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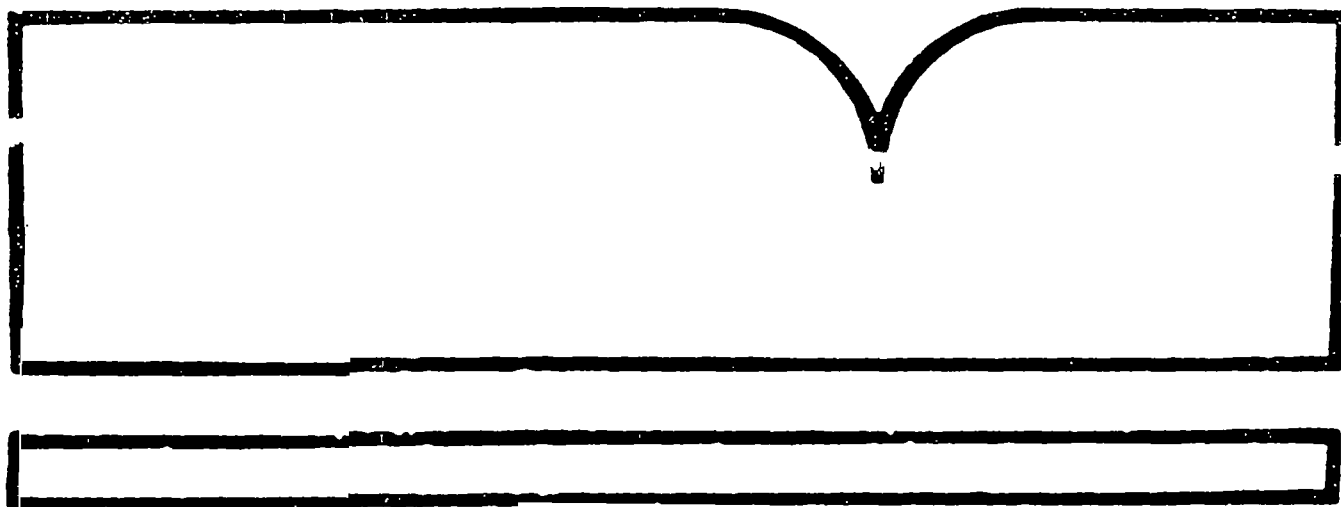
**Source Receptor Methodology for
Some Chlorinated Hydrocarbons**

SRI International, Menlo Park, CA

Prepared for

**Environmental Sciences Research Lab.
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**SOURCE RECEPTOR METHODOLOGY FOR
SOME CHLORINATED HYDROCARBONS**

by

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ABSTRACT

A source-receptor methodology is described that can be used to estimate emission rates of halogenated hydrocarbons from a manufacturing plant when access to the plant is not possible. An inert tracer is released at a known rate from a vehicle traveling back and forth on a road outside the plant area. Samples are collected downwind of the plant (at a distance of about 1 to 5 km) and analyzed for the tracer and the materials of interest. The relationship between the emission rates of the tracer and the materials of interest, and the measured concentrations has been derived. The method is generally insensitive to meteorological conditions, if applied at night or under overcast conditions during the day. It is suitable for estimating fugitive emissions from sources within 10 or 15 m of ground level. It must be applied with discretion, if interfering sources are present in the area. Once emission rates have been determined, conventional Gaussian methods may be used to estimate expected maximum ground-level concentrations of the materials of interest downwind of the source area. A suitable manufacturing plant was selected (Vulcan Materials Company near Wichita, Kansas) and the method was applied to estimate emission rates for four different halogenated hydrocarbons. The feasibility of the methodology was demonstrated and suggestions for improvements were made.

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SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is concerned that some hydrocarbon compounds, especially halogenated hydrocarbon compounds that may be hazardous at low concentrations, might have an immediate local impact downwind of the plants that manufacture them. However, there has been a lack of data that would allow the prediction of either the amounts of these materials that are released to the atmosphere or the concentrations that might exist downwind of the plants under various meteorological conditions.

Several factors have contributed to this lack of data. First, these compounds do not come from clearly identified sources such as stacks or vents. Instead, they are likely to come from more widely distributed sources such as leaks from valves, plumbing, incompletely sealed containers, and filling and emptying operations, or during transport from one place to another. The magnitude of sources of this type is extremely difficult to measure or even estimate. The second, and almost equally important, reason why so few data are available concerning the magnitude of sources of halogenated hydrocarbons is that the processes and equipment used to produce the materials are frequently proprietary. Similarly, the manufacturers are quite secretive, for competitive reasons, about their production and sales rates. In such an environment, it is not surprising that the manufacturers are very reluctant to allow outsiders on the grounds of the manufacturing plants to make measurements that would be necessary to characterize source strengths directly.

The major problem has been just such a determination of source strengths. Once a source strength is known, maximum ground-level concentrations can be estimated as a function of downwind distance and meteorological conditions. The EPA recognized a need for a source-receptor methodology that could be used to estimate source strength and to predict maximum ground-level concentrations, and, for the reasons cited above, required that the method not rely upon measurements made within the manufacturing complex. Originally, measurements in the study described in this report were to be made within some manufacturing plant and used to verify the performance of a different methodology that required only measurements from outside the manufacturing area. The original intent of the study described in this report was to meet the following objectives:

- (1) Select a suitable manufacturing site that produces two or three of the following chlorinated hydrocarbons: methylene chloride (CH_2Cl_2), trichloroethylene (C_2HCl_3), and perchloroethylene (C_2Cl_4).

- (2) Perform the necessary tests in the plant to establish the total fugitive emission rates of these compounds.
- (3) Develop sampling strategies for fence-line and downwind measurements of the ambient concentration of these compounds.
- (4) Develop a diffusion/transport methodology to predict the source strength and the downwind concentration from the fence-line measurements.
- (5) Verify the model using source strengths estimated from the in-plant measurements.
- (6) Develop a strategy for the use of the measurement methodology.

Four of the objectives were met. Objectives 2 and 5 were not achieved, because no suitable plant was found that would allow on-site measurements. Nevertheless, the project yielded a methodology that can be used to estimate the fugitive emissions from within a plant when access to the plant is not possible. The source-receptor methodology does not use measurements made literally at the fence line, unless the fence is sufficiently far from the sources that mixing will have produced reasonably uniform distributions through the lowest 10 m or so. This report describes that methodology and its application to a specific manufacturing plant. Suggestions are also included for improving the method and its application.

The theory underlying the methodology is discussed in the Section 2 of this report. Briefly, the methodology relies upon the release of an inert, nontoxic tracer gas at a known rate outside the manufacturing site. Concentrations of the tracer are measured downwind of the site to establish the magnitude of the atmospheric transport and dilution processes. This value is used in turn with simultaneous downwind measurements of the concentrations of the chlorinated hydrocarbons, allowing an estimate to be made of the magnitude of their sources within the plant. Once these source strengths have been established, conventional dispersion modeling techniques can be used to estimate downwind concentrations for various meteorological situations.

This report also describes the application of the methodology to a specific site and illustrates some of the important features of the method. The description begins with the selection of a candidate test site, followed by a discussion of the various parts of the test procedure:

- (1) The requirements for meteorological observations
- (2) The procedures used for tracer releases
- (3) The procedures used for collecting and analyzing tracer samples.
- (4) The procedures used for collecting and analyzing chlorinated hydrocarbon compounds.

Tests were conducted at the Vulcan Materials Company plant near Wichita, Kansas, on the nights of 8-9, 10-11, 11-12 and 12-13 August 1981. This report describes the conditions that prevailed during these tests and interprets the results that were obtained to provide estimates of source emissions rates for some chlorinated hydrocarbons. The report concludes with a review of the methodology and a summary of the results obtained in the test application.

SECTION 2

THEORY

The theory underlying the source-receptor methodology used in this study is presented below. The derivation provides a relationship between the dilution of a tracer released from a ground-level line source and the dilution of materials released from a nearby ground-level area or point source. First, consider the Gaussian formula for a ground-level concentration from an infinite ground-level line source:

$$C_1 = \frac{2Q_1}{\sin\theta u \sigma_z \sqrt{2\pi}} \quad (1)$$

where

C_1 = ground-level concentration (g m^{-3})

Q_1 = line-source emission rate ($\text{g m}^{-1} \text{s}^{-1}$)

θ = angle between wind and line source

u = windspeed (m s^{-1})

σ_z = standard deviation of Gaussian concentration distribution in the vertical at a distance from the source parallel to the wind direction (m).

The vertical standard deviation σ_z can be approximated by a function of the following form:

$$\sigma_z(x) = ax^b \quad (2)$$

where x is the distance from the source, parallel to the wind direction. Table 1 gives values of a and b suggested by Busse and Zimmerman (1) for use in the range from about 0.5 to 5 km downwind.

If we substitute from Eq. (2), Eq. (1) becomes:

$$C_1 = \frac{2Q_1}{\sin\theta \sqrt{2\pi} ax^b} \quad (3)$$

TABLE 1. SUGGESTED VALUES FOR THE
CONSTANTS IN EQUATION (2)

| Atmospheric Stability | Constants | |
|-----------------------|-----------------------|------|
| | a | b |
| Extremely unstable | 0.25×10^{-3} | 2.09 |
| Moderately unstable | 0.049 | 1.11 |
| Slightly unstable | 0.10 | 0.93 |
| Neutral (day) | 0.26 | 0.69 |
| Neutral (night) | 0.25 | 0.63 |
| Stable | 0.20 | 0.60 |

SOURCE: Busse and Zimmerman (1)

The formula for an area source (of infinite extent in the cross-wind direction) can be obtained by integrating Eq. (3) along x:

$$C_A = \frac{2Q_A (X_u^{1-b} - X_d^{1-b})}{\sin \phi \sqrt{2\pi} U_a (1-b)} \quad \text{for } b \neq 1 \quad (4)$$

where X_u and X_d are the distances to the upwind and downwind edges of the area source and Q_A ($\text{g m}^{-2} \text{s}^{-1}$) is the area-source emission rate. The "line sources" that are integrated to get Eq. (4) can be oriented arbitrarily. For convenience, we choose to orient them at the same angle to the wind ϕ as the tracer line source. Dividing Eq. (4) by Eq. (3) gives

$$\frac{C_A}{C_1} = \frac{Q_A (X_u^{1-b} - X_d^{1-b}) \cdot x^b}{Q_1 (1-b)} \quad (5)$$

Solving for Q_A gives:

$$Q_A = \frac{C_A Q_1}{C_1} \frac{(1-b)}{(X_u^{1-b} - X_d^{1-b}) \cdot x^b} \quad (6)$$

All quantities on the right side of Eq. (6) can be measured experimentally except b , which depends on atmospheric stability. For experiments conducted at night, the atmosphere will be either stable or neutral according to the commonly used methods for classifying atmospheric stability (2). If we limit the downwind distances at which measurements are made so that x, X_u, X_d are all between 0.5 and 5 km, then the appropriate values of b range from about 0.6 for stable conditions to about 0.7 for neutral conditions (1).

Although a value based on meteorological factors can be chosen for b , there is some uncertainty, so it is important to evaluate the sensitivity of the relationship to the choice of value for b . We begin by defining a factor containing all the b terms as follows:

$$B = \frac{1-b}{(X_u^{1-b} - X_d^{1-b}) \cdot x^b} \quad (7)$$

Substituting Eq. (7) in Eq. (6) gives:

$$Q_A = \left(\frac{C_A Q_1}{C_1} \right)^B \quad (8)$$

Table 2 gives values of B for $b = 0.6$ and $b = 0.7$, by using different combinations of x , X_u , and X_d . It is apparent from the table that the calculations are not very sensitive to atmospheric stability. Within the limits of experimental accuracy, b could be set equal to 0.65, and Eq. (6) would then become:

$$(Q_A)_{\text{night}} \approx \frac{0.35 C_A Q_1}{C_1 \left(X_u^{0.35} - X_d^{0.35} \right) x^{0.65}} \quad (9)$$

Some assumptions inherent in Eq. (9) should be understood:

- (1) Eq. (9) applies for nighttime conditions or neutral daytime atmospheric conditions.
- (2) Concentrations are measured 0.5 to 5 km downwind of the sources.
- (3) Concentrations are measured near the center of the plume where the assumption of an infinite crosswind extent of the sources is most nearly valid.
- (4) The crosswind extent of the sources is large compared to the dimensions of a point-source plume at the downwind distance where the concentrations are measured, e.g.,
 - At 5 km, about 600 m for neutral stability and about 300 m for stable.
 - At 2 km, about 300 m for neutral and about 150 m for stable.
- (5) The angle between the wind and the line source is relatively large, about 45° or greater.
- (6) The separation between the line source and the area source should be kept as small as possible, preferably within about 25% of the distance between the line source and the samplers.

In general, the above conditions that apply to the line source were met, except for the requirement that the wind direction be at a large angle to the line source. This was not met for the night test of 8-9 August 1981. This test, and the test of 7-8 August 1981, were only marginal with regard to the crosswind extent of the area from which fugitive emissions were expected. From the standpoint of meeting the

TABLE 2. VALUES OF B FOR TYPICAL EXPERIMENTAL CONDITIONS

| x (m) | x _u (m) | x _d (m) | B (m ⁻¹) | | Relative Difference (%) |
|----------|-----------------------|-----------------------|-------------------------|-----------------------|-------------------------------|
| | | | b = 0.6 | b = 0.7 | |
| 4000 | 4400 | 4200 | 5.22×10^{-3} | 5.26×10^{-3} | 0.7 |
| 4000 | 3800 | 3600 | 4.77×10^{-3} | 4.74×10^{-3} | 0.8 |
| 2000 | 2400 | 2200 | 5.44×10^{-3} | 5.51×10^{-3} | 1.3 |
| 2000 | 1800 | 1600 | 4.53×10^{-3} | 4.46×10^{-3} | 1.6 |
| 1500 | 1900 | 1700 | 5.57×10^{-3} | 5.68×10^{-3} | 2.0 |
| 1500 | 1300 | 1100 | 4.37×10^{-3} | 4.27×10^{-3} | 2.3 |

assumptions underlying Eq. (9), the last three tests were the best. The data analyses presented later focus on these three cases.

It is also possible to assume that the plant emissions come from a point or very small area at the surface, with a source strength Q_p . The concentration at the center of the plume (C_p) is given by:

$$C_p = \frac{Q_p}{\pi U \sigma_y \sigma_z} \quad (10)$$

where σ_y is the standard deviation of the Gaussian concentration distribution in the crosswind direction; σ_y is approximately proportional to $x_p^{0.9}$ (2). The constant of proportionality depends on stability. It ranges from 0.065 for moderately stable atmospheric conditions to 0.13 for neutral conditions, when both x_p and σ_y are expressed in the same units (m); x_p is the downwind distance from the point source.

If the point source and the line source are close together compared to the downwind distance, then $(x_p/x)^b = 1$ for the values of b discussed earlier. For example, if $0.85 \leq (x_p/x) \leq 1.15$, then $(x_p/x)^b$ will be between about 0.9 and 1.1. Using this fact, we can determine the ratio between Eq. (1) and (10), and solve for Q_p to give:

$$Q_p = K \frac{C_p Q_l}{C_l} \frac{x_p^{0.9}}{\sin \theta} \quad (11)$$

where

$$K = \begin{cases} 0.32 & \text{for a neutral atmosphere} \\ 0.25 & \text{for a slightly stable atmosphere} \\ 0.16 & \text{for a moderately stable atmosphere} \end{cases}$$

Eq. (11) is not quite as desirable as Eq. (9) for estimating source strength because it is subject to appreciable dependence on atmospheric stability. However, it does not require an estimate of the size of the area source in order to determine total emission rates. In the analyses that follow both Eqs. (9) and (11) have been used.

SECTION 3

THE TEST SITE

The EPA wanted this study to be performed at a site that manufactured two of the three following chlorinated hydrocarbons: methylene chloride (CH_2Cl_2), trichloroethylene (C_2HCl_3), and perchloroethylene (C_2Cl_4). There are only a limited number of such manufacturing sites in the United States; a list of these sites was compiled and each site was evaluated according to the criteria discussed below.

CRITERIA USED TO SELECT THE TEST SITE

Although it was not emphasized in the preceding section, it is essential to be able to establish that measured concentrations of the halocarbons of interest come from the plant in question. Therefore, the area surrounding the manufacturing site must be free of other sources of the same materials. Such sources would interfere with interpretation of the data and make it difficult to estimate source strengths within the plant itself. Therefore, one of the criteria for selecting the test site was that there be no other nearby sources of chlorinated hydrocarbons.

The use of a tracer to estimate dilution rates requires that the tracer be released as close to the sources of interest as possible. It also requires that samples of ambient air be collected or measured both upwind and downwind of the manufacturing site, preferably within a few kilometers of the site. Inasmuch as the wind can blow from any direction, it is desirable to have the area around the plant be accessible for a few kilometers in every direction. A flat, open terrain with many lightly traveled roads is most desirable.

The tracer methodology is most appropriately applied at night. Therefore, a plant that operates on an around-the-clock schedule is desirable so that the tests can be conducted at night when winds are light and the air is stable. This criterion was not very restrictive in the site selection process, because all the plants that were considered do operate on such a schedule. Nevertheless, it must be considered.

The diffusion/transport methodology assumes that most emissions occur near ground level and that mixing through the lower layers is about the same as that of the tracer. The methodology would not be applicable to a plant where appreciable quantities of the materials are emitted from tall stacks. This criterion was not restrictive for the plants considered in the selection process, because virtually all the emissions at these plants take place within 5 to 10 m of the surface and with little

buoyancy. When questioned, the manufacturers stated that all stack gases are processed through incinerators before venting, so there should be no emissions from the stacks.

