

Use of Open-Path FTIR Spectroscopy to Address Air Monitoring Needs During Site Remediations

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Although open-path Fourier-transform infrared (FTIR) spectroscopy has been a USEPA Toxic Organic Compendium Method since 1996, it has been underutilized as a means to assess exposure to gaseous contaminants during the remediation of hazardous waste sites. This might be considered surprising in light of the myriad benefits that proper application of this technology can offer. In this paper, we provide an overview of the technology and the principle of operation, describe the nature of the data generated, discuss the benefits associated with its use in site cleanup, present emission-rate estimation techniques, and examine the reasons why it has not gained more support over the years. Finally, we present a case study in which the technology was used to drive an 11-month emergency removal action under the direction of the U.S. Environmental Protection Agency.

INTRODUCTION

Assessment of the air migration pathway represents a significant aspect of many hazardous waste site remediations. Compliance with pre-established health-based action levels must be demonstrated in order to protect onsite workers and nearby residents. This can be an especially difficult task based on use of traditional point monitoring.

The nature of atmospheric plume dispersion, in conjunction with the need to consider acute health impacts arising from short-term contaminant exposure, has often resulted either in the implementation of ineffective remediation air monitoring programs which, unfortunately, are not protective of human health or, conversely, in the performance of site remediations at a painstakingly slow pace due to an excessive level of conservatism in the air monitoring results. This over-conservatism arises directly from an inability to adequately address the need for real-time data or the need for spatially representative data, or both. Analytical methods which require sample collection and subsequent offsite laboratory analysis cannot meet the requirements for real-time data. Similarly, point monitors (or samplers) which can characterize the air only at a single

point in space cannot meet the requirements for spatially representative data, unless many such monitors are employed at a considerable cost.

Open-path Fourier-transform infrared (FTIR) spectroscopy can be used together with onsite meteorological data to provide ongoing assessment of action-level compliance, in real time, for a virtually unlimited downwind receptor field, thereby overcoming the limitations associated with use of point monitors. As discussed in detail, this method involves, first, the continual back-calculation of site-specific emission rates, and second, the prediction of downwind concentrations (and, thus, assessment of action-level compliance) along the site perimeter and at all identified “sensitive receptors.”

THE TECHNOLOGY

Open-path FTIR spectroscopy is able to provide real-time, simultaneous analysis of up to several dozen gaseous contaminants. The technology is identical in principle to classical laboratory FTIR spectroscopy, except the cell into which a sample would be injected is extended to the open atmosphere. A beam of light spanning a range of wavelengths in the near-IR portion of the electromagnetic spectrum (approximately 2 to 14 microns) is propagated from the transmitter portion of the instrument. In the most common configuration, a “retroreflector,” comprised of an array of corner-cubed mirrors, is positioned to intercept this radiation and redirect it back upon itself to the receiver portion of the instrument.

As described by Grant,¹ an interferometer splits the returning beam of radiation into two paths, and then recombines them in a way to generate an interference from the phase differences. The phase difference, and thus the interference, is dependent on the wavelengths present in the beam. In one of the paths, the radiation is reflected off of a moving mirror, resulting in an intensity variation which is measured at the detector as a function of the path difference between the two mirrors. The result is an interferogram.

The interferogram obtained from a monochromatic beam is simply a cosine wave. The broadband interferogram is a sum of cosine waves (the Fourier series) for each spectral component as a function of mirror pathlength separation. A spectrum in the optical frequency units, cm^{-1} , is obtained by performing a Fourier transform on the interferogram.

Contaminants of concern are identified and quantified via a computer-based spectral search involving sequential, compound-specific analysis and comparison to the system’s internal reference spectra library. The most widely employed technique for analyzing FTIR spectral data is the multicomponent classical least squares (CLS) technique developed by Haaland and Easterling.² Any gaseous compound which absorbs in the IR region is a potential candidate for monitoring using this technology.

One-way pathlengths can range from less than 10 meters (as in the case for combustion source stack monitoring) to several hundred meters or more (as may be required for many ambient air applications).

