), the same path-integrated concentration will be reported regardless of pathlength, as long as the narrow plume remains contained within the observing pathlength and there is no upwind (or background) contaminant contribution.

Point-Source Technique

The point-source emissions estimation technique,[2] based on classical Gaussian dispersion theory, follows from the crosswind-integrated form of Turner's general equation for ground-level concentration for a continuously emitting point source.

Based on the approximation that the site-disturbance activity may be represented as a point source (reasonable for most MGP site cleanups), this relationship defines the source emission rate in terms of the crosswind-integrated concentration for the contaminant(s) of concern, the wind speed, and the vertical dispersion coefficient (which can easily be approximated). This emission rate then forms the source term to an appropriate dispersion model for assessing downwind community exposure.

Tracer-Ratio Technique

An even simpler emissions-estimation technique, which requires no assumptions about the nature of plume dispersion, is the tracer-ratio technique.[3] This approach involves the release of a tracer gas at a known, controlled flow rate from a location at or adjacent to the upwind edge of the site disturbance (e.g., excavation).

As long as the tracer and the source plume are fully contained by the downwind open-path beam, the emission rate is derived based on the following ratio: the downwind, path-integrated concentration of the contaminant of concern (measured) is to its emission rate (unknown) as the downwind, path-integrated concentration of the tracer (measured) is to *its* emission rate (measured). This ratio is simply solved for the unknown term, the contaminant emission rate.

Area-Source Technique

A more sophisticated emissions-estimation technique, applicable for small area sources, is referred to as the area-source technique.[4] This technique consists of the following step-wise approach: (a) identify source attribution with a ground-level, crossplume, path-integrated measurement downwind of the source; (b) use an appropriate area-source dispersion model (e.g., ISCST or AERMOD) to predict concentrations along the ORS measurement path based on relative (unity-based) emission rates and the actual meteorology and source configuration; (c) use an appropriate numerical techique to integrate the function defined by the point-concentration values predicted along the crossplume measurement path; and (d) scale the modeling results using the measured path-integrated source attribution to estimate the area-source emission rate.

Although each of these modeling-based approaches can certainly provide technically defensible and legally admissible data, they are not preferred for the demonstration of action-level compliance during MGP site cleanups. The main drawback is one of perception, as offsite impacts are based on air dispersion modeling instead of directly measured.

CROSS-SECTOR-AVERAGING TECHNIQUE FOR EXPOSURE ASSESSMENT

The cross-sector-averaging technique, as conceived of and employed by USEPA Region 7, [5] is the preferred means of assessing offsite exposure during MGP site cleanups. This technique involves: (a) collecting path-integrated, contaminant concentration data along the downwind site boundary; and (b) dividing each path-integrated concentration (10- or 15-minute average) by an appropriately conservative representation of plume width (discussed below) to yield a maximum point concentration which can be *directly* compared to an offsite action level.

Application of the cross-sector-averaging technique yields a continual assessment of maximum contaminant exposure along the downwind site boundary without relying on air dispersion modeling. For former MGP sites, acute exposure is almost never a consideration; accordingly, it is assumed that action levels are reflective of long-term (chronic) exposure and, as is typically the case, are defined in terms of hourly concentrations which cannot be exceeded.

The term, "cross-sector-averaging," implies that path-averaged data is considered along an appropriate cross-section of the cone-shaped contaminant sector created by the lateral (crosswind) spread of the plume as it emanates from a small source and is advected along the mean wind direction. As indicated above, the sector cross-section along which the maximum point concentration is determined typically coincides with a segment of the downwind property line.

Presented below are relevant meteorological considerations, together with the methodology for this preferred exposure assessment technique.

Meteorological Considerations

In general, the sector cross-section dimension may be determined based on two properties of the plume as it crosses the downwind site boundary: its lateral spread and its lateral meander. Each of these is discussed below in the context of Gaussian dispersion theory.

Lateral Plume Spread

The Gaussian or normal distribution, familiar in statistics, is used to describe the crosswind (and vertical) distribution of contaminants emanating from a continuously emitting point source. The plume spread under this bell-shaped curve is a function of both the downwind distance from the source and the atmospheric stability. The curve flattens and broadens with increasing downwind distance and decreasing atmospheric stability.

Atmospheric stability is broadly categorized into six discrete classes, in which Stability Class A is the most unstable (i.e., maximum plume dispersion for a given plume travel time), and Stability Class F is the most stable (i.e., minimum plume dispersion).