The final criterion used for selecting a test site was that the manufacturer be cooperative and allow access to the plant. This particular criterion proved impossible to satisfy. Although most of the manufacturers were willing to discuss the planned tests and to consider allowing access to the plant, none was actually willing to grant such access. The reasons for their unwillingness, which were cited in Section 1, are certainly valid from their perspectives. It should also be noted that the operator of the plant that was finally selected for this study was cooperative enough to furnish some information on plant products and operations.

CANDIDATE TEST SITES

Only seven plants in the United States produce the chlorinated hydrocarbons of interest. These are listed in Table 3. The table also identifies which of the compounds are produced at each of the sites. The operators of these plants were contacted, maps of the areas surrounding the plants were obtained, and climatological data for the regions were studied during the selection process. Initially, SRI believed that one or more of the operating companies might be willing to allow access to their plants, or that the EPA could expeditiously negotiate access on our behalf. Under the assumption that access could be obtained, SRI focused on three particular plants, which were visited. These plants were PPG Industries, Inc., Lake Charles, Louisiana; Stauffer Chemical Company, Louisville, Kentucky, and Vulcan Materials Company, Wichita, Kansas. The latter plant was finally chosen because it best met the selection criteria--other than the criterion regarding cooperation by the operator. This site will be discussed in detail in the next section.

The Louisville and Lake Charles sites were not selected because they would have been more difficult for field operations than the Wichita site. The marshy terrain surrounding the Lake Charles site limits the number of available roads in some directions from the plant. The Ohio River is next to the Louisville plant, so that extensive travel would have been required to get from the plant to some sampling areas. Although it would have been possible to conduct tests at the Louisville and Lake Charles sites, surroundings limited the number of wind directions under which tests could have been conducted and would have introduced some logistical problems that were not encountered at the Wichita site. Inasmuch as the purpose of the program was to develop and demonstrate the source-receptor methodology, it would have been counterproductive to introduce unnecessary complications.

There was another more serious reason for rejecting the Louisville site. It was not entirely clear that there were no other sources of

TABLE 3. PRODUCERS OF CHLORINATED HYDROCARBONS

| Company and Location | Products | | |
|---------------------------|--------------------------|--------------------------|-------------------------|
| | CH_2Cl_2 | C_2HCl_3 | C_2Cl_4 |
| Dow Chemical Company, USA | | | |
| Freeport, TX | ✓ | ✓ | ✓ |
| Plaquemine, LA | ✓ | ✓ | |
| Ethyl Corporation | | | |
| Baton Rouge, LA | | ✓ | ✓ |
| PPG Industries, Inc. | | | |
| Lake Charles, LA | | ✓ | ✓ |
| Stauffer Chemical Company | | | |
| Louisville, KY | ✓ | ✓ | |
| Vulcan Materials Company | | | |
| Geismar, LA | ✓ | ✓ | |
| Wichita, KA | ✓ | ✓ | |

chlorinated hydrocarbons in nearby industrial areas. This is also why the Dow Chemical plant at Freeport, Texas, and the PPG plant at Lake Charles, Louisiana, were not given serious consideration. The application of the methodology in an area of large-scale petrochemical production, such as Freeport, Texas, could pose some serious difficulties. SRI does not believe that applying the methodology in such areas would be impossible, but it would likely require careful selection of the conditions under which the tests were conducted and appreciably more measurements upwind of the plant to establish ambient background conditions. It would also require a careful analysis of land use and manufacturing operations in the region, and a more thorough interpretation of the collected data. It seemed premature to introduce these complications before the method had been demonstrated under more favorable conditions.

The reasons for rejecting the other plants listed in Table 3 were similar to those discussed above. Briefly, the Dow Chemical plant at Plaquemine, Louisiana, is located next to the Mississippi River, which would have posed serious logistical problems. The Vulcan plant at Geismar, Louisiana, and the Ethyl plant at Baton Rouge, Louisiana, were not given serious consideration because SRI had been refused entry earlier in the project. By the time it became evident that in-plant tests would not be possible, SRI had already selected the Vulcan plant at Wichita as the best site.

TEST SITE--THE VULCAN MATERIALS COMPANY, WICHITA, KANSAS

The Vulcan Materials Company plant was chosen as the site for testing the source-receptor methodology. The plant is located about 35 m southwest of the center of Wichita, Kansas. Figure 1 is a topographic map showing the area near the plant site. The area around the plant is quite flat; within 2 km of the plant, the elevation changes over a range of less than 15 m (about 1,280 to 1,320 feet). The site is serviced by a railroad, which also serves a grain elevator about 1 km to the northeast. A wastewater treatment plant and a fluorocarbon manufacturing plant (both operated by Vulcan) are adjacent to the Vulcan site and a power plant is located about 2 km to the northeast. A small chemical plant is located about 0.3 km south of the Vulcan site, but it does not use any of the materials of interest.

Other than these activities, the area surrounding the Vulcan plant is generally devoted to farming for at least 5 km in all directions. As the map shows, there is a grid of roads at 1.6-km intervals around the plant, but these are generally not heavily traveled, especially during the night and early morning hours when the tests were conducted. Figure 2 is an aerial photograph (taken February 1977 by the Kansas Gas and Electric Co.) of the immediate vicinity of the plant. Figures 3 and 4 are ground-level photographs of the plant that were taken during this project. Figure 3 shows the "perchloroethylene" unit (produces perchloroethylene and carbon tetrachloride) on the left and the "chloromethane" unit (produces methylene chloride, chloroform, and carbon tetrachloride) on the right. Figure 4 shows the plant and the surrounding farmland.

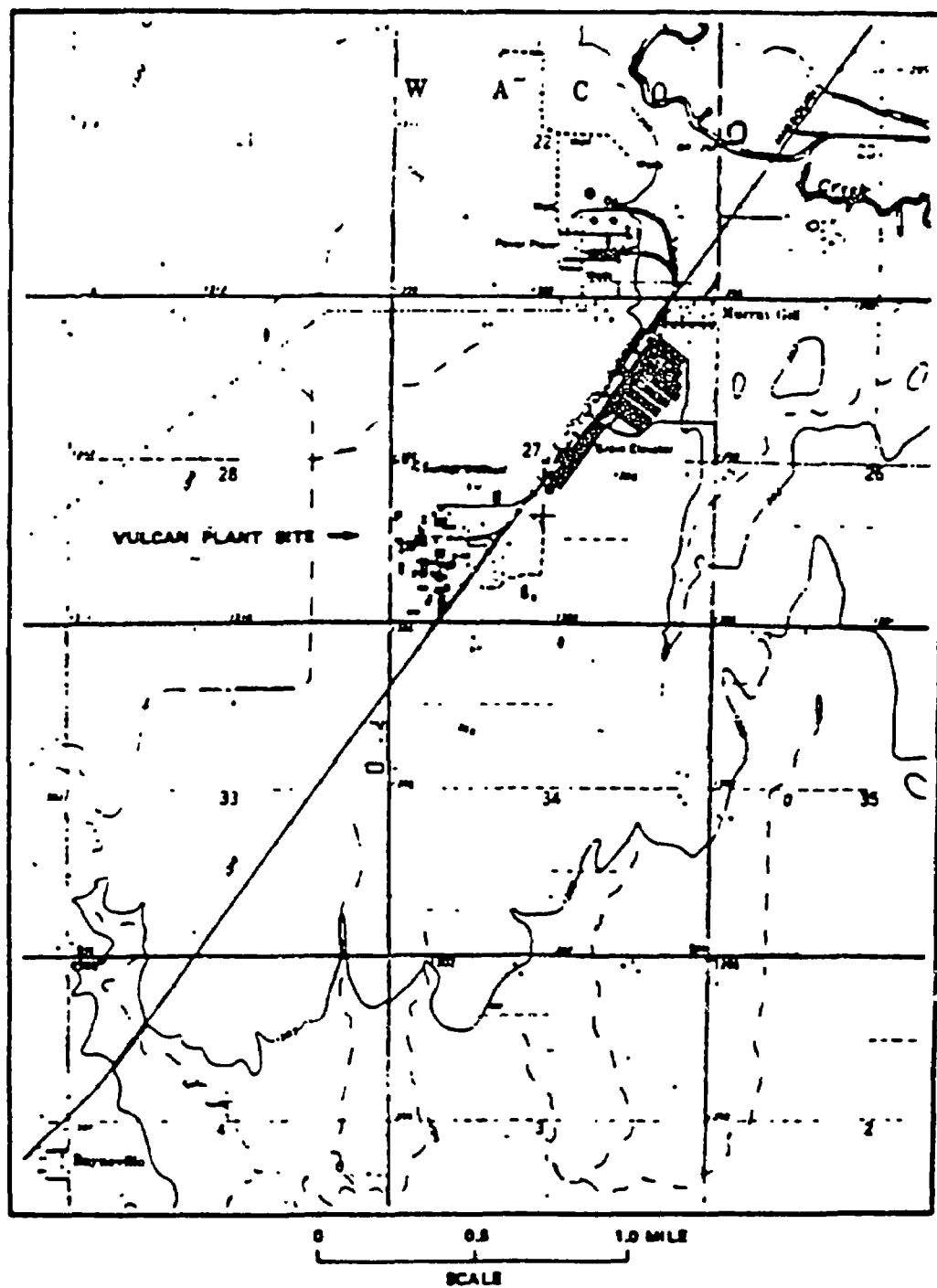


Figure 1. Topographic map of the Vulcan plant site.

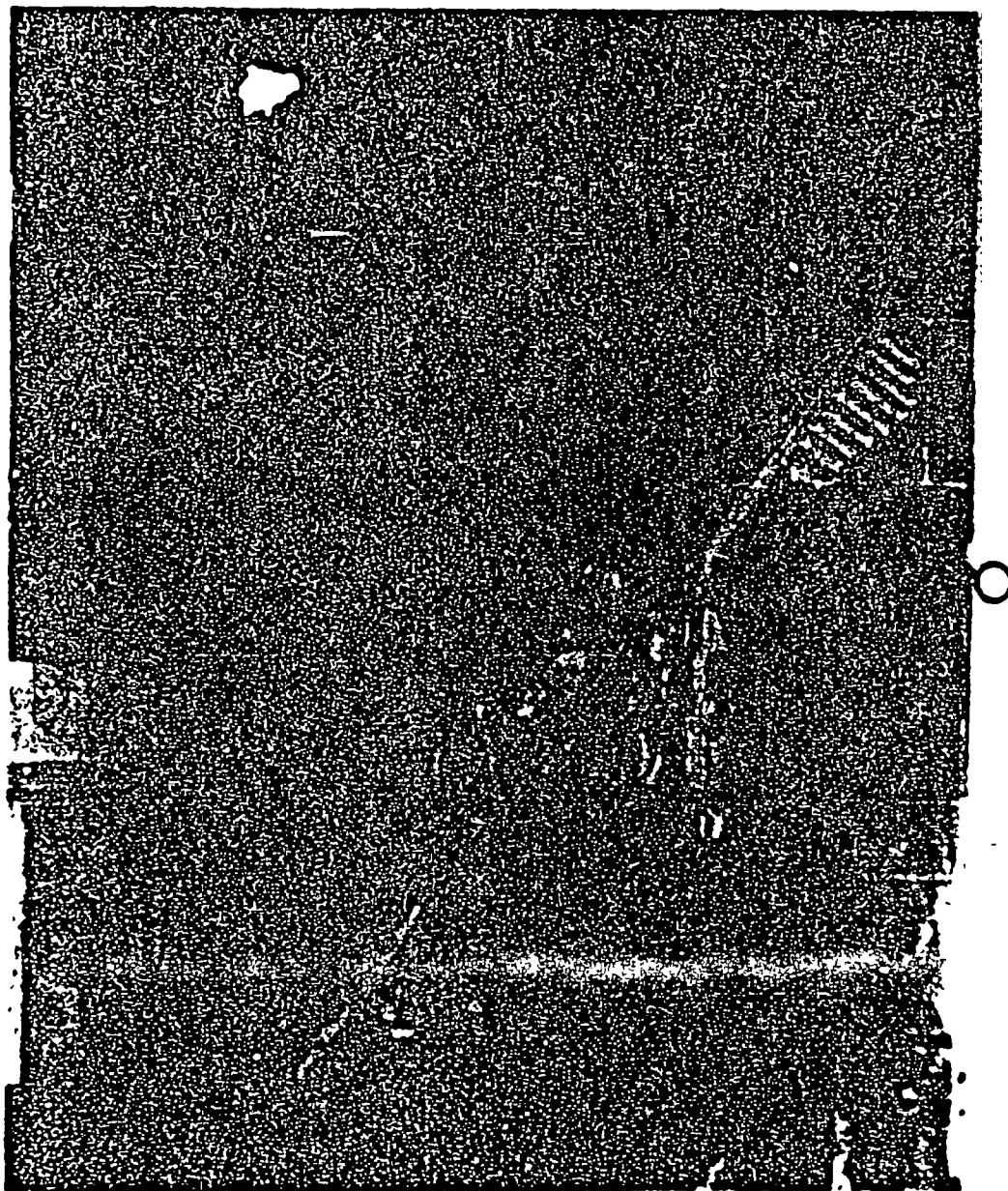


Figure 2. Aerial photograph of the area surrounding the Vulcan plant. (Photograph provided by Kansas Gas and Electric Company.)

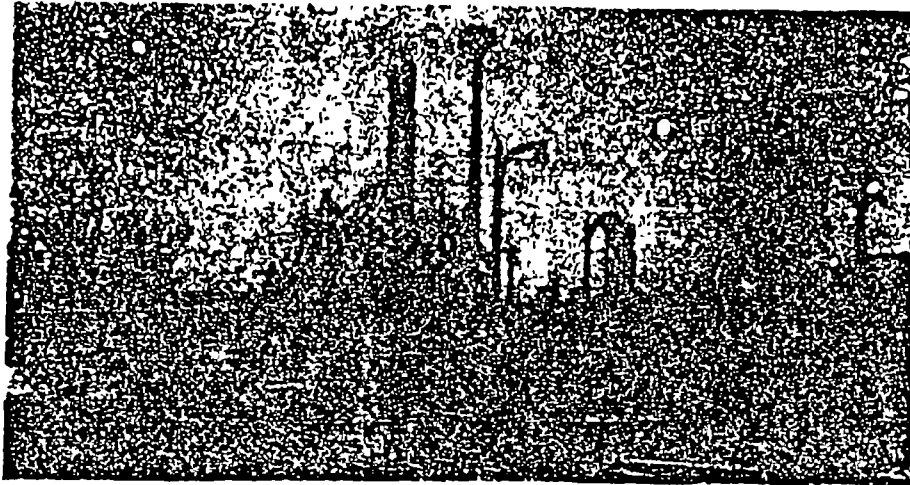


Figure 3. The perchloroethylene and chloromethane units at the Vulcan plant.

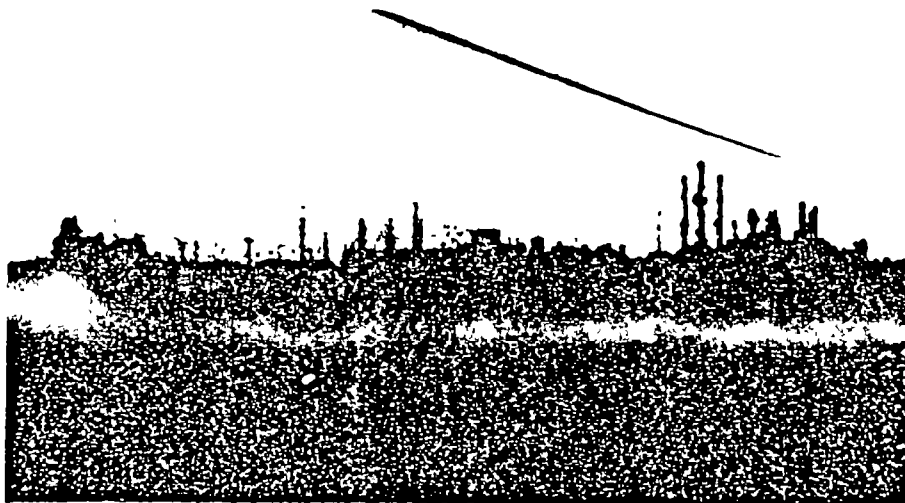


Figure 4. The Vulcan plant viewed from the north.

The Vulcan plant is a medium-sized plant occupying a rectangular space approximately 500 m in the east-west direction and 600 m in the north-south direction. However the area involved in solvent operations is much smaller. Figure 5, a section of the aerial photograph shown in Figure 2, indicates areas where operations might be conducted that would be related to the emissions of the solvents of concern. The outside boundaries of these sources are approximately 225 m in the east-west direction and 150 m in the north-south direction, but emissions of any given material are not likely to be present at all locations within these boundaries. Later, for the purpose of estimating the total emissions, it is assumed that the total emitting area is about 25,000 m²; this is about 60% of the solvent area described above. As noted earlier, it is believed that the emissions are all likely to occur within 5 to 10 m of the surface and at ambient temperatures, so there is not likely to be any significant buoyant rise.