PATH-INTEGRATED DATA

Gaseous contaminant concentrations are generally reported in units of mass of contaminant per volume of gas, such as micrograms per cubic meter ($\mu\text{g}/\text{m}^3$), 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). For reasons which will become apparent, it is often desirable to convert path-integrated concentrations (ppm-m) to units of milligrams per cubic meter times meter ($\text{mg}/\text{m}^3 \times \text{m}$), or mg/m^2 .

For an open-path FTIR 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 contaminant 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, 300 ppbv over a distance of 100 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.³

The generation of a path-integrated concentration yields contaminant information along the entire pathlength, and not just at a single point (or collection of points) in space as with traditional point-monitoring methods. This solves the issue of spatial data representativeness, as a non-buoyant ground-level plume cannot pass through the beam path undetected.

One may divide the path-integrated concentration by the pathlength to obtain an average concentration along the pathlength, but this concentration representation is of limited value when dealing with action-level averaging times typical of acute exposure assessment.

BENEFITS

The following benefits are identified for use of this technology in site cleanup:

- cost-effectiveness
- speed and versatility
- data quality
- documentation of contaminant exposure
- community relations

Cost-Effectiveness

A general perception exists that open-path FTIR spectroscopy is an expensive alternative to traditional air monitoring methods for site-cleanup applications. This is a misconception arising from what turns out to be an “apples and oranges” comparison. When compared to a traditional air monitoring program which is able to meet the necessary site cleanup data quality objectives, an open-path FTIR-based program is far less expensive. A typical cost for a 1-month program involving a single open-path FTIR unit with full upwind/downwind coverage would be on the order of about \$45,000. This includes all mobilization and demobilization activities, labor and equipment, and QC activities to ensure the technical validity and legal admissibility of the data.

The same program based on an automated gas chromatography network consisting of one upwind and eight downwind monitors would cost on the order of \$85,000. However, even with this number of downwind monitors, data representativeness is only marginally achievable, even for a small site. It would be difficult, if not impossible, to ensure the plume does not migrate offsite undetected, especially under stable atmospheric conditions. By way of illustration, even at a downwind distance of 100 meters, one needs only to move 12.8 meters away from plume centerline (i.e., normal to the wind direction) to see a full 90% reduction in concentration (point-source release) when the atmosphere is stable.

Speed and Versatility

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 absorption. Today, more than 40 compounds can be monitored simultaneously, with quantitation available within 30 seconds of data collection. Offsite contaminant exposure, via back-calculation of emission rates and subsequent modeling of downwind concentrations, can be assessed within about 1 minute.

Data Quality

As discussed earlier, information is obtained along an entire pathlength instead of at a single point in space. Because of this, data representativeness and comparability are unequaled when compared to point monitoring.

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.

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

Any sample collection error is eliminated, as there is no “sample” per se; the media is unaffected by measurement method.

Finally, no calibration is required as the instrument is intrinsically calibrated. Only daily precision and accuracy assessments need to be made in accordance with procedures set forth in Toxic Organic Compendium Method 16 (Compendium Method TO-16).

Documentation of Contaminant Exposure

The ability to generate a continual assessment of action-level compliance for an unlimited downwind receptor array can be important in reducing responsible-party or government liability associated with unsubstantiated future claims involving exposure (worker or public) to unknown contaminants during site cleanup.

Another benefit of exposure-documentation capabilities concerns personal protection. For example, field decisions to downgrade personal protection levels (e.g., from Level B to Level C) can be supported by generation of real-time action-level compliance data.

Community Relations

It has been our experience that the “high-tech” nature of the open-path FTIR technology invariably leads to community appeal and positive public perception. Total fence-line coverage (the “eye which never sleeps”) allays public fear. Such community appeal, in turn, benefits regulatory agencies, as there is less opposition to the selected cleanup remedy.