Table 1 presents the key to atmospheric stability classes based on a method developed by Pasquill.[6] Because buoyancy-induced turbulence dominates during the day and mechanically induced turbulence during the night, this method considers wind speed and solar radiation (insolation) for daytime, and wind speed and cloud cover for nighttime.

Table 1. Key to Pasquill Stability Categories

Surface (10m) Wind Speed (m/s)	Insolation (Daytime)			Cloud Cover (Nighttime)	
	Strong	Moderate	Slight	Thinly Overcast or ≥ 4/8 low cloud	≤ 3/8 cloud
< 2	A	A - B	B	--	--
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	D	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

During the daytime, it can be seen that atmospheric stability is greatest (less plume dispersion) with strong winds and low insolation, conditions under which buoyant turbulence is minimized. During the nighttime, stability is greatest with very light winds and clear skies, conditions under which mechanical turbulence is minimized.

There are other, more sophisticated methods for determining atmospheric stability which involve consideration of such measured parameters as solar radiation (watts per square meter), standard deviations of the horizontal or vertical wind directions, and nighttime vertical temperature gradient. However, discussion of these methods is beyond the scope of this paper.

Table 2 identifies the plume width of a contaminant emanating from a point source for various combinations of downwind distance and atmospheric stability class.[7]

Plume width may be defined as the lateral distance from the plume centerline (ground-level) beyond which the contaminant concentration drops to 2 standard deviations (about 5.0 percent) of the centerline concentration. For example, under Stability Class C at a location 15 meters downwind of the source, the plume width is shown to be 8.6 meters. This means that the contaminant concentration drops to only 5 percent of its maximum value once one moves in a lateral direction, away from the plume centerline, a distance of 4.3 meters.

Table 2. Plume Width for Various Combinations of Downwind Distance and Atmospheric Stability Class

Downwind Distance From Point Source (m)	Contaminant Plume Width for Given Stability Class (m)					
	A	B	C	D	E	F
10	13.4	9.3	5.9	3.8	2.9	1.9
15	19.4	13.6	8.6	5.6	4.2	2.8
20	25.2	17.7	11.2	7.3	5.5	3.6
25	30.8	21.7	13.8	9.0	6.7	4.5
30	36.3	25.6	16.3	10.7	8.0	5.3
35	41.7	29.5	18.8	12.4	9.2	6.1
40	47.1	33.4	21.3	14.0	10.5	6.9

Lateral Plume Meander

Plume meander may be defined as the lateral distance the plume centerline moves for a constant mean wind direction. Typically expressed as the standard deviation of the (horizontal) wind direction (also referred to as sigma theta or σ_θ), plume meander is a function of the atmospheric stability. The more unstable the atmosphere, the greater the plume meander.

Table 3 presents the relationship between sigma theta (measured at a height of 3 meters) and atmospheric stability class. [8] It is noted that this relationship is employed in the method to determine atmospheric stability based on sigma theta (mentioned earlier).

Table 3. Relationship Between Sigma Theta and Atmospheric Stability Class

Standard Deviation of Horizontal Wind Direction @ 3m (°)	Corresponding Stability Class
$24.2 \le \sigma_\theta$	A
$21.0 \le \sigma_\theta < 24.2$	B
$15.3 \le \sigma_\theta < 21.0$	C
$9.9 \le \sigma_\theta < 15.3$	D
$6.0 \le \sigma_\theta < 9.9$	E
$\sigma_\theta < 6.0$	F

Methodology

The cross-sector-averaging technique for directly assessing offsite exposure consists of simply dividing the path-integrated contaminant concentration (as measured along the downwind site boundary) by an appropriate plume width, taking into account the observed atmospheric stability class and the averaging times over which the action levels of concern are based. The key to employment of this method is the determination of the appropriate plume width for each 10- or 15-minute-averaged ORS measurement.

Table 4 presents the sector cross-section dimension as a function of downwind distance. For a given distance, this dimension is simply the sum of the plume width (from Table 2) and the plume meander based on the smallest (most conservative) sigma-theta value corresponding to a Stability Class of D (9.9º from Table 3). The most stable sigma-theta value for Stability Class D is selected as a conservative condition, based on the assumption that site-disturbance activities will not extend into the night.