SECTION 4

TEST PROCEDURES

GENERAL

This section describes the test procedures that were applied at the Vulcan manufacturing site near Wichita, Kansas. These procedures would generally apply for all sites. The need to collect samples upwind and downwind of the plant, as well as the methods for collecting and analyzing these samples would not change. The theory underlying the source-receptor methodology dictates that the best results will be obtained during the nighttime hours, because the method is not particularly sensitive to prevailing meteorological conditions when the atmosphere is stable, as it often is at night. The theory also dictates that the tracer releases be made in a line that is as close to the manufacturing plant as possible and as nearly perpendicular to the wind direction as possible.

Several considerations suggest that the sample collection be done as near the source as possible. Concentrations should be higher near the source; hence, the results of the chemical analysis should be more reliable. Collecting the samples near the source should also minimize the lateral spreading effects that negate the assumption of an infinite line source, which was used in deriving some of the equations for the methodology. However, one very important factor dictates that the samples not be collected too close to the source. The theory presumes that both the tracer and the materials of interest are released at approximately the same low altitude. Vertical mixing will tend to minimize the effects of differences in the release heights of the various materials at distances of 1 km or more from the source, where the vertical spread--as measured by the vertical standard deviation, σ_z , of a Gaussian concentration distribution--should be at least 15 m, even under moderately stable conditions. This would be enough to provide a reasonably uniform concentration distribution (when averaged over about an hour) through the lowest 10 to 20 m of the atmosphere for materials that have been released within that same layer. As noted earlier, the assumption of an infinite line source makes it desirable to minimize the lateral spreading. During nighttime conditions, the lateral spread--as measured by the horizontal standard deviation, σ_y , of a Gaussian distribution from a point source--will generally be 200 m or less to downwind distances of about 3 km. Therefore, the downwind samples should usually be collected at distances between 1 and 3 km downwind.

METEOROLOGICAL OBSERVATIONS

One of the reasons for developing a methodology based on the release of a tracer gas was to minimize the need for meteorological observations. Conventional, easily made meteorological observations are not directly related to all the factors that affect the diffusion and transport of emissions released from a plant. The relationship between conventional measurements and atmospheric stability is particularly subject to uncertainties. Nevertheless, there are operational requirements for some meteorological observations when using the tracer technique. Furthermore, meteorological observations provide an important source of backup information as well as information that can be used to interpret concentration data.

Most important to both the data interpretation and operational planning of the study are windspeed and wind direction observations. These were measured at an altitude of about 10 m in the immediate vicinity of the test site. The measurements were made with a propeller-vane anemometer at SRI's mobile laboratory site, indicated in Figure 2. The temperature and humidity were also measured at the same site, at a height of about 5 m.

In addition, SRI obtained copies of the official hourly weather observations made by the U.S. National Weather Service at Mid-Continent Airport in Wichita, Kansas, about 8 km north of the test area. These observations included temperature, humidity, windspeed and wind direction, and visual estimates of cloud amount and type. Airport wind directions represent more or less instantaneous measurements, subjectively averaged over about a minute or two, while those at the site were averaged over the hour, beginning at the time shown in the table. Cloud amount and type are important to the estimation of atmospheric stability class.

TRACER RELEASE PROCEDURES

The tracer chosen for this study was sulfur hexafluoride (SF_6), commonly used because it is totally inert and nontoxic, and because it occurs only at very low concentrations in the atmosphere. The tracer was released from the back of a moving vehicle through a flow-limiting needle valve. The use of a flow-limiting valve ensured a relatively constant emission rate. The flow rate was measured at nominal half-hour intervals using a Singer Model 115, dry test meter. Flow rates were very constant ($\pm 3\%$) over an 8-hour period. The total emissions during a test were determined from the weight of the SF_6 cylinder before and after the test. The average emission rate was determined from the following relationship:

$$\bar{Q}_1 = \frac{W}{Lt} \quad .$$

where

\bar{Q}_1 = the average line-source emission rate of SF_6
($\text{g m}^{-1} \text{s}^{-1}$)

W = the total weight of SF_6 released, as determined
by weighing (g)

L = the length of the road segment over which the
vehicle drove while releasing SF_6 (m)

t = the time interval over which the SF_6 release
took place (s)

It is possible to use an average emission rate, determined as described above, for these tests because the samples that are collected are also averaged over extended periods of time (1 h). If the averages obtained this way are to be reasonable approximations of the true average, the release vehicle must traverse the road segment at least six or seven times per hour. (In the experiments reported, it was traversed approximately 40 times per hour.)

There is the tacit (and reasonable) assumption that the meteorological conditions are uncorrelated with the location of the release vehicle.

For all of the test data considered in this report, a segment of road approximately 0.82 km in length was used. This road is immediately west of the plant, approximately 225 m from the center of the hydrocarbon manufacturing area (see Figure 2). It was possible to make quick U-turns at the intersections at each end of the road segment, because traffic was light during night hours on the road. Because the U-turns could be made quickly, it was not necessary to turn off the tracer release at these times. The release vehicle generally traveled about 32 km h^{-1} while traversing the road segment, so about 40 passes over the segment could be made during each hour.

Table 4 lists the release data for each night's testing.

TABLE 4. SF_6 RELEASE DATA

| Date of Test | Release Path Length (m) | Average Speed m/s | Passes per Hour | Total Release Rate (g/hr) | Line Release Rate ($\mu\text{g/m s}$) |
|--------------|-------------------------|-------------------|-----------------|---------------------------|---|
| 8/8 - 8/9 | 815 | 8.9 | 40 | 839 | 290 |
| 8/10 - 8/11 | 815 | 9.1 | 40.2 | 988 | 336 |
| 8/11 - 8/12 | 815 | 8.9 | 39.2 | 900 | 308 |
| 8/12 - 8/13 | 815 | 9.7 | 40 | 918 | 291 |

SAMPLE COLLECTION PROCEDURES

Bag Samplers

The downwind samples were taken at ground level by using the automatic samplers that SRI routinely uses for this type of work. These samplers manufactured by Environmental Measurements Inc. (EMI), are multiple-bag samplers containing 12 pumps and an electronic timing circuit by which up to 12 1-hour bag samples can be obtained sequentially. The EMI sampler is approximately 60 cm in diameter and 110 cm high, and weighs 11 kg. The sampler is operable over a temperature range of -10° to 50° C.

Each sampler is battery operated and uses a timing circuit that actuates the pumps intermittently to conserve battery life. The start time for sequential sampling (for the night operation) can be set in advance on each timer. As a result, it was possible to service the samplers in advance, before they were placed at the sampling sites in the early evening.

The EMI samplers were initially designed to actuate the pumps on a duty cycle of 2 s on and 30 s off to produce a 5-liter sample each hour. The timing circuits on a set of these samplers owned by SRI have been modified to obtain a duty cycle of 80 ms on and 1 s off. In addition, the bag size has been reduced to 2 L. These modifications provide a more representative hourly sample than can be obtained with the factory-supplied pump duty cycle, while still providing more than adequate sample volume.

From our experience with these samplers, SRI has found that Tedlar is the best material for these bags. It has no background of chlorinated hydrocarbons and it has very low permeability, so samples can be stored without contamination or loss. The bags are fabricated at SRI and a large number of them were in stock for use in the study. The bags were routinely checked for leakage during the test program. SRI has developed a routine bag cleaning process that was used between each sampling. The cleaned bags were tested on a random basis to ensure that they had been cleaned properly and that there was no inadvertent contamination. Each of the bags was identified with a label listing the sampler number and the time that the sample started.

Sample Locations

The samplers were placed at ground level, at power poles whenever possible. They were chained to the poles for security. For the first three tests, the samplers were placed at approximately 300-meter intervals. For the last test, the spacing was decreased to approximately 150 m, because a preliminary review of the data indicated that the plume might be passing between samplers.

The arc covered by the samplers was dictated by the wind direction and the prediction of wind direction from the U.S. National Weather Service. The sampler locations are shown on the maps presented in Section 5.

The samplers were placed at the designated locations by 2200 CST, and they were collected the following morning, beginning at 0700. After the samplers were returned to the mobile laboratory site, the bags were removed, checked for proper inflation, and hung in special racks pending analysis. Bags from the previous night's run were cleaned and used to reload the samplers.

SAMPLE ANALYSIS PROCEDURES

Chlorinated Hydrocarbons

The samples were analyzed using two Perkin-Elmer Model 3920 gas chromatographs (GCs), each with dual columns, injectors, and detectors. Each GC was equipped with a 1-meter injection loop, which was cooled with liquid oxygen to trap the halocarbons from 50-cm³ gas samples. It was then heated with boiling water to transfer the concentrated sample into the GC. The columns were 10 ft x 1/8 in (304 x 0.32 cm) 80/100 mesh SP2100. They were operated isothermally at 50° C with a total analysis time of 20 min.

Tracer Gas

SF₆ analysis was performed using a System Science and Software Model 215 AVP Environmeter, which is an electron-capture GC that operates at ambient temperatures. This GC uses an internal vacuum pump to flush and fill a 2-cm³ gas sampling loop, which is valved to introduce the samples. The output of the electron capture detector is sensed by an electrometer circuit, which is coupled to a peak read-and-hold circuit for digital peak maximum display, and a buffer amplifier that drives the analog output. In the test, the analog output was connected to a Hewlett-Packard Model 3390A computing integrator, which automatically labeled the sample, the peak elution time, and the peak area. The only modification used from the standard production model was the addition of a Brooks flow controller to allow finer control of the carrier gas flow rate.

Calibration

Calibration standard gases (Scott-Marin) were diluted with ultra-high purity nitrogen to make a series of calibration gases for the chlorinated hydrocarbons. In addition, there was a series of six prediluted standards for SF₆. The concentrations of these standards are given in Table 5.

Data Reduction

A data acquisition system was connected to the output of the GC. This system was designed to actively record the elution time and area of each peak. The peak area was then used to calculate the concentration of the species. During the test program, an intermittent failure occurred in the data acquisition system, causing it to record incorrect areas for some of the peaks. This failure was not discovered until

detailed data analysis was performed. For those cases where an incorrect area was recorded, SRI attempted to estimate the area from peak height. This was only partially successful, so any data based on peak height are considered unreliable.

The GC analyses provided measurements of CCl_4 concentrations, as well as those for the other three compounds. Although not required by the contract, results based on the CCl_4 measurements are presented in the following sections.

TABLE 5. CONCENTRATION OF
REFERENCE STANDARDS

| Gas | Concentration |
|-----------------------------------|-----------------|
| C_2HCl_3 | 1.2 ppb |
| C_2Cl_4 | 1.2 ppb |
| $\text{C}_2\text{H}_3\text{Cl}_3$ | 1.25 ppb |
| CCl_4 | 1.3 ppb |
| SF_6 | 25.6 ± 5 ppt |
| | 55.7 ± 5 ppt |
| | 105 ± 5 ppt |
| | 511 ± 5 ppt |
| | 1050 ± 50 ppt |
| | 10600 ± 500 ppt |

SECTION 5

TEST RESULTS

GENERAL

This section describes the conduct of the four successful tests and the concentrations observed during those tests. An interpretation of these observations will be presented in Section 6, along with dilution ratios and inferred emission rates. In this section, each of the four tests is presented separately, beginning with an overview of the meteorological conditions that prevailed during the test and followed by a description of the tracer release and the sampling array. Any information about samplers that were moved during the evening to better measure the patterns that were expected from the observed wind direction is also included. Finally, the observed concentrations for each test are tabulated.

TEST OF 8-9 AUGUST 1981

Meteorological Conditions

Table 6 summarizes the prevailing meteorological conditions during this test. It can be seen that the skies were clear until about 0500 CST on the morning of 9 August 1981. The temperature fell, in response to radiative cooling under clear skies. Winds tended to be light, generally less than 3 m s^{-1} at the site and at the airport. The winds were blowing from directions between about 200° and 250° (approximately from south-southwest to west-southwest). Light winds and cloudless skies generally accompany stable atmospheric conditions, so it is reasonable to assume that the atmosphere was stable during this evening.

Test Operations

Figure 6 shows the locations where samples were collected during this test. With winds generally blowing from the southwest, the samplers were located northeast of the plant. The road segment over which the SF_6 releases took place is also shown in Figure 6. With a southwest wind, it was not possible to find a road segment that was normal to the wind. The data collected on this evening were not as useful as those collected on some of the other evenings, because of the location of the line-source tracer release relative to wind directions.

TABLE 6. OBSERVED WEATHER CONDITIONS IN WICHITA AREA,
8-9 AUGUST 1981

| Hour (CST) | Sky Cover (tenths) | Wind | | | | Temperature (°F) | Relative Humidity (%) |
|---------------|--------------------------|------------------|------------------------------|--------------------------|------------------------------|---------------------|-----------------------------|
| | | At Site | | Mid-Continent Airport | | | |
| | | Direction (°) | Speed (ms ⁻¹) | Direction (°) | Speed (ms ⁻¹) | | |
| 2100 | 0 | | | 150 | 2.1 | 74 | 66 |
| 2200 | 0 | | | 200 | 1.5 | 73 | 66 |
| 2300 | 0 | | | 190 | 2.6 | 71 | 68 |
| 2400 | 0 | 200 | 1.8 | 210 | 2.1 | 72 | 64 |
| 0100 | 0 | 210 | 2.7 | 230 | 2.1 | 69 | 68 |
| 0200 | 0 | 210 | 2.7 | 230 | 2.1 | 68 | 68 |
| 0300 | 0 | 220 | 3.1 | 250 | 2.6 | 67 | 70 |
| 0400 | 0 | 210 | 2.7 | 240 | 2.1 | 67 | 70 |
| 0500 | 2 | 200 | 1.8 | --- | 0 | 64 | 78 |

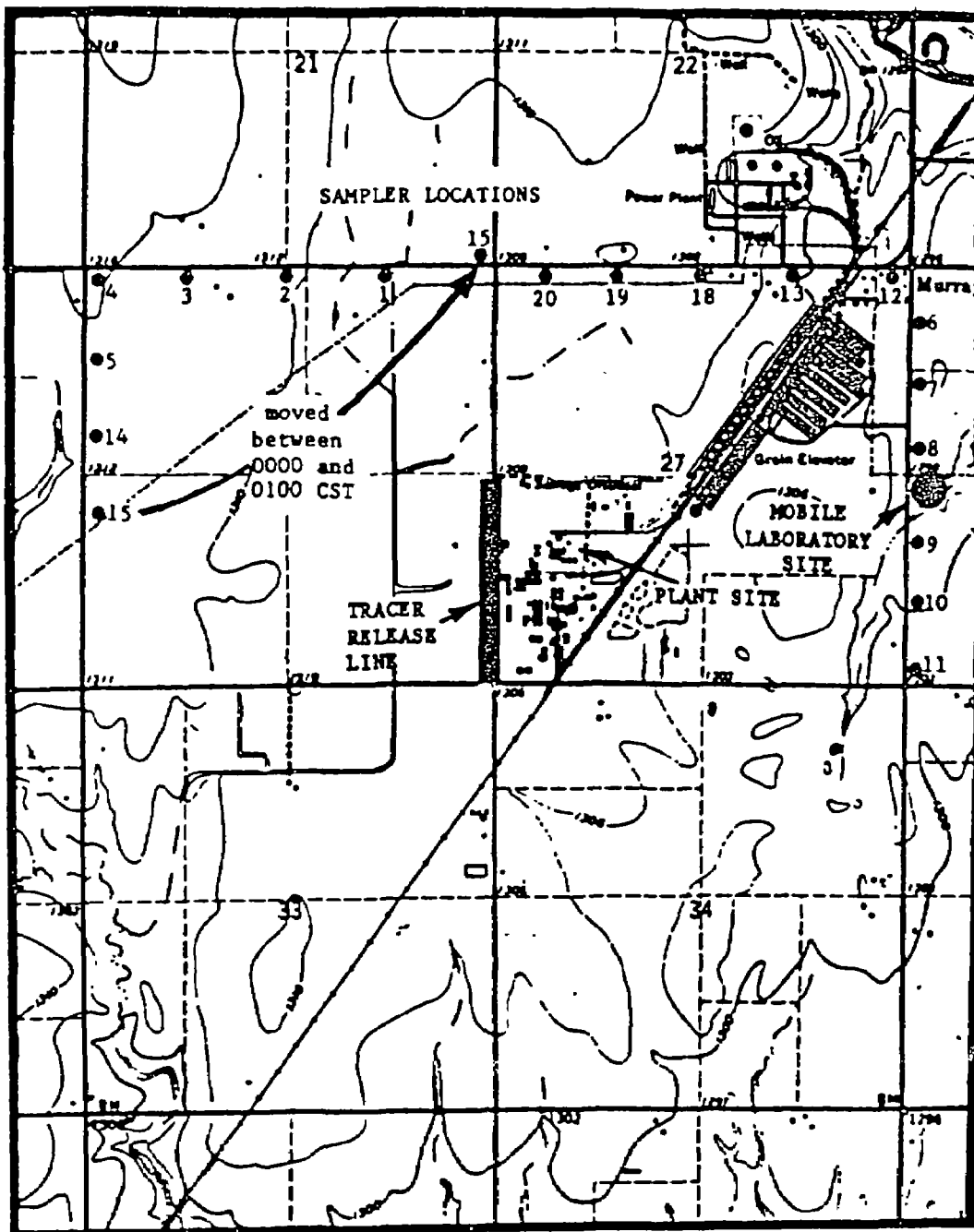


Figure 6. Sampling locations and tracer release line for the night of 8-9 August 1981.

Observed Concentrations

Table 7 summarizes the concentrations of the tracer and the chlorinated hydrocarbons that were measured. The sampling locations refer to those marked in Figure 6. It should be noted that some of the samplers were moved during the course of the test in order to provide an arc that was more nearly centered on the downwind direction. Complete analyses were not performed on samples for which the SF₆ results indicated little effect from the plant area.