EMISSION-RATE ESTIMATION TECHNIQUES

The inability to assess acute exposure based on the direct use of path-integrated data would, on first thought, seem to be a drawback. However, when coupled with onsite meteorology, this type of data is actually unparalleled, as all of the limitations associated with traditional point-monitoring approaches are eliminated. Action-level compliance can be assessed, in real time, for a virtually unlimited downwind receptor field.

The cornerstone of this methodology is the back-calculation of contaminant emission rates. Rather than relying on receptor monitoring for a direct assessment of action-level compliance, having an accurate emission-rate estimation facilitates application of traditional dispersion

modeling to predict action-level compliance for any locations of concern (e.g., site perimeters and sensitive offsite receptors such as residences and schools). Because 5 minutes of coadded spectra are more than sufficient from a precision and accuracy perspective, it is a straightforward task to generate a new, site-specific emission rate -- and a corresponding assessment of action-level compliance -- up to 12 times each hour.

To estimate the health impacts to downwind receptors, reliance upon some type of conservative dispersion model offers the only practical alternative.

Actual concentrations could be continuously measured at each receptor of concern, but this activity is generally both cost- and labor-prohibitive. All dispersion models rely upon accurate estimates of emission rates. The ability to provide accurate emission-rate estimates continually and in real time is the key to the power of the path-integrated concentration.³

Three specific back-calculation techniques appropriate for action-level compliance are discussed below.

Point-Source Technique

Within classical Gaussian dispersion theory, the general equation for concentration calculated at ground-level ($z = 0$) for a continuously emitting point source is given as follows:⁴

$$\chi(x,y,0;H) = Q (\pi\sigma_y\sigma_z u)^{-1/2} \exp[-1/2 (y/\sigma_y)^2] \exp[-1/2(H/\sigma_z)^2] \quad \text{(Eq. 1)}$$

where:

- χ = concentration, g/m³
- x = downwind distance to a receptor, m
- y = crosswind distance to a receptor, m
- z = vertical distance to a receptor, m
- H = effective height of contaminant emission, m
- Q = uniform emission rate of contaminant, g/s
- σ_y = standard deviation of plume concentration distribution in the horizontal direction at the distance of measurement, m
- σ_z = standard deviation of plume concentration distribution in the vertical direction at the distance of measurement, m
- u = mean wind speed, m/s

This relationship forms the basis for many of the USEPA atmospheric dispersion models currently employed for estimating downwind air quality impact.

Examination of this relationship shows that the downwind concentration at a given location increases with increasing source strength, but decreases with increasing wind speed and horizontal and vertical dispersion (as determined via σ_y and σ_z). The standard deviations of the plume concentrations in the horizontal and the vertical are, in turn, functions of atmospheric stability and the distance downwind of the source. Nomographs which define σ_y and σ_z as a function of downwind distance for each of six stability classes are frequently used to estimate these parameters. Larger σ_y and σ_z values are associated with unstable atmospheric conditions (greater dispersion) and greater downwind distances.³

If one integrates Equation 1 in the y (cross-plume) direction, the resultant representation is a crosswind-integrated concentration instead of a point concentration. Performing this integration with respect to y, from $y = -\infty$ to $+\infty$, yields:

$$C(x,0;H) = 2Q [(2\pi)^{1/2} \sigma_z u]^{-1} \exp [-1/2(H/\sigma_z)^2] \quad \text{(Eq. 2)}$$

where:

C = ground-level crosswind-integrated contaminant concentration at distance x, g/m^2

Equation 2 has historically been employed in diffusion experiments to determine vertical dispersion coefficients (standard deviations of the plume concentration in the vertical direction), σ_z , from ground-level data where the source strength, Q, was known and the ground-level crosswind-integrated concentration was determined from a crosswind line or arc of point-sampling measurements made at some predetermined downwind distance.³

The effective height of emissions, H, is defined as the sum of the actual height of emissions and the buoyancy-induced height increment arising from an elevated effluent temperature. Because most site remediation activities occur at ground level and without elevated effluent temperatures, H generally equals zero and Equation 2 reduces to:

$$C(x) = 2Q [(2\pi)^{1/2} \sigma_z u]^{-1} \quad \text{(Eq. 3)}$$

Rearranging, Equation 3 may be written as:

$$Q = 1/2(2\pi)^{1/2} C(x) \sigma_z u \quad \text{(Eq. 4)}$$

Equation 4 is the general emission-rate equation for a point source involving path-integrated measurement data. For a measured crosswind-integrated concentration at some specified downwind distance, the emission rate, Q, depends only upon σ_z at that distance and on

wind speed, u . The point-source emission-rate technique is applicable for those site disturbance activities which may be approximated as point sources (e.g., excavations).