Table 4. Sector Cross-Section Dimension as a Function of Downwind Distance

Downwind Distance (m)	Plume Width (m)	Plume Meander Based on σ_θ = 9.9º (m)	Cross-Section Dimension (m)
10	3.8	3.5	7.3
15	5.6	5.2	10.8
20	7.3	7.0	14.3
25	9.0	8.7	17.7
30	10.7	10.5	21.2
35	12.4	12.2	24.6
40	14.0	14.0	28.0

Plume meander is calculated by multiplying the tangent of 9.9º (0.1745) by 2 times the downwind distance. For example, at a downwind distance of 10 meters, the plume meander is 0.1745 times 20 meters, or 3.5 meters.

Application of the cross-sector-averaging methodology is illustrated in the following example. Suppose a 4-week MGP site cleanup involves a property of 80 by 80 meters aligned along the cardinal points, and excavation activities are limited to a small area (3 by 3 meters) centered in the north-south dimension, 25 meters west of the eastern site boundary. The principal contaminant of concern is benzene to which, based on the proximity of the nearest residence, a 1-hour-averaged, site-perimeter action level of 2 mg/m^3 (626 ppb) has been conservatively assigned.

The wind is from the west, as determined by means of a calibrated, portable meteorological system sited and operated (3 meter height) in accordance with applicable USEPA guidance.[9]

An FTIR spectrometer is positioned along the eastern (downwind) site boundary. The beam pathlength is a total of 120 meters, extending 20 meters either side of the two site boundary corners. Earlier dispersion modeling has shown that the plume will easily be contained within the beam under the combinations of wind direction, source-beam configuration, and atmospheric stability expected to be encountered during the day.

The measured path-integrated benzene concentration is 8.40 ppm-m (26.80 mg/m^2). Based on a sector cross-section dimension of 17.7 meters from Table 4, the path-averaged concentration across the plume is 26.80 mg/m^2 divided by 17.7 meters, or 1.5 mg/m^3, below the pre-established action level of 2 mg/m^3.

ADDITIONAL ADVANTAGES

As discussed above, the cross-sector-averaging technique can be used to conclusively demonstrate action-level compliance during MGP site cleanups. Described below are additional advantages over point monitors which might also be realized. These include data quality, documentation, and community relations.

Data Quality

Employment of the cross-sector-averaging technique generates data which is unequalled in terms of its representativeness (both spatial and temporal), comparability, and completeness when compared to methods based on point monitoring. Sequential 10- or 15-minute-averaged concentrations are generated and continually compared to pre-established, health-based action levels to provide a continuous assessment of maximum offsite exposure.

A very high quality of generated data is assured, as the spectrometer (FTIR or UV) is intrinsically calibrated; accordingly, precision and accuracy assessments need be made on a daily basis only.

Sample collection error is eliminated, as there is no “sample” per se; the media is unaffected by the ORS measurement method. Toxic Organic Compendium Method TO-16 (Method TO-16) [10] provides the requisite quality control procedures to ensure the integrity of the data for open-path FTIR spectrometers.

Library spectra exist for several hundred compounds, and new ones can be created within a few days for virtually any gaseous compound which exhibits IR or UV absorption. Today, more than 40 compounds can be monitored simultaneously, with quantitation available within seconds of data collection.

Path-averaged minimum detection limits (MDLs) are generally in the single-digit-ppb range based on a pathlength of 100 meters. This is usually more than sufficient for assessment of action-level compliance for acute exposure.

Documentation

Assessment of action-level compliance along the downwind site boundary can be conclusively documented on a continuous basis, encompassing all aspects of the site cleanup. This is particularly important with respect to the minimization of responsible party liability.

An infinite "sample holding" time exists, as analysis information is stored as an electronic document. This means that the data can be reexamined at some later date for evidentiary reasons, or even reanalyzed should an additional target contaminant be later identified.

Community Relations

It has been our experience that the "high-tech" nature of open-path FTIR and UV spectroscopy invariably leads to community appeal and positive public perception. Total fenceline coverage (the "eye which never sleeps") ensures that any offsite air toxics migration will not go undetected, thereby allaying public fear. Such community appeal, in turn, benefits regulatory agencies, as there is less opposition to the selected cleanup remedy.

CONCLUSIONS

Compliance with pre-established, health-based action levels associated with gaseous contaminants released during MGP site cleanups can be conclusively demonstrated using ORS. The cross-sector-averaging technique represents a particularly straightforward approach for meeting this objective.

Because of the type and quality of data generated, this technique offers considerable appeal to parties responsible for such cleanups. In contrast to point-monitoring approaches typically employed, this technique can greatly minimize the liability associated with claims alleging exposure and adverse health effects, as the measurement of contaminants along the entire downwind site boundary eliminates the opportunity for the plume to migrate offsite undetected.

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