The concentrations varied considerably from one location to another and from one time period to another. This high degree of variability is frequently observed; it appears to reflect a corresponding variability in the emissions from the plant. The importance of this variability to the design and execution of future experiments will be discussed later. Although none of the data collected during this evening were suitable for estimating the emission rates, they do indicate the concentration levels that are observed in the vicinity of the plant.

TEST OF 10-11 AUGUST 1981

Meteorological Conditions

Table 8 summarizes the meteorological conditions during this test. As was the case during the 8-9 August test, the winds were light, generally less than about 2 m s⁻¹ at the site. (They were slightly stronger at the airport.) Wind directions and sky conditions differed considerably from those of 8-9 August. Winds were initially from the east-southeast, but around midnight they switched to north-northeast. Overcast skies accompanied this wind shift. Initially, the overcast was altocumulus at about 3,000 m. Later, a layer of cirrostratus was observed at about 7,500 m. The cirrostratus overcast was dense enough to be considered opaque by the observer. Overcast skies are generally accompanied by neutral stability (2).

Test Operations

The location of the samplers and the route over which the line-source tracer release was made are shown in Figure 7. Initially, when the wind direction was from the east, a line of samplers was placed west of the site, as shown in the figure. However, as the wind developed a more northerly component, it was deemed necessary to add samplers south of the plant. Thus, samplers were installed and operated after about 0115 CST at the locations marked 19, 20, 1, and 2. Unfortunately, these samplers were faulty, and the samples collected could not be used. It would probably have been wise to realign the tracer release route at about the same time that the additional samplers were placed. This would have provided a line-source release that was more nearly perpendicular to the wind direction during the later hours.

TABLE 7. MEASURED CONCENTRATIONS, 8-9 AUGUST 1961^a

| Compound | Hour (CST) | Sampling Location ^b | | | | | | | | | |
|------------------|------------|--------------------------------|------|------|-------|-------------------|-------------------|-------|-------------------|-------------------|-------------------|
| | | 2 | 1 | 15 | 20 | 19 | 18 | 13 | 12 | 6 | 7 |
| CCl ₄ | 2000 | F ^c | | 1.72 | .98 | 1.20 ^d | 2.03 ^d | .97 | 12.0 | 3.08 ^d | .95 ^d |
| | 2100 | F | | 2.23 | 3.06 | 5.83 | 4.94 ^d | 20.5 | 3.71 | 5.32 ^d | 1.97 ^d |
| | 2200 | 6.28 | | 8.65 | 9.21 | .81 ^d | F | | 2.19 | 2.03 ^d | 2.20 ^d |
| | 2300 | 4.4 | 3.42 | .97 | 164.0 | .74 ^d | 3.62 ^d | 1.64 | 3.43 | 1.39 ^d | .65 ^d |
| | 0000 | 0.43 | 3.71 | .75 | 15.6 | 4.12 | 2.54 ^d | 8.72 | .38 ^d | 1.30 ^d | .30 |
| | 0100 | 2.69 ^d | 3.28 | .35 | .90 | 8.47 | F | 15.3 | 1.75 ^d | 1.77 ^d | 3.13 ^d |
| | 0200 | .296 ^d | 3.13 | 1.01 | F | 4.77 ^d | F | 69.2 | 1.44 ^d | 3.67 ^d | 2.54 ^d |
| | 0300 | .327 ^d | 2.67 | .72 | F | 1.14 ^d | .47 ^d | 183.0 | 12.0 | 11.8 ^d | 1.85 |
| | 0400 | .325 ^d | 9.86 | .88 | | .67 ^d | F | | 11.5 | 7.11 ^d | |
| | 0500 | 3.76 | | | 1.91 | 1.22 ^d | 6.10 ^d | 186.0 | 11.3 | F | .57 ^d |
| | 0600 | | | 4.10 | | | F | 15.1 | 1.08 | 1.43 ^d | 1.03 |
| SF ₆ | 2000 | | .09 | .14 | .13 | .16 | 13.7 | .16 | .07 | .17 | .11 |
| | 2100 | | | .05 | .58 | .09 | .15 | .06 | .04 | .09 | .05 |
| | 2200 | 2.61 | | .81 | 2.64 | .11 | F | | .11 | .09 | .20 |
| | 2300 | .05 | .10 | .02 | 1.57 | .02 | .04 | .02 | .01 | .03 | 6.26 |
| | 0000 | .09 | .08 | .02 | 5.87 | .02 | .03 | .02 | .02 | .05 | .52 |
| | 0100 | .04 | .10 | .16 | 6.92 | 12.7 | F | .06 | .02 | .04 | .19 |
| | 0200 | .02 | .15 | .61 | F | 9.35 | F | .93 | .05 | .01 | 1.66 |
| | 0300 | .01 | .10 | .06 | F | 9.57 | 9.70 | 4.05 | 1.78 | .48 | .10 |
| | 0400 | .03 | 19.4 | .03 | 5.87 | 8.35 | F | 2.39 | 1.07 | | |
| | 0500 | .04 | | | 12.3 | 19.0 | 5.96 | 1.51 | .23 | | .11 |
| | 0600 | | | 14.5 | | | F | .03 | .02 | .07 | .59 |

See footnotes at end of table.

(continued)

TABLE 7 (continued)

| Compound | Hour (CST) | Sampling Location ^b | | | | | | | | | |
|---------------------------------|---------------|--------------------------------|-------------------|-------------------|------|-------------------|-------------------|------|-------------------|-------------------|-------------------|
| | | 2 | 1 | 15 | 20 | 19 | 18 | 13 | 12 | 6 | 7 |
| C ₂ HCl ₃ | 2000 | F | | 4.67 | 4.65 | 4.50 ^d | 16.9 ^d | 9.57 | 5.56 | 26.1 ^d | 5.64 ^d |
| | 2100 | F | | 2.02 | 5.13 | 1.45 ^d | 3.62 ^d | 3.92 | 10.1 | 10.5 ^d | 2.79 |
| | 2200 | 16.3 | | 9.57 | 4.75 | | F | | 6.76 | 6.50 ^d | 10.2 ^d |
| | 2300 | 1.37 ^d | 1.91 | 6.53 | 2.05 | 1.67 ^d | | 6.98 | 2.06 ^d | 13.7 ^d | 1.69 |
| | 0000 | 1.82 | 1.57 | 10.8 | 5.22 | 2.77 ^d | 1.97 ^d | 5.26 | .88 | 4.42 ^d | 1.34 ^b |
| | 0100 | 1.34 ^d | 1.73 | 2.62 | 3.56 | 1.37 ^d | F | 5.33 | 1.20 | 5.94 ^d | 4.72 ^d |
| | 0200 | 1.25 ^d | 1.76 ^d | 6.58 | F | 1.52 ^d | F | 2.53 | 1.40 | 7.00 ^d | 4.13 ^d |
| | 0300 | 1.17 ^d | 1.99 | 8.23 | F | 1.52 ^d | 6.61 ^d | 2.80 | 1.83 | 9.63 ^d | 6.57 |
| | 0400 | 1.54 ^d | 5.18 | 4.00 | | 1.07 ^d | F | | 2.82 | 6.33 ^d | |
| | 0500 | | | | 3.56 | 1.25 ^d | 4.75 ^d | 2.93 | 1.25 ^d | F | 8.32 ^d |
| | 0600 | | | 27.6 | | | F | 3.04 | 10.5 | 9.52 ^d | 5.24 |
| C ₂ Cl ₄ | 2000 | | | 2.04 | 2.02 | .44 ^d | 2.48 ^d | 1.58 | 3.16 | 18.7 ^d | 10.4 |
| | 2100 | | | 1.26 | 2.75 | .48 ^d | 2.17 ^d | 1.35 | 21.8 | 5.36 ^d | 1.67 |
| | 2200 | 24.0 | | 2.84 | 1.94 | .00 ^d | F | | 4.63 | 4.43 ^d | 3.56 ^d |
| | 2300 | .35 ^d | .95 | 4.63 | 4.75 | 1.03 ^d | 1.38 ^d | 1.62 | .60 ^d | 7.14 ^d | .43 |
| | 0000 | .35 ^d | .58 | 1.22 ^d | 2.14 | .48 ^d | 1.01 ^d | 1.75 | .44 ^d | .32 ^d | .79 ^d |
| | 0100 | .31 ^d | .56 | 1.03 | 1.58 | .89 ^d | F | 1.66 | .67 | 4.02 ^d | 2.57 ^d |
| | 0200 | .31 ^d | .66 | 1.67 | F | .74 ^d | F | 2.74 | .48 | 5.05 ^d | 2.20 ^d |
| | 0300 | .31 | .91 | 2.69 | F | .33 | 2.48 ^d | | 2.02 | 18.2 ^d | 4.18 |
| | 0400 | .31 ^d | 1.06 | 1.17 | | .33 ^d | F | | 1.14 | 10.8 ^d | |
| | 0500 | .31 | | | 1.27 | .37 ^d | 3.10 ^d | 2.74 | 1.57 ^d | | .41 ^d |
| | 0600 | | | 45.2 | | | F | .35 | 4.84 | 2.40 ^d | 2.46 |

See footnotes at end of table.

(continued)

TABLE 7 (continued)

| Compound | Hour (CST) | Sampling Location ^b | | | | | | | | | |
|---|---------------|--------------------------------|------------------|------|------|------------------------------------|-------------------|------|------|-------------------|-------------------|
| | | 2 | 1 | 15 | 20 | 19 | 18 | 13 | 12 | 6 | 7 |
| C ₂ H ₃ Cl ₃ | 2000 | | | 7.76 | 1.36 | 328.0 ^d | 10.8 ^d | 7.21 | 6.97 | 10.7 ^d | 5.0 ^d |
| | 2100 | | | 6.65 | 7.93 | 9.24 | 9.26 ^d | .41 | 5.97 | 9.76 | 5.53 ^d |
| | 2200 | 11.1 | | 14.2 | 5.19 | (4.03)10 ⁶ ^d | F | | 9.26 | 10.1 | 10.6 ^d |
| | 2300 | 13.5 | 13.3 | 5.36 | .41 | 36200.0 ^d | 10.6 ^d | 5.79 | 14.0 | 13.6 ^d | 5.49 ^d |
| | 0000 | 2.99 | 4.10 | 4.75 | 6.51 | 9.72 | 6.16 ^d | 4.67 | 6.0 | 8.83 ^d | 5.73 ^d |
| | 0100 | 3.89 ^d | 3.19 | 3.65 | 9.29 | 10.9 | F | 21.9 | 3.18 | 9.95 ^d | 10.0 ^d |
| | 0200 | 3.53 ^d | .34 ^d | 6.27 | F | 3.30 ^d | F | 4.14 | 5.03 | 10.4 ^d | 9.76 ^d |
| | 0300 | 4.69 ^d | 3.27 | 11.1 | F | 12.7 | 12.7 ^d | 5.37 | 6.17 | 9.83 ^d | 7.27 |
| | 0400 | 4.51 ^d | 6.35 | 4.72 | | 11.9 | | | 10.7 | 9.46 ^d | |
| | 0500 | 11.3 | | | 11.4 | 13.4 | 11.6 ^d | 8.18 | 12.1 | | 4.09 ^d |
| | 0600 | | | 8.95 | | | F | 5.12 | 9.59 | 10.6 | 9.14 ^d |

^aConcentrations expressed in $\mu\text{g m}^{-3}$.

^bSee Figure 6 for sampling locations.

^cF = flat bag.

^dPeak height measurements.

3/39
RSD
meter

TABLE 8. OBSERVED WEATHER CONDITIONS IN WICHITA AREA,
10-11 AUGUST 1981

| Hour (CST) | Sky Cover (tenths) | Wind | | | | Temperature (°F) | Relative Humidity (%) |
|---------------|--------------------------|------------------|------------------------------|--------------------------|------------------------------|---------------------|-----------------------------|
| | | At Site | | Mid-Continent Airport | | | |
| | | Direction (°) | Speed (ms ⁻¹) | Direction (°) | Speed (ms ⁻¹) | | |
| 2200 | 1 | 70 | 1.8 | 100 | 2.1 | 69 | 73 |
| 2300 | 7 | 100 | 1.8 | 110 | 2.1 | 69 | 73 |
| 2400 | 10 | 85 | 1.3 | 40 | 2.6 | 69 | 73 |
| 0100 | 10 | 45 | 0.4 | 360 | 1.5 | 69 | 76 |
| 0200 | 10 | 30 | 0.9 | 20 | 2.1 | 68 | 79 |
| 0300 | 10 | 30 | 0.9 | 350 | 2.1 | 66 | 84 |
| 0400 | 10 | 20 | 0.9 | 40 | 2.1 | 66 | 84 |
| 0500 | 8 | 15 | 0.9 | 30 | 2.6 | 65 | 84 |
| 0600 | 9 | 20 | 0.9 | -- | 0 | 64 | 84 |

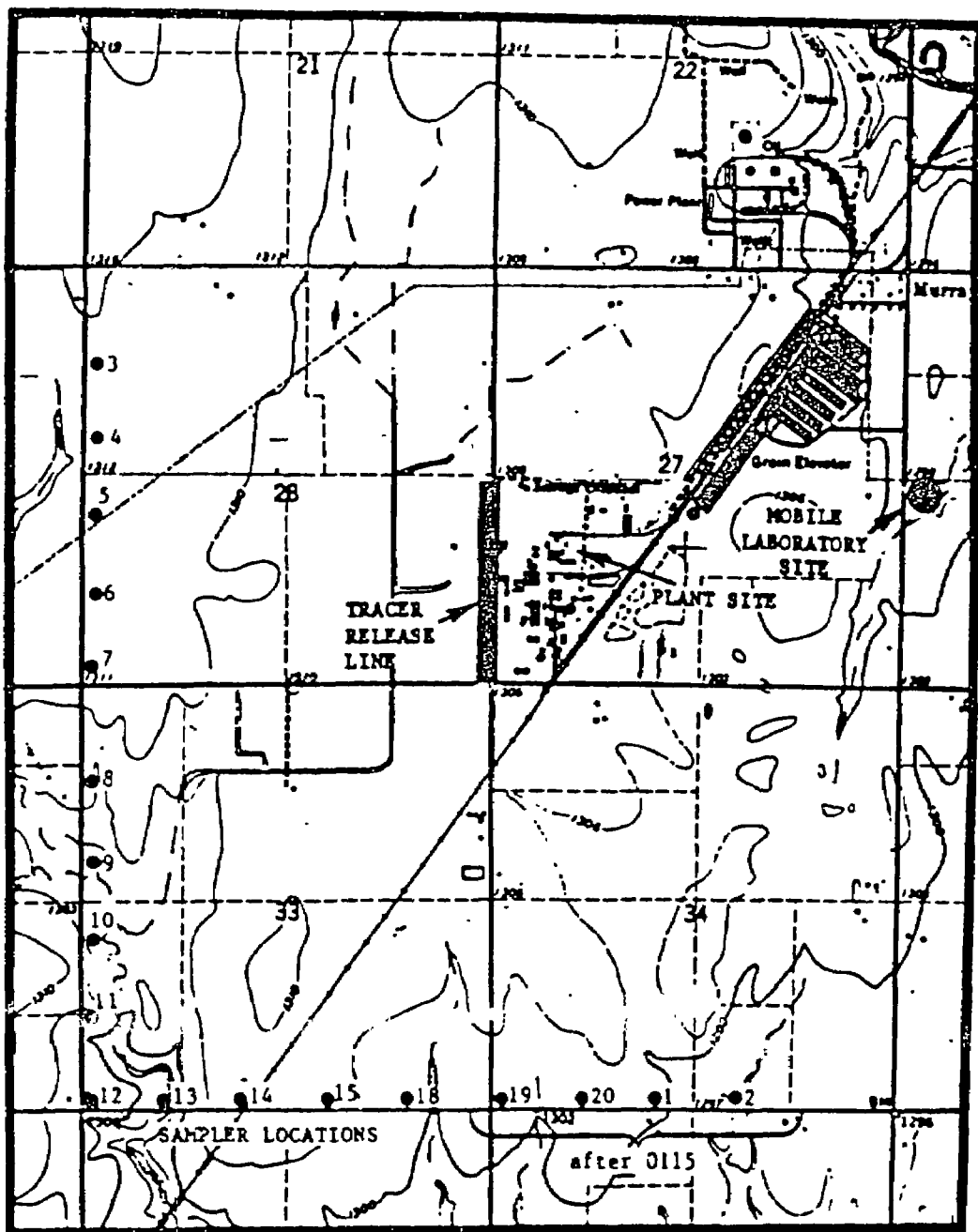


Figure 7. Sampling locations and tracer release line for the night of 10-11 August 1981.

Observed Concentrations

Table 9 gives the observed concentrations of the tracer and the chlorinated hydrocarbons. As shown in Table 8, the winds between 2400 and 0100 at the site were generally from the east (85°) and shifted to the northeast during the following hour. The data collected during these 2 h show significant concentrations of CCl_4 and C_2HCl_3 . It appears that there may have been above-normal releases of material that were detected by the sampling network during this period. For that reason, 2 h have been chosen for interpretation and for estimating the release rates. They will be discussed in greater detail in the next section.