Tracer-Ratio Technique

The tracer-ratio technique is appropriate for estimating emission rates from any type of site disturbance activity (i.e., point source or area source) and, in contrast to the point-source technique, does not rely on the contaminant distribution in the plume being Gaussian.⁵ The tracer-ratio technique involves the release of an appropriate tracer gas (such as sulfur hexafluoride) at a known, controlled flow rate from locations which adequately simulate the source geometry. Assuming that the tracer and source plumes are fully contained by the downwind FTIR beam, the following ratio applies:

$$C / Q = C_T / Q_T \quad \text{(Eq. 5)}$$

where:

$$\begin{aligned} C_T &= \text{ground-level crosswind-integrated concentration of tracer at distance } x, \text{ g/m}^2 \\ Q_T &= \text{uniform emission rate of tracer, g/s} \end{aligned}$$

Equation 5 simply states that the ratio of the path-integrated concentration of the contaminant to its emission rate is equal to the ratio of the path-integrated concentration of the tracer to its emission rate. (It is important to note that all concentrations must be expressed in units of g/m^2 or mg/m^2 , as use of ppm-m units will yield erroneous results owing to the fact that molecular weights are unaccounted for.)

Rearranging Equation 5 and solving for Q yields:

$$Q = (Q_T C) / C_T \quad \text{(Eq. 6)}$$

If the emitting source is not too large, a tracer will typically be released from a single point positioned at the source edge furthest upwind. The simplicity of such a source simulation generally outweighs the resultant increased conservatism (i.e., higher emission rates).

Area-Source Technique

The area-source technique is simple to implement and can be used to estimate emission rates from area sources which are too large for simple treatment via the tracer-ratio technique. The technique is applicable for both homogeneous and nonhomogeneous sources (i.e., sources which emit uniformly and sources which have “hot spots”). However, for nonhomogeneous sources, some information on the extent and magnitude of the hot spots is required. If no hot-spot

information exists, it is possible to generate reasonable bounds upon the site emission rate.

Like the point-source technique, the area-source technique does not involve use of a tracer gas and the plume is generally assumed to obey Gaussian dispersion theory. The following four-step methodology is employed.⁵

1. Identify Source Attribution

This step involves making ground-level FTIR measurements upwind and downwind of the source to identify source attribution. The instrument background will typically serve as the upwind measurement, and site attribution is obtained by subtraction. It is essential that the downwind pathlength be of a magnitude sufficient to encompass the entire width of the plume.

2. Predict Point Concentrations Along the Measurement Path

This step involves use of an appropriate dispersion model, preferably the ISCST (Industrial Source Complex Short-Term) Model, to predict point concentrations along the downwind FTIR measurement path at a nominal receptor spacing of 1 or 2 meters. Relative emission rates are modeled (i.e., unity emissions, with hot-spot subareas represented as multiples of unity) based on actual meteorology and source configuration.

Site-specific σ_z values based on tracer releases are generally preferable to model (textbook) σ_z values, and should be substituted to back-calculate emission rates whenever possible. Equation 4 can be rearranged, as follows, to facilitate site-specific σ_z calculation:

$$\sigma_z = [(2\pi)^{1/2} Q_T] / \pi C_T u \quad \text{(Eq. 7)}$$

By knowing Q_T , C_T , and u , a site-specific σ_z value is calculated directly. However, because σ_z is a function of stability and downwind distance, a curve comprised of σ_z values at several downwind distances should be generated for the range of stability classes expected to be encountered. Similarly, the downwind distances at which σ_z is measured should span the range of downwind distances to be encountered during site-disturbance activities. All tracer work should be carried out in advance.