TEST OF 11-12 AUGUST 1981

Meteorological Conditions

The meteorological conditions that prevailed during this test are summarized in Table 10. The skies were overcast during most of the period, so the atmospheric stability was neutral. Winds at the site were generally from the east until about 0300, when they shifted to the southeast. Winds were from the east at the Mid-Continent Airport until about midnight, when they shifted to southerly; later, the winds were more from the southeast. During the last 3 h of the test period, the airport winds were approximately south-southeast. Table 10 shows that the temperature dropped about 3° F during this period. Relative humidity rose correspondingly from 64 to 78%. The cloud cover throughout this period was cirrostratus at an altitude of about 7,500 m.

Test Operations

Figure 8 shows the sampler locations and the route traveled during the tracer release operations. The sampling array was set up to accommodate the winds at the beginning of the period. These winds were from the east or slightly northeast, so the array was quite suitable for measuring influences from the tracer line and from the plant. However, around 0400 CST, the winds shifted, so most of the materials were carried north of the sampling line.

Observed Concentrations

Table 11 gives the concentrations of the various materials. As noted earlier, the wind directions during the first few hours of this period were nearly perpendicular to the roadway on which the tracer was released. This is the most suitable alignment for application of the method described earlier. One of the test hours (2200-2300 CST) has provided interesting data that could be used to estimate emissions from the plant.

TABLE 9. MEASURED CONCENTRATIONS, 10-11 AUGUST 1981^a

| Compound | Hour (CST) | Sampling location ^b | | | | | | | | | | | | | |
|---------------------------------|------------|--------------------------------|-------------------|-------------------|-------------------|------|------|-------------------|------|----------------|-------------------|----------------|------|----------------|-------------------|
| | | 18 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 |
| SF ₆ | 2200 | 1.32 | | .21 | | .01 | | .06 | | r ^c | .05 | .04 | .05 | | .07 |
| | 2300 | .05 | | | .01 | .01 | | .02 | | | 1.38 | r ^c | .20 | .03 | .05 |
| | 0000 | 3.56 | | .18 | .03 | .01 | | .01 | | | .61 | 1.11 | 2.25 | .20 | .04 |
| | 0100 | .10 | .03 | .07 | | | | .27 | | | .05 | .05 | .04 | r ^c | .08 |
| | 0200 | .10 | .03 | .02 | | .07 | | | | | .06 | .06 | .06 | r ^c | r ^c |
| | 0300 | .10 | .03 | .13 | .03 | | | .02 | | | 2.44 | .07 | .04 | .04 | .01 |
| | 0400 | .06 | | | .16 | .04 | | r ^c | | | .51 | | .07 | r ^c | r ^c |
| | 0500 | .20 | | .15 | | .02 | | .01 | | | .04 | .05 | .07 | .03 | .05 |
| | 0600 | | .03 | .01 | .14 | | .01 | .04 | | | .07 | .07 | .06 | .02 | .03 |
| | | | | | | | | | | | | | | | |
| CCl ₄ | 2200 | | | 7.17 | .51 ^d | 54.4 | 193 | 23.2 | 51.6 | | 1.52 ^d | | | | .15 |
| | 2300 | 1.39 ^d | .91 ^d | 4.51 | 1.19 ^d | .39 | 3.65 | .66 ^d | 10.5 | 154 | 7.31 ^d | | | 3.89 | .13 |
| | 0000 | 1.59 | .65 ^d | 6.18 | .23 ^d | .29 | 12.3 | 4.26 | 2.46 | 13.8 | 4.45 ^d | 5.25 | 2.69 | 3.31 | .33 |
| | 0100 | 1.20 | | 25.9 | 4.41 ^d | 6.7 | 22.2 | .45 ^d | 1.01 | 6.08 | 1.73 ^d | | | | .63 |
| | 0200 | 5.47 ^d | | .79 ^d | .72 ^d | .45 | 7.27 | .69 ^d | | | 1.25 ^d | | | | |
| | 0300 | 1.16 ^d | | | 1.16 ^d | .09 | | .72 ^d | | | 1.53 ^d | | | | .50 |
| | 0400 | 2.12 ^d | | | 1.78 ^d | .99 | | | | | 1.84 ^d | | | | |
| | 0500 | 4.17 | | .66 | 1.09 ^d | .21 | | .55 ^d | | | 1.41 ^d | | | | .95 |
| | 0600 | | | .51 ^d | 1.10 ^d | .21 | | 3.60 | | | 1.18 ^d | | | | .57 |
| | | | | | | | | | | | | | | | |
| C ₂ HCl ₃ | 2200 | 12.0 ^d | | 8.92 | 1.79 ^d | 8.04 | 8.95 | 1.95 ^d | 5.06 | | 3.28 ^d | | | | 1.46 ^d |
| | 2300 | 26.7 | 1.42 ^d | 5.33 | 4.64 ^d | 2.61 | 3.59 | 2.77 ^d | 10.4 | 8.42 | 12.9 ^d | | | 2.02 | 2.85 ^d |
| | 0000 | 20.3 | 0.2 ^d | 15.8 | 2.68 ^d | 18.4 | 10.5 | 5.66 | 22.1 | 16.5 | 22.4 ^d | 26.7 | 3.79 | 32.8 | 8.69 ^d |
| | 0100 | 17.2 | | 8.72 | 14.3 ^d | 26.5 | 13.5 | 8.04 ^d | 28.0 | 12.7 | 13.6 ^d | | | | 16.4 |
| | 0200 | 19.3 ^d | | 5.00 ^d | 5.08 ^d | 17.2 | 5.26 | 4.50 | | | 10.4 ^d | | | | |
| | 0300 | 2.79 ^d | | | 4.75 ^d | 15.4 | | 5.64 ^d | | | 9.69 ^d | | | | 2.90 ^d |
| | 0400 | 3.56 ^d | | | 8.46 ^d | 10.8 | | | | | 3.93 ^d | | | | |
| | 0500 | 4.84 | | 5.79 | 1.79 ^d | 6.53 | | 2.15 ^d | | | 3.64 ^d | | | | 2.74 ^d |
| | 0600 | | | 1.43 ^d | 5.71 ^d | 9.65 | | 22.1 | | | 4.30 ^d | | | | 4.50 |
| | | | | | | | | | | | | | | | |

See footnotes at end of table.

(continued)

TABLE 4 (continued)

| Compound | Hour (CST) | Sampling Location ^b | | | | | | | | | | | | | |
|--------------|---------------|--------------------------------|-------------------|-------------------|-------------------|------|------|-------------------|------|------|-------------------|------|------|------|-------------------|
| | | 13 | 15 | 14 | 11 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 |
| C_2Cl_4 | 2200 | 1.38 | | 1.61 | .39 ^d | 2.32 | 5.12 | .87 | 1.68 | | 2.02 ^d | | | | .31 |
| | 2300 | | .48 ^d | 1.50 | 1.80 ^d | 3.86 | .18 | .52 ^d | 2.50 | 4.29 | 3.18 ^d | | | 1.57 | .68 ^d |
| | 0000 | 2.42 | .44 ^d | 1.65 | .22 ^d | 7.04 | 1.76 | .48 ^d | 1.67 | 3.01 | 2.48 ^d | 3.85 | | 1.70 | .48 |
| | 0100 | 2.89 | | 2.12 | 2.04 ^d | 3.25 | 1.76 | .52 ^d | 2.08 | 1.48 | 2.09 ^d | | | | 3.07 |
| | 0200 | 2.75 ^d | | .74 | .64 | 2.45 | 2.05 | .40 ^d | | | 1.82 ^d | | | | |
| | 0300 | .55 | | | .78 | 2.93 | | .15 | | | 1.74 ^d | | | | .48 |
| | 0400 | 1.35 ^d | | | 2.29 ^d | 2.08 | | | | | 1.74 ^d | | | | |
| | 0500 | 1.55 ^d | | 1.40 | .49 | 2.20 | | .26 ^d | | | 1.10 ^d | | | | 1.19 |
| | 0600 | | | .44 ^d | 1.01 ^d | 1.86 | | .09 | | | 1.21 ^d | | | | .98 |
| | | | | | | | | | | | | | | | |
| $C_2H_3Cl_3$ | 2200 | | | 5.20 | 3.47 ^d | 8.39 | 6.10 | 10.0 ^d | 3.31 | | 7.34 ^d | | | | 6.09 ^d |
| | 2300 | | 11.6 ^d | 6.29 | 9.04 ^d | 19.8 | .93 | 7.14 ^d | 9.58 | 6.90 | 9.46 ^d | | | 5.34 | 5.94 ^d |
| | 0000 | 4.76 | 4.34 ^d | 7.79 | 8.12 ^d | 9.81 | 9.39 | 7.03 ^d | 7.54 | 5.99 | 9.33 ^d | 9.38 | 5.05 | 8.57 | 3.10 |
| | 0100 | 5.69 | | 6.37 | 7.12 ^d | 8.34 | 8.52 | 5.30 ^d | 9.44 | 7.84 | 8.77 ^d | | | | 7.94 |
| | 0200 | 5.92 ^d | | 6.30 ^d | 11.6 | 8.77 | 8.71 | 7.18 ^d | | | 8.61 ^d | | | | |
| | 0300 | 3.04 | | | 6.14 ^d | 8.66 | | 13.1 | | | 8.70 ^d | | | | 8.09 ^d |
| | 0400 | .55 ^d | | | 9.05 ^d | 8.58 | | | | | 8.34 ^d | | | | |
| | 0500 | 6.22 ^d | | 6.01 | 10.1 | 8.43 | | 5.10 ^d | | | 8.67 ^d | | | | |
| | 0600 | | | 4.08 ^d | 7.25 ^d | 5.93 | | | | | 8.49 ^d | | | | 7.06 |
| | | | | | | | | | | | | | | | |

^aConcentrations expressed in $\mu\text{g m}^{-3}$.^bSee Figure 7 for sampling locations.^cF = flat bag.^dPeak height measurement.

TABLE 10. OBSERVED WEATHER CONDITIONS IN WICHITA AREA,
11-12 AUGUST 1981

| Hour (CST) | Sky Cover (tenths) | Wind | | | | Temperature (°F) | Relative Humidity (%) |
|---------------|--------------------------|------------------|------------------------------|--------------------------|------------------------------|---------------------|-----------------------------|
| | | At Site | | Mid-Continent Airport | | | |
| | | Direction (°) | Speed (ms ⁻¹) | Direction (°) | Speed (ms ⁻¹) | | |
| 2100 | 10 | 80 | 2.2 | 70 | 3.1 | 72 | 64 |
| 2200 | 10 | 90 | 1.8 | 80 | 2.6 | 71 | 66 |
| 2300 | 10 | 100 | 1.8 | 90 | 3.1 | 70 | 68 |
| 2400 | 10 | 110 | 1.3 | 190 | 1.5 | 67 | 78 |
| 0100 | 10 | 90 | 0.4 | 140 | 1.5 | 67 | 73 |
| 0200 | 10 | 100 | 0.9 | 130 | 2.6 | 67 | 71 |
| 0300 | 10 | 95 | 0.9 | 130 | 2.1 | 65 | 78 |
| 0400 | 10 | 135 | 0.9 | 160 | 1.5 | 64 | 79 |
| 0500 | 8 | 155 | 0.9 | 160 | 1.5 | 64 | 78 |
| 0600 | 8 | 140 | 0.9 | 160 | 1.5 | 65 | 78 |

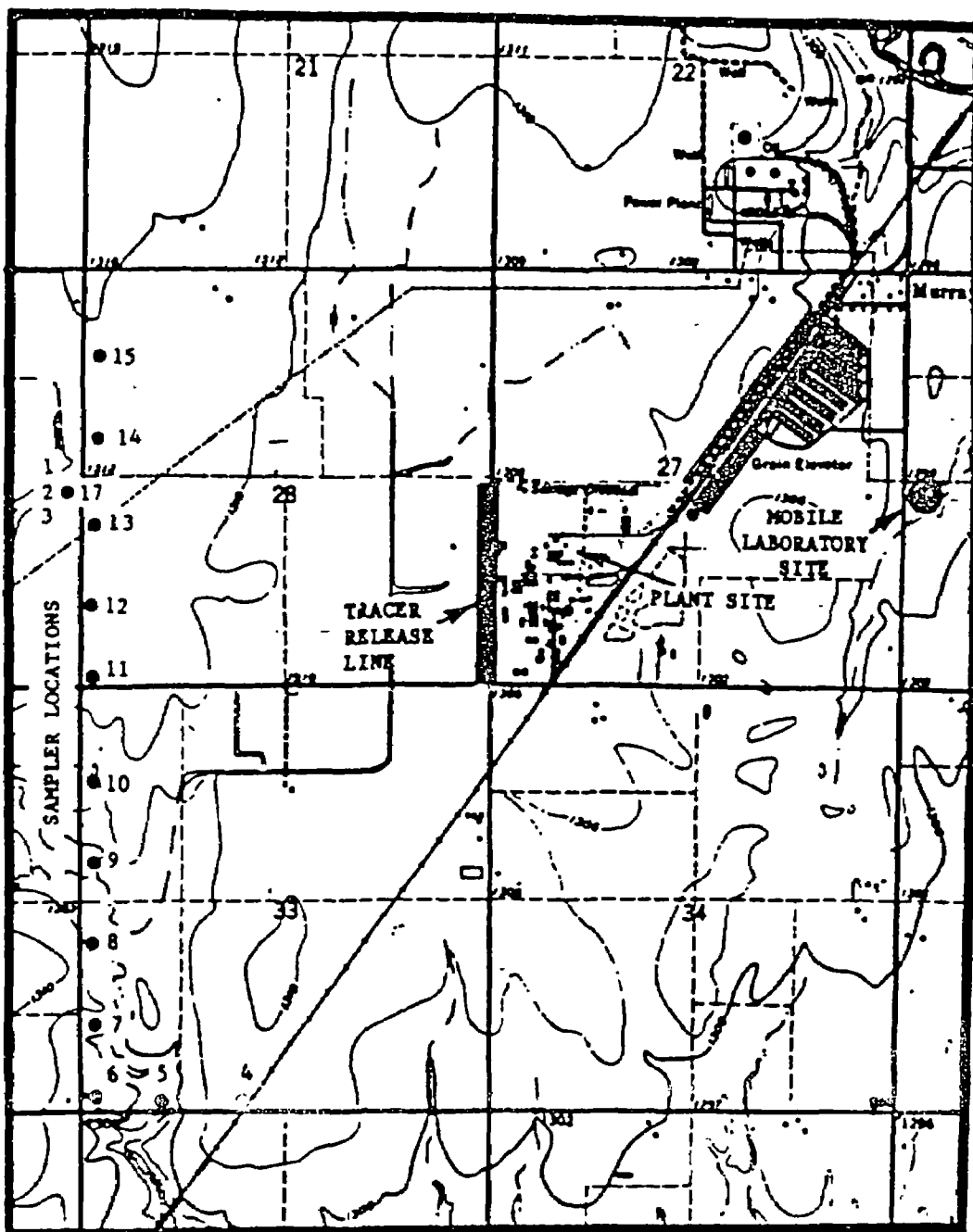


Figure 8. Sampling locations and tracer release line for the night of 11-12 August 1981.

TABLE 11. MEASURED CONCENTRATIONS, 11-12 AUGUST 1981^a

| Compound | Hour (CST) | Sampling Location ^b | | | | | | | | | | | | |
|---------------------------------|---------------|--------------------------------|------|-------------------|------------------|-------------------|------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 1 | 17 | 14 | 15 |
| SF ₆ | 2200 | .04 | .06 | .05 | | .04 | .03 | .10 | .69 | .13 | .15 | 1.14 | .14 | .14 |
| | 2300 | .03 | .03 | .03 | .01 | .04 | .07 | 1.53 | 3.08 | 1.42 | .52 | .79 | .57 | .43 |
| | 0000 | .30 | .25 | .06 | .05 | .04 | .03 | .39 | 1.17 | 1.60 | 3.47 | 1.35 | 1.39 | 1 ^c |
| | 0100 | .88 | .90 | .03 | .02 | .04 | .42 | 1.04 | 16.7 | 2.21 | 1.33 | 1.68 | 2.08 | 1.68 |
| | 0200 | .05 | .04 | .02 | .02 | .09 | .61 | 1.37 | 3.52 | 2.70 | 2.21 | 4.83 | .83 | .67 |
| | 0300 | .03 | .04 | .02 | .03 | .07 | .18 | .60 | 5.74 | 2.98 | 2.88 | 1 ^c | 6.00 | .33 |
| | 0400 | .97 | 1.84 | .03 | .02 | .26 | .04 | .05 | .10 | .83 | | 3.61 | 1.54 | 12.9 |
| | 0500 | .06 | .11 | .02 | .04 | .04 | .04 | .02 | .11 | .09 | 1.11 | 2.03 | .88 | .15 |
| | 0600 | .78 | 2.32 | .03 | .13 | .03 | .05 | .61 | .13 | .05 | .81 | 1.97 | .17 | |
| CCl ₄ | 2200 | 2.46 ^d | 14.8 | 1.15 | | 1.66 ^d | 61.8 | 5.42 ^d | 44.7 | 6.92 | .45 ^d | .72 | .63 | 2.05 ^d |
| | 2300 | 1.42 ^d | 9.36 | .75 | | .23 | 39.8 | 1.32 ^d | 13.3 | 7.02 | 1.99 ^d | | 12.0 | 1.06 ^d |
| | 0000 | 3.53 ^d | 10.6 | .72 | 1.02 | .58 ^d | 4.01 | 1.13 ^d | 33.7 | 9.06 | 9.31 | 17.7 | 51.1 | |
| | 0100 | | 76.7 | .50 | .60 | .50 ^d | 10.5 | 1.44 ^d | | 11.0 | 7.27 ^d | 5.71 ^d | 28.0 | 8.23 ^d |
| | 0200 | 2.04 ^d | 7.12 | | | .65 ^d | 4.87 | 1.84 ^d | 5.28 | 11.3 | 4.95 | 11.5 | 6.74 | 4.37 ^d |
| | 0300 | 1.60 ^d | 8.07 | .92 | .60 | .47 ^d | 21.7 | 4.15 ^d | 15.9 | 9.81 | 10.0 | | 243 | 4.51 ^d |
| | 0400 | 6.97 ^d | 153 | 1.03 | .32 | .58 ^d | .81 | 1.37 ^d | .82 ^d | 1.19 | | 73.2 | 13.5 | 6.87 ^d |
| | 0500 | 1.70 ^d | 6.77 | | .86 ^d | .57 ^d | 8.32 | 1.54 ^d | 1.40 ^d | 1.54 | 14.1 | 11.7 ^d | | 1.39 ^d |
| | 0600 | 3.27 ^d | 188 | .80 | .84 | .52 ^d | 140 | 1.65 ^d | 2.34 | 1.76 | 2.62 ^d | .004 ^d | .78 ^d | |
| C ₂ HCl ₃ | 220 | 18.4 ^d | 23.3 | 37.3 | | 12.2 ^d | 22.4 | 28.3 ^d | 18.9 | 6.11 | 8.69 ^d | 32.8 | 26.8 | 24.2 ^d |
| | 230 | 5.60 ^d | 10.3 | 6.15 | | 2.88 ^d | 3.44 | 6.66 ^d | 1.97 ^d | 1.61 | 7.99 ^d | .03 | 9.16 | 7.90 ^d |
| | 0000 | 5.77 ^d | 3.57 | 9.90 | 9.90 | 2.35 | 6.32 | 6.78 ^d | 3.65 | 1.87 ^d | 4.22 | 52.0 | 5.49 | |
| | 0100 | | 2.95 | 6.92 ^d | 6.85 | 2.36 | 8.15 | 7.50 ^d | | 2.15 ^d | 3.66 ^d | 31.5 ^d | 4.22 | 5.60 ^d |
| | 0200 | 5.88 ^d | 5.45 | | | 2.46 ^d | .52 | 3.76 ^d | 1.59 ^d | 1.70 ^d | 2.90 ^d | 49.7 | 5.08 | 5.60 ^d |
| | 0300 | 4.87 ^d | 5.33 | 5.83 | 5.99 | 1.16 ^d | 13.9 | 8.40 ^d | 3.27 | 1.41 ^d | 3.80 ^d | | 9.26 | 4.93 ^d |
| | 0400 | 4.59 ^d | 2.83 | 6.62 | 7.36 | 2.77 ^d | 13.7 | 6.10 ^d | 2.11 | 2.69 ^d | | 29.9 | 40.8 | 5.44 ^d |
| | 0500 | 4.68 ^d | .67 | | 9.90 | 1.97 ^d | 13.7 | 6.94 ^d | 5.38 ^d | 1.78 ^d | 3.24 ^d | 50.5 | .53 | 3.94 ^d |
| | 0600 | 4.64 ^d | 3.17 | 6.44 | 8.91 | 2.96 ^d | 60.1 | 3.57 ^d | 2.04 | 1.63 | 3.49 ^d | 37.5 ^d | 67.7 ^d | |

See footnotes at end of table.

(continued)

TABLE 11 (continued)

| Compound | Hour (CST) | Sampling Location ^b | | | | | | | | | | | | |
|---|---------------|--------------------------------|------|------|------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 1 | 17 | 14 | 15 |
| C ₂ Cl ₄ | 2200 | 1.88 ^d | 2.90 | 2.23 | | .92 ^d | 4.10 | 3.93 ^d | 2.05 | .87 ^d | .52 ^d | 2.78 | 2.10 | 1.93 ^d |
| | 2300 | 1.90 ^d | 4.04 | 1.85 | | .48 ^d | 1.26 | 1.29 ^d | .81 ^d | 4.72 | .65 ^d | 2.02 ^d | 6.13 ^d | 1.23 ^d |
| | 0000 | 1.72 ^d | 2.04 | 2.56 | 1.52 | .35 ^d | .67 | 1.09 ^d | 1.67 | .33 | .85 | 4.39 | 9.5 ^d | |
| | 0100 | | 3.34 | 1.55 | 1.28 | .29 | 2.35 | 1.47 ^d | | .49 | .52 ^d | 3.61 ^d | 5.22 | 6.37 ^d |
| | 0200 | 1.35 ^d | 2.28 | | | .31 ^d | 1.15 | .68 ^d | .61 | 2.34 | .83 ^d | 3.96 | 2.74 | 2.03 ^d |
| | 0300 | 1.47 ^d | 1.71 | 1.34 | 1.74 | .22 ^d | 1.36 | 1.83 ^d | 1.60 | .06 | .70 ^d | | 11.8 | 1.38 ^d |
| | 0400 | 4.22 ^d | 7.15 | 2.77 | 1.34 | .26 ^d | 1.06 | 1.28 ^d | .43 | .45 | | 1.66 | 2.26 | 3.99 ^d |
| | 0500 | 1.09 ^d | 1.72 | | 2.74 | .35 ^d | 1.18 | 1.10 ^d | 1.37 ^d | .37 | .31 | 2.88 | 1.20 | 1.01 ^d |
| | 0600 | 1.11 ^d | 1.47 | 1.61 | .97 | .26 ^d | 1.12 ^d | 1.29 ^d | .31 | .31 | .39 ^d | 2.00 ^d | 1.04 ^d | |
| | | | | | | | | | | | | | | |
| C ₂ H ₃ Cl ₃ | 2200 | 5.63 ^d | 5.46 | 5.10 | | 3.30 ^d | 5.05 | 5.19 ^d | 3.99 | 7.04 | 4.46 | 5.71 ^d | 5.51 | 8.90 ^d |
| | 2300 | 5.07 ^d | 5.56 | 4.21 | | 2.15 ^d | 4.42 | 5.76 ^d | 14.8 | 2.62 | 2.93 ^d | 9.85 | 4.86 | 3.65 ^d |
| | 0000 | 5.86 ^d | 3.29 | 4.48 | 4.21 | 3.38 | 2.87 | 4.64 ^d | 5.63 | 18.1 | 3.91 | 6.34 | 11.0 | |
| | 0100 | 4.92 ^d | 4.63 | 3.57 | 3.87 | 3.20 | 7.64 | 6.18 ^d | | 14.0 | 7.05 | 7.61 ^d | 5.61 | 9.11 ^d |
| | 0200 | 6.07 ^d | 5.24 | | | 3.60 ^d | 8.11 | 3.13 ^d | 3.49 | 5.31 | 4.16 ^d | 16.3 | 4.29 | 8.91 ^d |
| | 0300 | 4.86 ^d | 4.91 | 3.61 | 3.08 | 2.79 | 11.3 | 8.43 ^d | 5.78 | 16.6 | 7.53 | | 8.16 | 5.06 ^d |
| | 0400 | 6.30 ^d | 4.14 | 4.00 | 3.80 | 3.76 ^d | 5.25 | 12.2 ^d | 6.55 | 3.35 ^d | | .90 | 4.56 | 6.26 ^d |
| | 0500 | 5.97 ^d | 3.42 | | 5.65 | 11.2 | 4.67 | 8.73 ^d | 10.4 ^d | 14.6 | 4.45 | | | 4.91 ^d |
| | 0600 | 6.66 ^d | 4.65 | 3.94 | 4.79 | 8.25 ^d | 8.38 ^d | 8.90 ^d | 12.9 | 3.61 ^d | 3.39 ^d | 6.79 ^d | 4.85 ^d | |
| | | | | | | | | | | | | | | |

^aConcentrations expressed in $\mu\text{g m}^{-3}$.^bSee Figure 8 for sampling locations.^cF = flat bag.^dPeak height measurement.

TEST OF 12-13 AUGUST 1981

Meteorological Conditions

Table 12 summarizes the observed weather conditions for 12-13 August 1981. This was another overcast night, but the clouds were lower on this night than on the preceding two nights. The overcast was altostratus at altitudes of a few thousand meters. During the earlier part of the period, there was light drizzle; a 2-hour period of light rain turned to drizzle at about 2015 CST. Because of the rain and the heavy overcast, temperatures remained nearly constant throughout the period, and the humidity was consistently high.

The winds during this night were generally from the south and south-southeast, usually within 30° of a south wind. The windspeeds were light, but somewhat stronger than on the other nights, exceeding 4 m s^{-1} by 0600 CST.

Test Operations

Figure 9 shows the location of the samplers used during this test. It should be noted that the selection of these sampling locations was based on the southeast winds that prevailed at the beginning of the test. As the winds became more southerly at later hours, this array proved to be less than ideally located. As the winds became more southerly, they also became more nearly parallel to the tracer release line shown in the figure. This was a poor choice of tracer release route. A better choice would have been along the east-west road to the south of the plant.

Observed Concentrations

Table 13 summarizes the observed concentrations at various locations on this night. Two of the hours during the period, when winds were at a greater angle to the tracer release line, were suitable for analysis and for estimating the emission rates.

TABLE 12. OBSERVED WEATHER CONDITIONS IN WICHITA AREA,
12-13 AUGUST 1981

| Hour (CST) | Sky Cover (tenths) | Wind | | | | Temperature (°F) | Relative Humidity (%) | Remarks |
|---------------|--------------------------|------------------|------------------------------|--------------------------|------------------------------|---------------------|-----------------------------|----------------------|
| | | At Site | | Mid-Continent Airport | | | | |
| | | Direction (°) | Speed (ms ⁻¹) | Direction (°) | Speed (ms ⁻¹) | | | |
| 2100 | 10 | 150 | 2.2 | 160 | 3.1 | 72 | 84 | Light drizzle |
| 2200 | 10 | 160 | 1.3 | 160 | 2.6 | 72 | 84 | |
| 2300 | 10 | 160 | 1.3 | 150 | 2.1 | 72 | 84 | |
| 2400 | 10 | 175 | 1.3 | 170 | 3.1 | 72 | 84 | |
| 0100 | 10 | 170 | 1.3 | 180 | 3.1 | 71 | 87 | |
| 0200 | 10 | 170 | 1.8 | 170 | 3.1 | 71 | 87 | light rain |
| 0300 | 10 | 160 | 1.8 | 150 | 3.1 | 71 | 87 | |
| 0400 | 10 | 150 | 2.2 | 170 | 3.6 | 71 | 84 | |
| 0500 | 10 | 160 | 2.7 | 170 | 3.6 | 71 | 84 | |
| 0600 | 10 | 160 | 4.0 | 160 | 4.6 | 71 | 87 | light shower, fog |

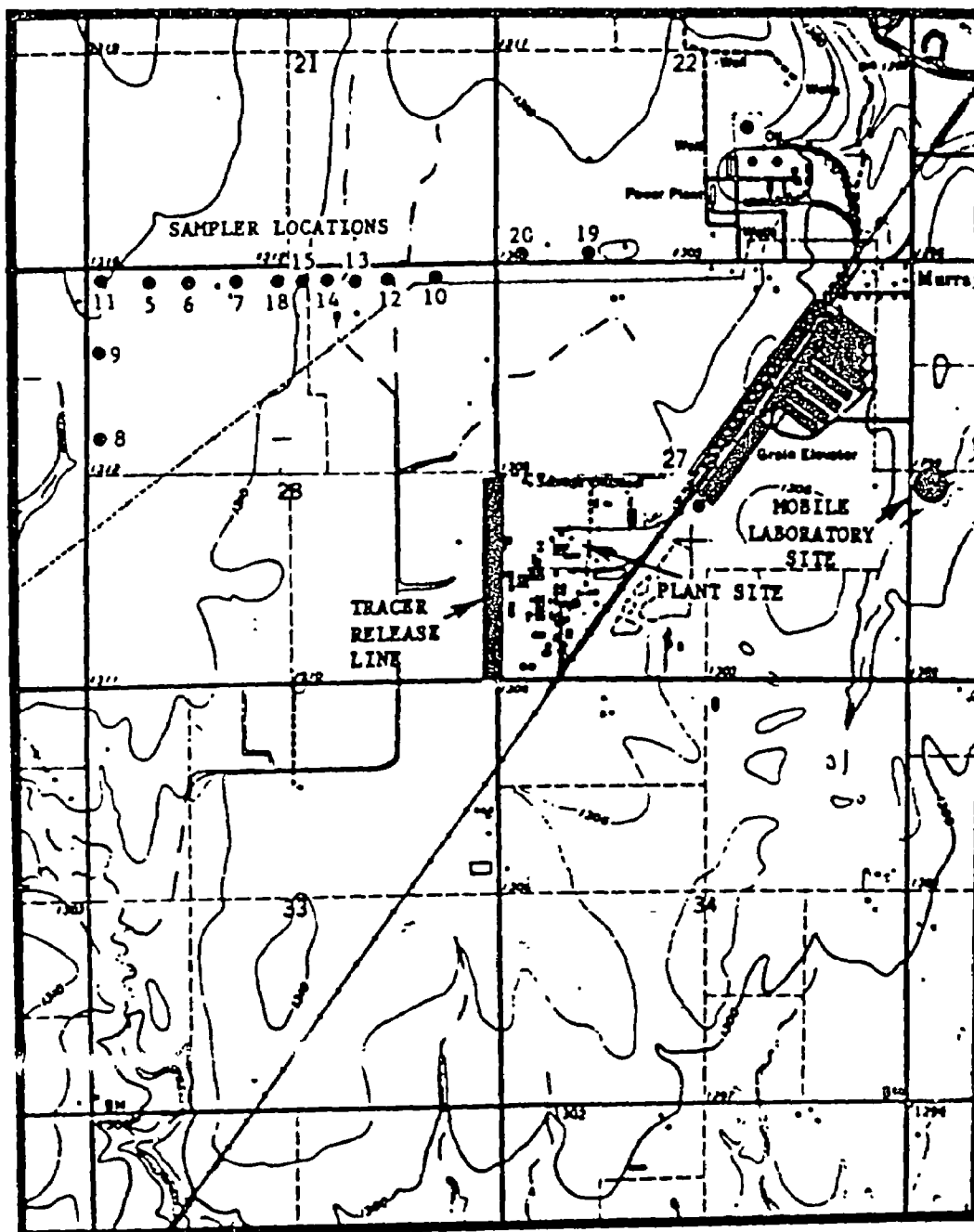


Figure 9. Sampling locations and tracer release line for the night of 12-13 August 1981.