3. Integrate the Function Defined by the Point Concentrations Along the Measurement Path

Some type of rudimentary numerical technique will generally be required to integrate this function (e.g., Simpson's Three-Point Rule, in which the line representing the value of the function is replaced by a second-order equation, $y = ax^2 + bx + c$). The resultant path-integrated concentration is what the FTIR is predicted to "see" based on the relative emission rates used in the dispersion modeling.

4. *Scale Modeling Results to Estimate Area Emission Rate*

The actual contaminant emission rate, Q , is estimated in a manner which is conceptually similar to the tracer-ratio technique:

$$C_M / Q = C_P / Q_R \quad \text{(Eq. 8)}$$

where:

- C_M = measured ground-level crosswind-integrated contaminant concentration at distance x , g/m^2
- C_P = predicted ground-level crosswind-integrated contaminant concentration at distance x , g/m^2
- Q_R = relative emission rate of contaminant, g/s

Equation 8 simply states that the ratio of the measured path-integrated concentration to its emission rate is equal to the ratio of the predicted path-integrated concentration to its emission rate. Rearranging Equation 8 and solving for Q yields:

$$Q = (Q_R C_M) / C_P \quad \text{(Eq. 9)}$$

REASONS FOR UNDERUTILIZATION

We identify at least three reasons why open-path FTIR spectroscopy has been underutilized as a means to assess exposure to gaseous contaminants during remediation of hazardous waste sites. These are:

- Lack of USEPA Headquarters support
- Resistance from the air monitoring community
- Poor marketing of the technology by the manufacturers

Lack of USEPA Headquarters Support

Lack of support from USEPA Headquarters for the use of open-path FTIR spectroscopy (and all optical remote sensing technologies) as a preferred means to assess gaseous contaminant emissions is, in general, perhaps the single biggest reason for its underutilization in the hazardous waste site remediation arena.

It should be pointed out, however, that this lack of support does not exist in all ten USEPA regions, but lack of programmatic support and policy directives on a national level has had a substantial effect. It should also be stated that the national Environmental Reponse Team (ERT)

is one Agency group which has been very proactive in use of this technology, and it is under their direction and support that much of the applied research in developing emission-rate estimation techniques has been conducted.

Factors leading to the lack of programmatic and policy support on a national level are many and complex, but can generally be traced back to the early 1980s when government budget issues forced a fundamental change in the way the Agency operated. Over the span of several years, the USEPA underwent a difficult transition from being a highly proactive agency with arguably unparalleled scientific resources, to one largely relegated to the management of outside technical contractors. This transition resulted in the replacement of retiring senior atmospheric scientists -- who had pioneered the design of innovative air measurement programs and the entire field of atmospheric dispersion modeling since the Agency's inception -- with either existing individuals of unrelated technical background or new hires having little or no prior professional experience. Compounding the situation at the time was low morale and less-than-competitive pay which resulted in many highly competent technical/management personnel at mid-levels also leaving the Agency for better positions in industry and consulting.

Headquarters' support of open-path FTIR spectroscopy took a step further backwards in 1995 following a series of stakeholders meetings and workshops held around the country as part of the Agency's "Common Sense Initiative." Created by the Clinton Administration to protect public health and the environment more effectively and less expensively, the goal of the Initiative was to look at pollution on an industry-by-industry (vs. pollutant-by-pollutant) basis. All aspects of environmental policy were examined for a total of six pilot industries, and stakeholders ranging from industry to environmental consultants to community organizations were involved.

Based on our participation in the compliance assurance monitoring (CAM) portion of these meetings, it was evident that the Agency was "outmatched" against the industry interests whose goal was to keep the status quo of the state-of-the-art of the air monitoring field and maintain use of indirect means to characterize facility emissions. Also apparent was the fallout from an audit of CERCLA program activities performed by the Inspector General's office several years earlier, which concluded that some contractors were being used -- inappropriately -- to help create Agency policy.