TABLE 13. MEASURED CONCENTRATIONS, 12-13 AUGUST 1981^a

| Compound | Hour (CST) | Sampling location ^b | | | | | | | | | | | | | |
|---------------------------------|---------------|--------------------------------|-------------------|------|-------------------|-------------------|------|------|----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | | 8 | 9 | 11 | 5 | 6 | 7 | 18 | 15 | 14 | 13 | 12 | 10 | 20 | 19 |
| SF ₆ | 2200 | .66 | .82 | .60 | r ^c | .40 | .82 | 2.37 | 1.51 | 1.80 | .52 | .30 | 3.63 | | |
| | 2300 | .04 | .04 | .14 | .78 ^d | 1.59 | 18.4 | 1.13 | r ^c | 1.32 | 2.06 | 1.71 | 1.57 | .71 | 28.9 |
| | 0000 | 1.12 | 17.6 | .84 | r ^c | .31 | .77 | 5.44 | .98 | .92 | 3.39 | .73 | 4.48 | 7.31 | .38 |
| | 0100 | 27.4 | 8.05 | | 43.5 ^d | .07 | 3.26 | 1.14 | r ^c | 7.79 | 6.44 | 6.87 | 3.43 | 2.09 | 1.13 |
| | 0200 | .02 | .23 | .23 | .21 | 24.4 | 0.1 | 1.76 | 1.73 | 2.82 | 2.93 | 4.31 | 3.02 | 1.02 | 1.17 |
| | 0300 | 15.5 | .28 | 28.2 | 2.06 | 1.46 | 1.63 | 2.28 | 1.60 | r ^c | 20.7 | | 1.37 | | .06 |
| | 0400 | .05 | .55 | 3.87 | 3.25 | 11.5 | 2.51 | 2.46 | 3.59 | 2.89 | .29 | 1.92 | .11 | .08 | .15 |
| | 0500 | .03 | 26.0 | .66 | 1.41 | 1.42 | 2.31 | 4.70 | 2.05 | 3.22 | .73 | .15 | .25 | | .73 |
| | | | | | | | | | | | | | | | |
| CCl ₄ | 2200 | 1.13 | | 13.7 | r ^c | 5.66 ^d | 9.16 | 3.86 | 74.7 | 6.00 ^d | 3.13 ^d | 4.07 | 3.75 ^d | | |
| | 2300 | 1.45 | .59 ^d | 7.52 | .84 ^d | 1.51 ^d | 23.3 | 1.53 | r ^c | 6.39 ^d | 4.23 ^d | 13.5 | 5.95 ^d | 84.7 | 1.98 ^d |
| | 0000 | .30 | | 10.6 | r ^c | 1.35 ^d | 7.67 | .84 | 41.4 | 5.66 ^d | 3.72 ^d | 7.07 | 5.32 ^d | 24.3 | 6.44 ^d |
| | 0100 | 1.51 | .61 ^d | | 2.60 ^d | 1.01 ^d | 8.62 | 3.38 | r ^c | 2.36 ^d | .98 ^d | 10.5 | 8.28 ^d | 12.2 ^d | 4.55 ^d |
| | 0200 | | .83 ^d | 9.16 | .82 ^d | 2.96 ^d | 17.8 | 9.95 | 23.0 | 5.66 ^d | 5.52 ^d | 73.5 | 8.47 ^d | 1.68 ^d | 5.52 ^d |
| | 0300 | .87 | .68 ^d | 15.5 | .80 ^d | 1.82 ^d | 1.43 | 59.5 | 119 | r ^c | 4.86 ^d | 4.86 ^d | 7.07 ^d | | 4.12 ^d |
| | 0400 | .92 | 1.14 ^d | 11.8 | 1.71 ^d | 5.37 ^d | 142 | 72.1 | 182 | 60.5 | 4.86 ^d | 59.5 | 6.63 ^d | 12.5 | 1.81 ^d |
| | 0500 | | 1.24 ^d | .52 | .78 ^d | 1.62 ^d | 65.7 | 6.74 | 478 | 5.87 ^d | 5.65 ^d | 44.1 | 6.39 ^d | | 1.22 ^d |
| | | | | | | | | | | | | | | | |
| C ₂ HCl ₃ | 2200 | 8.33 | | 2.29 | r ^c | 6.44 ^d | 4.23 | 8.33 | 2.32 | 6.27 ^d | 2.31 ^d | 31.8 | .38 ^d | | |
| | 2300 | 12.4 | .25 ^d | 1.42 | 1.32 ^d | 5.23 ^d | 10.3 | 10.4 | r ^c | 4.75 ^d | 1.61 ^d | 5.12 | .26 ^d | 4.04 | 3.49 ^d |
| | 0000 | 6.10 | | 9.45 | r ^c | 5.39 ^d | 9.91 | 7.06 | 1.71 | 7.06 ^d | 1.79 ^d | 4.94 ^d | .06 ^d | 5.98 | 6.94 ^d |
| | 0100 | 9.82 | .10 ^d | | 2.56 ^d | 7.39 ^d | 9.91 | 10.1 | r ^c | 4.16 ^d | 1.83 ^d | 27.0 | .34 ^d | 4.27 | 1.97 ^d |
| | 0200 | | .02 ^d | 1.39 | 1.88 ^d | 6.83 ^d | 9.14 | 7.68 | 8.08 | 5.88 ^d | 1.79 ^d | 5.94 | 9.16 ^d | 8.02 | 2.46 ^d |
| | 0300 | 6.91 | .14 ^d | 7.43 | 2.49 ^d | 5.23 ^d | 5.79 | 3.99 | 2.21 | r ^c | 2.96 ^d | | 5.94 ^d | | 2.79 ^d |
| | 0400 | 9.24 | .02 ^d | 9.45 | 1.61 ^d | 5.02 ^d | 2.02 | 4.64 | 2.28 | 5.21 | 1.61 ^d | 6.85 | 4.27 ^d | 3.81 | 5.82 ^d |
| | 0500 | | .06 ^d | .41 | 3.16 ^d | 4.60 ^d | 2.30 | 13.7 | 2.88 | 1.37 ^d | 2.23 ^d | 6.75 | 6.95 ^d | | 6.44 ^d |
| | | | | | | | | | | | | | | | |

See footnotes at end of table.

(continued)

TABLE 11 (Continued)

| Compound | Hour (CST) | Sampling Location ^b | | | | | | | | | | | | | |
|---|---------------|--------------------------------|-------------------|------|-------------------|-------------------|------|------------------|----------------|-------------------|-------------------|-------------------|-------------------|--------------------|-------------------|
| | | 8 | 9 | 11 | 5 | 6 | 7 | 18 | 15 | 14 | 13 | 12 | 10 | 20 | 19 |
| C ₂ Cl ₄ | 2200 | 1.80 | | 1.46 | F ^c | 2.95 ^d | 4.20 | 3.18 | 3.22 | 2.48 ^d | .69 ^d | 1.75 | 1.74 ^d | | |
| | 2300 | 2.06 | .60 ^d | 1.58 | .70 ^d | 3.79 ^d | 3.28 | 1.32 | F ^c | 2.11 ^d | 1.26 ^d | 4.24 | | 2.43 | .70 ^d |
| | 0000 | 2.78 | | 3.32 | F ^c | 3.41 ^d | 1.61 | 3.32 | 1.51 | 2.20 ^d | 1.00 ^d | .12 | 2.57 ^d | 2.14 | 2.70 ^d |
| | 0100 | 1.63 | .41 ^d | | .92 ^d | 1.65 ^d | .32 | 3.14 | F ^c | 2.49 ^d | .56 ^d | 2.82 ^d | 6.25 ^d | 1.97 | .92 ^d |
| | 0200 | | .79 ^d | 1.56 | .62 ^d | 2.11 ^d | 1.83 | 20.9 | 2.16 | 1.57 ^d | .65 ^d | 3.98 | 2.37 ^d | 2.15 | .96 ^d |
| | 0300 | 1.58 | 1.46 ^d | 1.98 | .75 ^d | 2.11 ^d | 1.47 | 3.96 | 3.05 | F ^c | .98 ^d | | 2.38 ^d | 15600 ^d | .95 ^d |
| | 0400 | 2.88 | .55 ^d | 3.17 | .72 ^d | 2.16 ^d | 4.20 | 3.91 | 5.61 | 7.09 | 2.13 ^d | 9.10 | 2.02 ^d | 1.45 | 1.52 ^d |
| | 0500 | | .83 ^d | .75 | .52 ^d | 2.63 ^d | 1.38 | .01 ^d | 9.73 | 5.15 ^d | 5.45 ^d | 6.92 | 2.85 ^d | | 2.38 ^d |
| | | | | | | | | | | | | | | | |
| C ₂ H ₃ Cl ₃ | 2200 | 68.5 | | 2.99 | F ^c | 5.73 ^d | 0.0 | 3.36 | 5.33 | | | | | | |
| | 2300 | 7.17 | | 7.64 | 2.74 ^d | 10.6 ^d | 11.3 | | 5.05 | | | 4.35 | | 15.3 | |
| | 0000 | 7.00 | | 11.6 | F ^c | 9.14 ^d | 7.52 | 5.52 | 4.16 | | | 6.51 | | 17.7 | |
| | 0100 | 6.91 | | | 10.9 ^d | 9.04 ^d | 8.16 | 5.18 | F ^c | | | 7.83 | | 11.7 | |
| | 0200 | | | 7.81 | 6.19 ^d | | 7.47 | 5.02 | 6.80 | | | 7.60 | | 20.0 | |
| | 0300 | 5.55 | | 16.7 | 5.00 ^d | | 5.39 | 5.05 | 4.46 | | | | | | |
| | 0400 | 5.51 | | 6.58 | | | 5.90 | 4.73 | 7.39 | 7.17 | | 7.95 | | 7.48 | |
| | 0500 | | | 4.42 | | | 5.27 | 9.79 | 14.9 | | | 7.92 | | | |

^aConcentrations expressed in μm^{-3} .^bSee Figure 9 for sampling locations.^cF = flat bag.^dPeak height measurements.

SECTION 6

INTERPRETATION OF RESULTS

GENERAL APPROACH

For reasons that were alluded to earlier, not all the data were suitable for estimating emission rates. Frequently, the alignment of the tracer release line and the wind were not as they should have been. Sometimes there were too few valid samples. Flat bags, GC traces suitable for peak height analysis but not for peak area analysis, concentrations too low to be reliably estimated, and uncertainties regarding background concentrations all contributed to making many of the cases unsuitable for complete analysis. However, it was possible to identify five 1-hour test periods for which data could be used to estimate emission rates. These five periods are:

- (1) 11 August 1981, 0000-0100 CST
- (2) 11 August 1981, 0100-0200 CST
- (3) 11 August 1981, 2200-2300 CST
- (4) 12 August 1981, 2300-2400 CST
- (5) 13 August 1981, 0400-0500 CST.

For each case, the concentration data (excluding those obtained by peak height analysis) were plotted as a function of distance along the sampling line. Smooth curves were drawn by hand to estimate the concentration distribution of each of the materials along this line. The lower concentrations near the ends of the line were taken to represent the background concentrations. In this way, it was possible to estimate the concentration contribution from the plant for each material believed to be emitted from the plant. Concentration distributions for SF_6 were plotted in the same way for SF_6 . Estimates of the term B in Eq. (1) were derived from the data, using a value of 0.65 for b [from Eq. (2)] and estimates of distance to the upwind and downwind edges of the area source were based on the geometry of each test and the extent of the region where emissions were believed to be probable (as shown earlier in Figure 2). As noted earlier, the assumed area from which emissions took place was $2.5 \times 10^4 \text{ m}^2$.

The same ratios of chlorinated hydrocarbon concentration to tracer concentration were used with Eq. (11) to obtain other estimates of the emission rates from the plant. The appropriate value of the term K in Eq. (11) was selected on the basis of meteorological observations.

ESTIMATED EMISSION RATES

11 August 1981, 0000-0100 CST

Figure 10 shows the concentrations observed at the various sampling locations for SF_6 , CCl_4 , C_2Cl_4 , and C_2HCl_3 . The measurements of $\text{C}_2\text{H}_3\text{Cl}_3$ were not sufficiently reliable on this day to be used to estimate the emission rates. The curves shown in Figure 10 were used to estimate the ratio of the peak concentration of the various compounds (above background) to that of the peak SF_6 . These ratios are entered in the second column of Table 14.

Table 14 summarizes the values used for the various terms in order to estimate the emission rates of the three compounds for which reliable measurements were available. The last two columns are of greatest interest; they give the emission rates obtained from the area-source formulation (assuming a total area of $2.5 \times 10^4 \text{ m}^2$) and from the point-source formulation. It is evident that in this case the two approaches for estimating total emission rates are quite consistent. The emission rates given are in g s^{-1} ; 1 g s^{-1} is equal to 3.6 kg h^{-1} , so the emission rates given in Table 14 range from about 300 g h^{-1} to about 3 kg h^{-1} .

11 August 1981, 0100-0200 CST

Figure 11 shows the observed concentrations for the various compounds and the smooth curves that were drawn through the available points in order to estimate peak values. As before, ratios were determined between the observed peak concentrations of the chlorinated hydrocarbons and those of the tracer. These ratios are given in Table 15, which also summarizes the calculations used to estimate the emission rates.

The last two columns in Table 15 show the estimated emission rates for the compounds. As was true before, the two approaches for estimating emission rates yield quite consistent results. However, this hour shows emission rates much higher than those estimated for the preceding hour. It appears that emission rates of about 20 to 25 kg h^{-1} were observed for C_2HCl_3 and CCl_4 . This is a factor of 10 to 20 times those rates observed during the preceding hour. The apparent emission rates for C_2Cl_4 were also much higher during this hour than during the preceding hour. As will be seen from subsequent discussions, the lower values seem more typical, but similarly high estimates of CCl_4 emission rates were observed on at least one other occasion.

11 August 1981, 2200-2300 CST

Figure 12 shows the observed concentrations of three of the chlorinated hydrocarbons and that of the tracer. The concentrations of C_2HCl_3 were not above background, and it can be assumed that the emissions for this compound were quite low. The ratios determined from the graphs in Figure 12 are shown in Table 16.

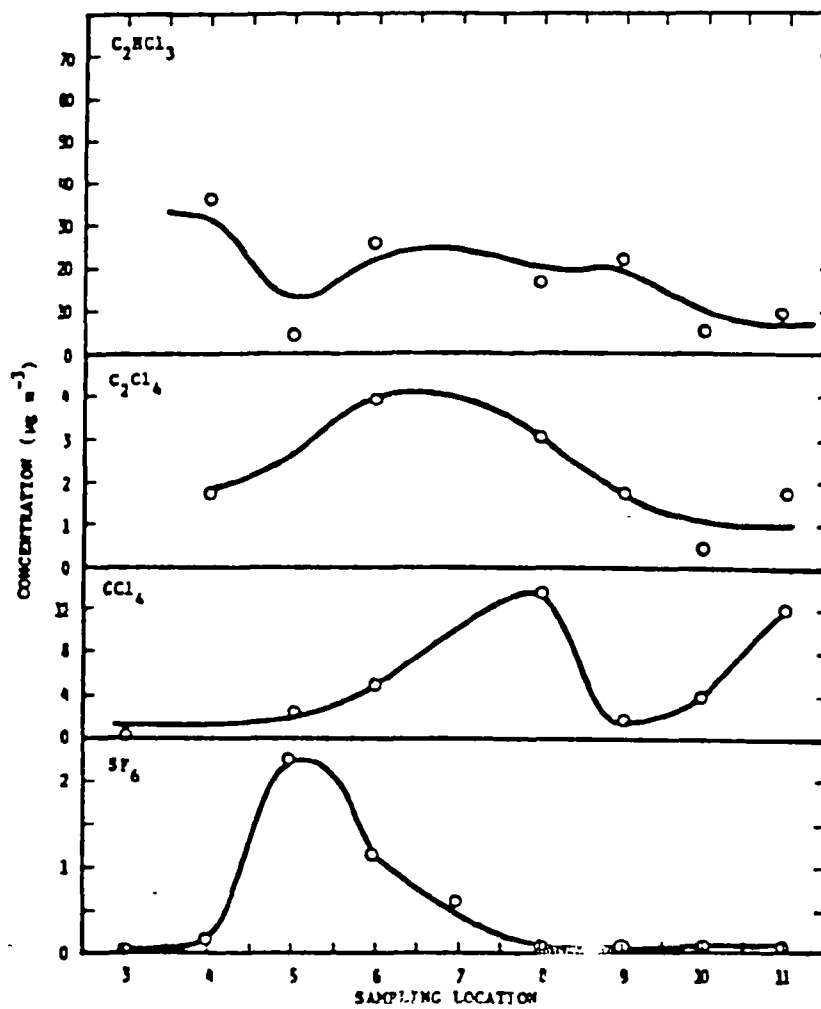


Figure 10. Concentrations on 11 August 1981, 0000-0100 CST.

TABLE 14. EMISSION RATE ESTIMATES FOR 11 AUGUST 1981, 0000-0100 CST

| Compound | C_c/C_1 | B in Equation 9 | Q_1 ($\text{g m}^{-1} \text{s}^{-1}$) | $\frac{KQ_1 x_p^{0.9}}{\sin \phi}$ in Equation 11 | Estimated Emission Rates | | |
|--------------------------|-----------|--------------------|--|--|---|---|--------------------------------------|
| | | | | | Equation 9 ($\text{g m}^{-2} \text{s}^{-1}$) | Assuming area of $2.5 \times 10^4 \text{ m}^2$ (g s^{-1}) | Equation 11 (g s^{-1}) |
| CCl_4 | 5 | 10^{-2} | 3.4×10^{-4} | 6.7×10^{-2} | 1.7×10^{-5} | 0.4 | 0.3 |
| C_2Cl_4 | 1 | 10^{-2} | 3.4×10^{-4} | 6.7×10^{-2} | 3.4×10^{-6} | 0.08 | 0.06 |
| C_2HCl_3 | 9 | 10^{-2} | 3.4×10^{-4} | 6.7×10^{-2} | 3.1×10^{-5} | 0.8 | 0.6 |

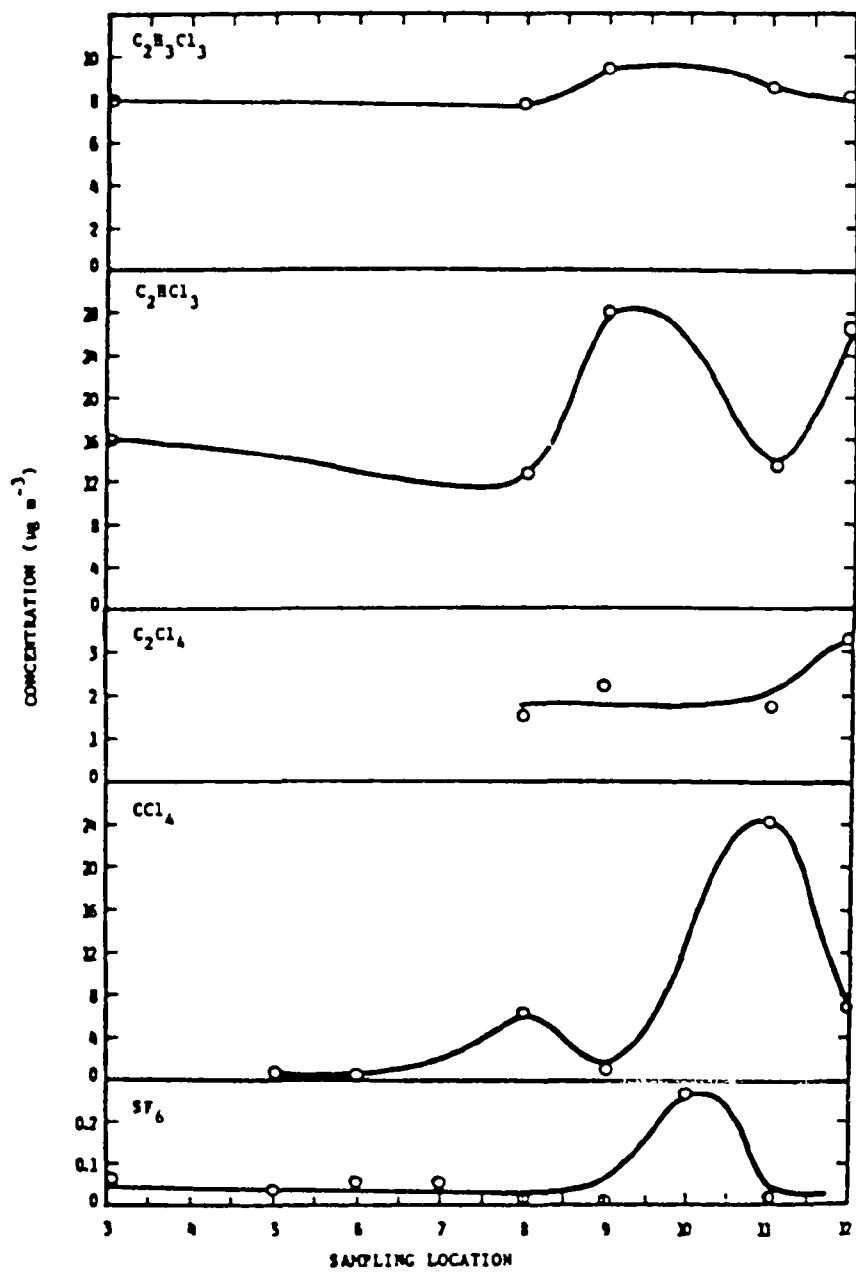


Figure 11. Concentrations on 11 August 1981, 0100-0200 CST.