So, not only was the Agency unable to stand up technically to the industry advocates during the CAM meetings, they were also unable to have consultant assistance in the negotiations because of internal directives to keep consultants and policy making "at a safe distance."

Even though open-path spectroscopy received a lot of support as a means to monitor total facility emissions, in the end, lobbyists for the petroleum refining industry (one of the six pilot

industries) were successful in keeping this technology out of the Initiative. The stated reason for the refining industry's rejection of the technology was that it was "too good," as there was fear that proprietary formulations would be revealed because of the creation of a permanent electronic record of the absorbance spectra.

Even today, the Office of Air Quality Planning and Standards, which is responsible for development of both MACT (Maximum Available Control Technologies) standards and guidance concerning the assessment of "residual risk" following MACT application, is divided on acceptance of the technology. Some of the individuals support its use and others believe it has little value or has been oversold (a point to be addressed later).

Within the USEPA, we believe the utility of the path-integrated concentration is still not fully appreciated, and that there continues to be misunderstanding concerning application of the technology for assessment of emission rates. This, in turn, stems from an inability or unwillingness to consider atmospheric dispersion theory and meteorology as part of the "formula" for addressing the fundamental deficiencies of point monitors as relating to data representativeness and comparability.

Resistance From the Air Monitoring Community

Resistance to change from the air monitoring community has also inhibited acceptance of open-path FTIR spectroscopy. There are at least three reasons why such resistance occurs: (a) the technology poses an economic threat to the suppliers of traditional air monitoring equipment and associated analytical services; (b) individuals who have been doing traditional air monitoring for years still do not understand the FTIR technology and would rather resist it than admit their lack of understanding; and (c) many air monitoring decision-makers do not have a background in atmospheric dispersion and, because the open-path FTIR technology is truly revolutionary in terms of the data generated, there is simply an entrenched mentality which requires a significant effort to overcome.

Poor Marketing of the Technology by the Manufacturers

As a rule, manufacturers of open-path FTIR spectrometers have had very poor success in marketing the technology, as can be evidenced by the number of times open-path FTIR product lines have been sold over the past 10 years. Market research has repeatedly demonstrated an enormous potential for instrument sales, and this has often been sufficient to attract outside capital. However, vendors have consistently realized actual sales below those projected.

We have worked with most of the open-path FTIR vendors, and can point to a single factor for this lack of success: an overly simplistic view of what is necessary to achieve sales in a field which is simultaneously complex and immature. Until the market becomes mature -- which may

take another 10 or even 15 years -- the focus must be on selling a service as opposed to a selling a “black box.” This latter approach has, in several unfortunate instances, led to overselling the technology to the USEPA and other regulators.

It is a natural tendency for instrument manufacturers to become myopic as they struggle to perfect their product (and, indeed, the instruments on the market today are very good); however, there is a serious problem when the potential customers are, in general, not sophisticated enough to fully understand how it should be used to solve their problem. Add a price tag on the order of \$100,000, and it’s easy to see why sales have not met projections.

The correct approach is the one consultants have always employed: solve the client’s problem. There are two reasons why manufacturers might choose to resist this, however. The first is that the best solution to the client’s problem often will not involve sale of an instrument. Perhaps an instrument lease (on the order of a week to a month) might be optimum. The manufacturer needs to structure itself so that instrument leases are desirable.

The second reason is that the requisite expertise to solve the client’s problem is generally not found within a manufacturer’s organization. Essential to the successful marketing of this technology is a thorough familiarity of regulatory laws such as the Clean Air Act and CERCLA, as well as a strong technical background in meteorology and atmospheric dispersion. Unless such expertise is acquired, strong alliances with consultants are essential.

Keeping in mind the earlier discussion on lack of USEPA support, it is now easy to see why manufacturers trying to deal directly with USEPA have often been counterproductive to the advance of this technology.

CASE STUDY

The Michigan Avenue Dump Site, a 1.8-acre hazardous waste site located in Canton, Michigan, was used by 3M Corporation during the 1960s to dispose of industrial wastes. In 1993, an imminent threat to public health was identified by the USEPA, Region 5, due to large volumes of waste materials entering the Rouge River, which cut through the center of the site. In July of that year, an emergency removal action was initiated, and wastes were excavated and hauled away for offsite disposal while contractors shored up the riverbank with sheet piling.

The USEPA identified a potential for significant offsite exposure to airborne gaseous contaminants generated during excavation and stockpiling of contaminated waste materials. After extensive Agency review of available monitoring methods and based upon ongoing consultation with USEPA-ERT, open-path FTIR spectroscopy was selected as the technology to “drive” the action.

While working for Blasland, Bouck and Lee, we were retained by 3M’s consultant, Roy F. Weston, to design and implement the air monitoring program. The objective was to ensure that emissions generated during the excavation and offsite transport of waste materials did not exceed the health-based property-line exposure levels established by the USEPA for this site, and to support the application of vapor suppressants whenever action levels were approached.

Exhibit 1 identifies a total of 15 target contaminants and associated 30-minute action levels developed specifically for this emergency removal action.

Exhibit 1. Target Contaminants and Associated 30-Minute Action Levels

Contaminant	Action Level (mg/m ³)	Contaminant	Action Level (mg/m ³)
benzene	1.60	ethylbenzene	21.70
chloromethane	5.15	hexane	8.80
dichloromethane	15.00	methyl isobutyl ketone	10.25
1,2-dichloroethane	2.00	octane	70.00
acetone	89.00	toluene	9.40
2-butanone (MEK)	29.50	1,1,1-trichloroethane	95.50
cyclohexane *	5.00	xylene	21.70
1,2-dichloropropane	17.35		

* As approximated by the sum of n-octane and iso-octane.

Open-path monitoring was performed, using a single FTIR unit, in such manner as to provide full coverage of the site perimeter, regardless of the wind direction. The instrument was positioned at the NW corner of the nearly rectangular site and could pivot to monitor along either the W or the N leg of the site. Flat mirrors were placed in the NE and SW corners to “bend” the beam along the E and S legs, respectively, and retroreflectors were positioned in the SE corner to send the beams back upon themselves to the FTIR for analysis. Up to six 5-minute-averaged

(70 coadded spectra) path-integrated downwind measurements were made each hour.

The tracer-ratio technique was used to back-calculate emission rates for the 15 target contaminants. The source (area of site disturbance) was represented as a virtual point conservatively positioned at the upwind site perimeter.

A proprietary plume dispersion model software package (SPECTRAMET) was used to assess action-level compliance based on the back-calculated emission rates and on meteorology supplied by a portable 3-meter meteorological tower equipped to generate 5-minute averages of wind speed and wind direction.

SPECTRAMET was configured to generate maximum predicted fenceline concentrations (mg/m^3) in near real-time (within 15 or 20 minutes of actual occurrence) approximately twice each hour for the duration of waste disturbance or vapor suppressant activities, or on demand by the Weston field manager. Whenever an action level was exceeded, waste disturbance activities were immediately stopped and a vapor suppressant applied. Activities could not recommence until maximum fenceline concentrations fell to background levels.

The local press was successful in gaining community support for the technology. “Like something right out of the Star Wars defense initiative, the Fourier Transform Infra-Red system has been doing some surreptitious defense work of its own in Canton.

“By quietly and inconspicuously testing the air at a Michigan Avenue dumpsite, the system -- introduced by 3M to monitor its cleanup of the site -- has been defending residents against the possible inadvertent release of any harmful chemicals.”⁶

Because of the proximity of the emission sources to the site perimeter, action-level exceedances occurred frequently and 11 months was required for completion of the entire emergency removal action. However, during the course of the project, the USEPA stated that if open-path FTIR spectroscopy had not been utilized in the manner it was, the whole operation would had to have been performed under an enclosure, at a greatly increased cost to 3M.

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