TABLE 15. EMISSION RATE ESTIMATES FOR 11 AUGUST 1981, 0100-0200 CST

| Compound | C_c/C_1 | B in Equation 9 | Q_1 ($\text{g m}^{-1} \text{s}^{-1}$) | $\frac{\kappa Q_1 x_p^{0.9}}{\sin \phi}$ in Equation 11 | Estimated Emission Rates | | |
|-----------------------------------|-----------|--------------------|--|--|---|---|--------------------------------------|
| | | | | | Equation 9 ($\text{g m}^{-2} \text{s}^{-1}$) | Assuming area of $2.5 \times 10^4 \text{ m}^2$ (g s^{-1}) | Equation 11 (g s^{-1}) |
| CCl_4 | 90 | 10^{-2} | 3.4×10^{-4} | 6.7×10^{-2} | 3.1×10^{-4} | 8 | 6 |
| C_2Cl_4 | 7.5 | 10^{-2} | 3.4×10^{-4} | 6.7×10^{-2} | 2.6×10^{-5} | 0.6 | 0.5 |
| C_2HCl_3 | 70 | 10^{-2} | 3.4×10^{-4} | 6.7×10^{-2} | 2.4×10^{-4} | 6 | 5 |
| $\text{C}_2\text{H}_3\text{Cl}_3$ | 7 | 10^{-2} | 3.4×10^{-4} | 6.7×10^{-2} | 2.4×10^{-5} | 0.6 | 0.5 |

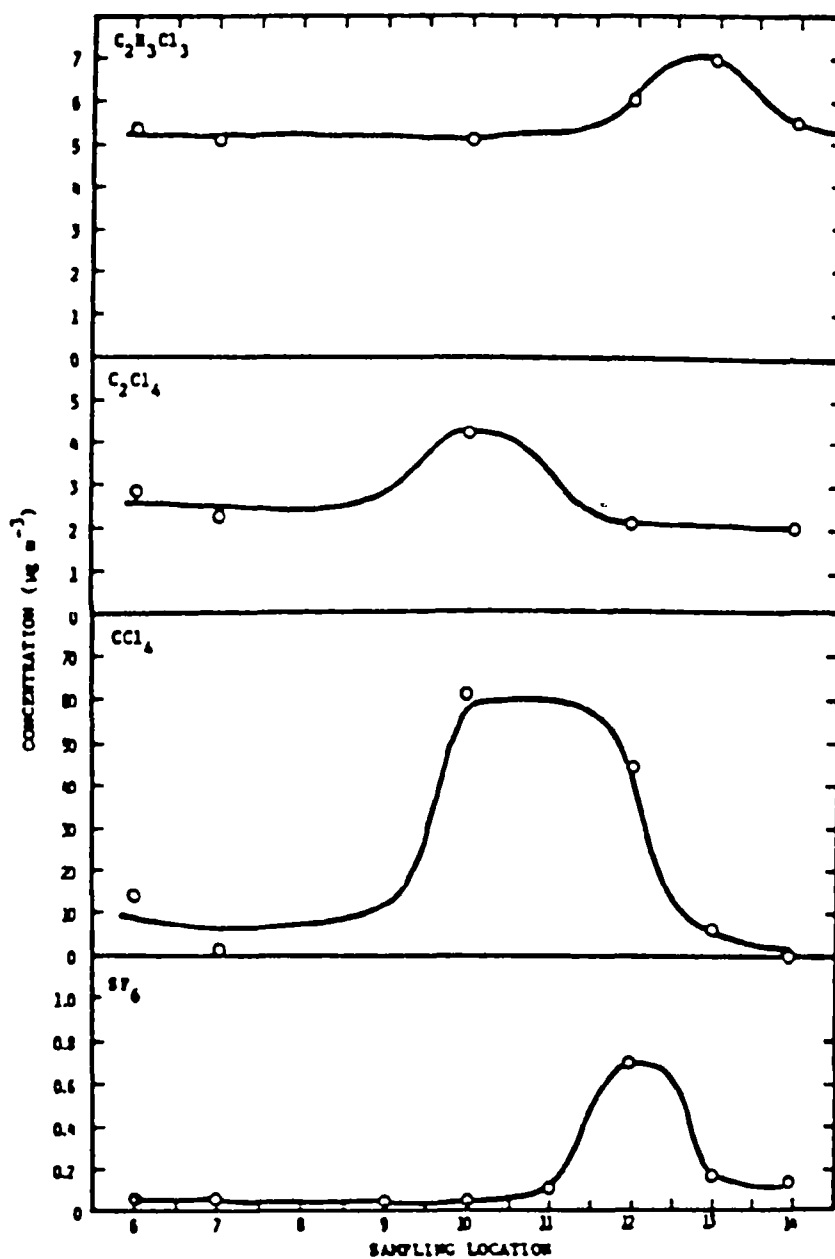


Figure 12. Concentrations on 11 August 1981, 2200-2300 CST.

TABLE 16. EMISSION RATE ESTIMATES FOR 11 AUGUST 1981, 2200-2300 CST

| Compound | C_c/C_1 | B in Equation 9 | Q_1 ($g\ m^{-1}\ s^{-1}$) | $\frac{KQ_1X_p^{0.9}}{\sin\phi}$ in Equation 11 | Estimated Emission Rates | | |
|--------------|-----------|--------------------|----------------------------------|--|---------------------------------------|--|--------------------------------|
| | | | | | Equation 9 ($g\ m^{-2}\ s^{-1}$) | Assuming area of $2.5 \times 10^4\ m^2$ ($g\ s^{-1}$) | Equation 11 ($g\ s^{-1}$) |
| CCl_4 | 85 | 10^{-2} | 2.6×10^{-4} | 5.2×10^{-2} | 2.2×10^{-4} | 6 | 4 |
| C_2Cl_4 | 2.7 | 10^{-2} | 2.6×10^{-4} | 5.2×10^{-2} | 7.0×10^{-6} | 0.2 | 0.1 |
| $C_2H_3Cl_3$ | 2.7 | 10^{-2} | 2.6×10^{-4} | 5.2×10^{-2} | 7.0×10^{-6} | 0.2 | 0.1 |

The estimated emission rates are shown in the last columns of the table. Again, the estimates made by the two approaches are in reasonable agreement. The apparent emissions for this hour were somewhat smaller than those for the last hour discussed, 0100-0200 CST. The estimated CCl_4 emissions were about 20 kg h^{-1} , and those of the other two compounds were about 0.5 kg h^{-1} .

12 August 1981, 2300-2400 CST

Figure 13 shows the observed concentrations of the chlorinated hydrocarbons and the tracer, and the estimated distribution of these concentrations along the sampling line. The ratios shown in the second column of Table 17 were derived from the estimated peak concentrations of the various compounds.

The last two columns of Table 17 show the estimated emission rates obtained by the two approaches discussed in this report. The agreement in this case is much poorer than it was in the preceding case. Furthermore, the estimate derived from a point-source approximation is greater than the estimate derived from the area-source approximation; in the three preceding cases, the area-source approximation yielded larger estimates. During this test, the angle of the wind to the line-source release was only about 20° or 30° , a fact that may have contributed to the observed discrepancy between the two approaches. As noted before, a release more nearly normal to the wind direction better satisfies the approximations made in the derivation of the equations.

13 August 1981, 0400-0500 CST

This was the last case that was suitable for estimating emission rates. It suffered from the same shortcomings with regard to the angle between the wind direction and the line source as did the case for 12 August, 2300-2400 CST. Figure 14 shows the observed concentrations of the chlorinated hydrocarbons and the tracer, along with the smooth curves that were used for estimating the ratios shown in Table 18.

As was the case for 12 August, the estimates derived from the area-source and the point-source approximations do not agree very well. (See the last two columns of Tables 17 and 18.) Again, the estimate based on the point-source assumption is greater than the estimate based on the area-source assumption. The two results differ by about a factor of 3. The estimate based on Eq. (11) indicates that the emissions of CCl_4 were about 5 kg h^{-1} ; the estimate based on Eq. (9) indicates the emissions were about 2 kg h^{-1} . The Eq. (11) estimates for the other compounds range from about 100 g h^{-1} for C_2HCl_3 to about 700 g h^{-1} for $\text{C}_2\text{H}_3\text{Cl}_3$. As noted before, the estimates with Eq. (1) are about one-third those from the other equations.

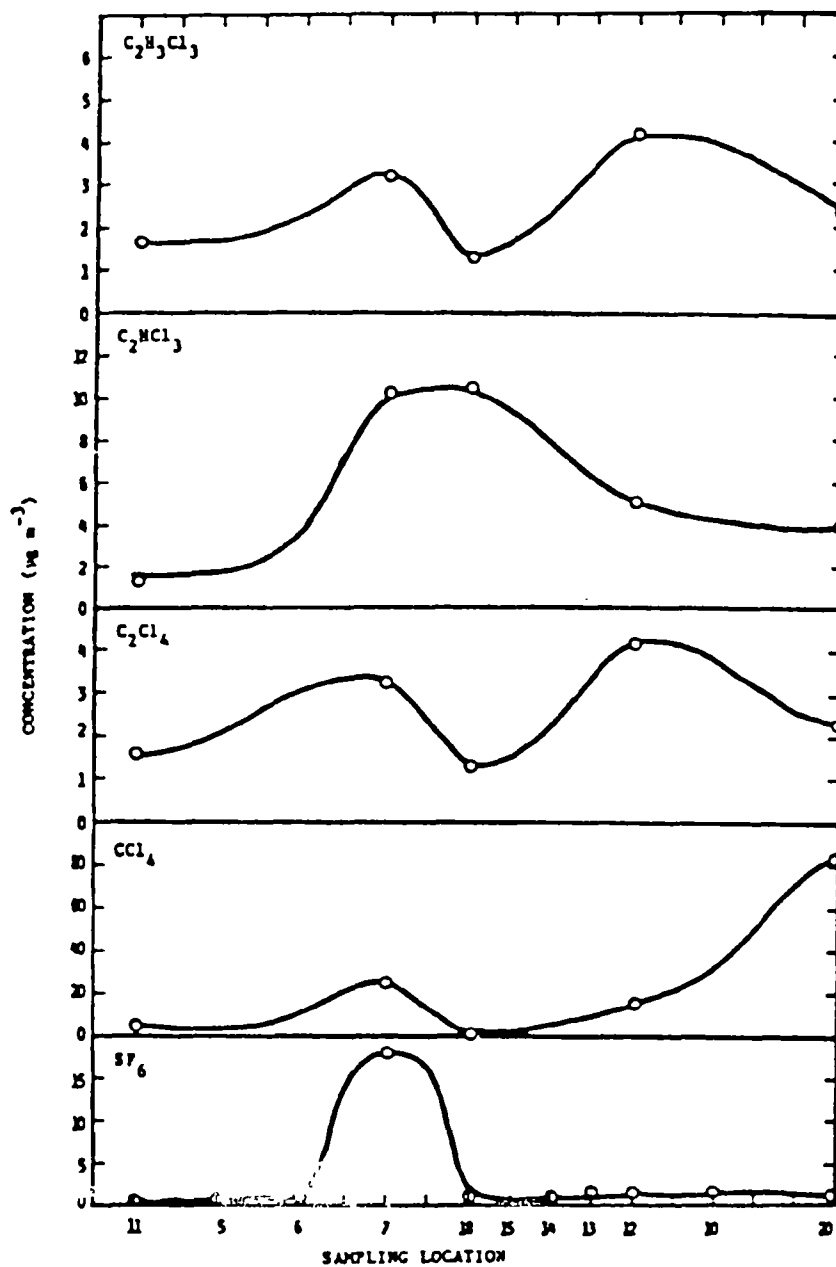


Figure 13. Concentrations on 11 August 1981, 2300-2400 CST.

TABLE 17. EMISSION RATE ESTIMATES FOR 12 AUGUST 1981, 2300-2400 CST

| Compound | C_c/C_l | B in Equation 9 | Q_1 ($g \cdot m^{-1} \cdot s^{-1}$) | $\frac{KQ_1^{0.9}}{\sin \phi}$ in Equation 11 | Estimated Emission Rates | | |
|--------------|-----------|----------------------|--|--|---|--|-------------------------------------|
| | | | | | Equation 9 ($g \cdot m^{-2} \cdot s^{-1}$) | Assuming area of $2.5 \times 10^4 \cdot m^2$ ($g \cdot s^{-1}$) | Equation 11 ($g \cdot s^{-1}$) |
| CCl_4 | 1 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 1.5×10^{-6} | 0.04 | 0.1 |
| C_2Cl_4 | 0.1 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 1.5×10^{-7} | 0.004 | 0.01 |
| C_2HCl_3 | 0.4 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 5.9×10^{-7} | 0.01 | 0.04 |
| $C_2H_3Cl_3$ | 0.1 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 1.5×10^{-7} | 0.004 | 0.01 |

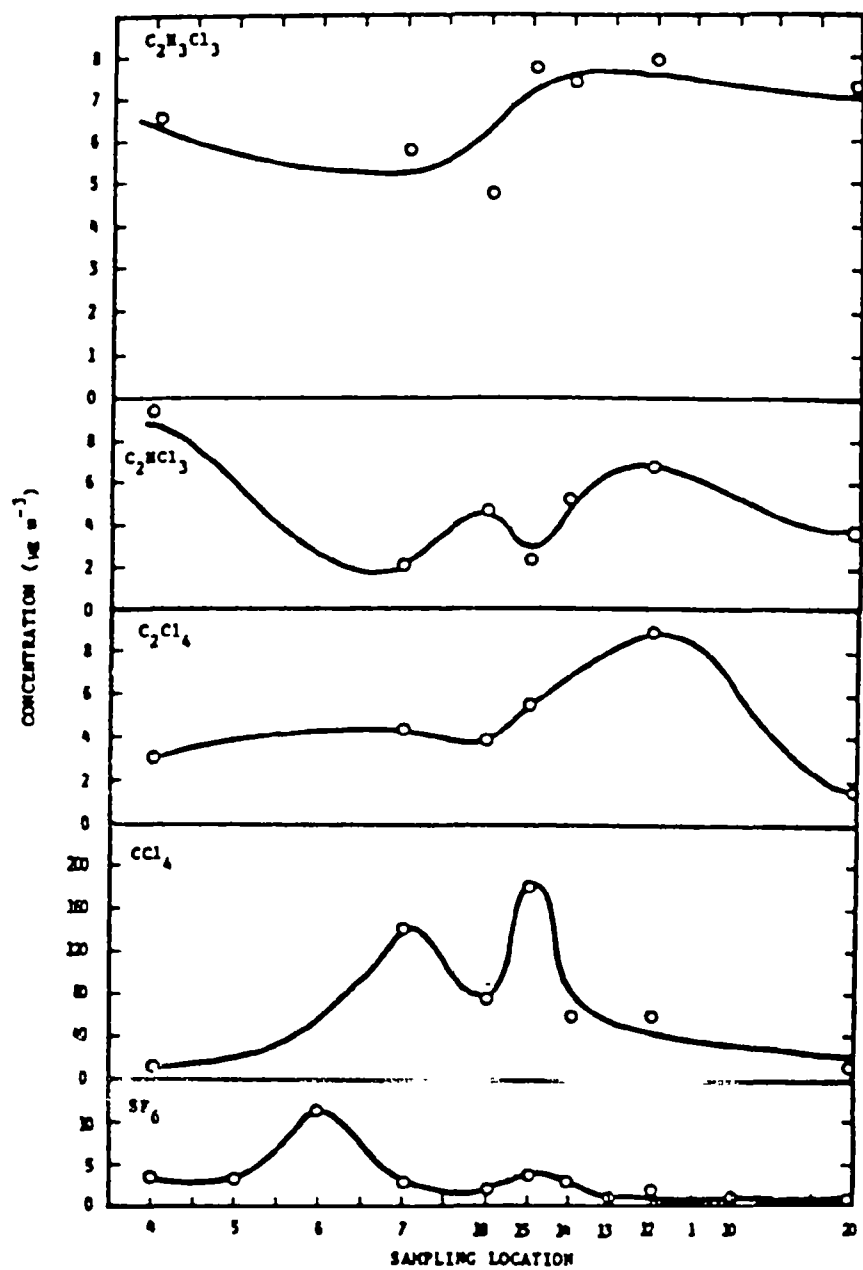


Figure 14. Concentrations on 13 August 1981, 0400-0500 CST.

TABLE 18. EMISSION RATE ESTIMATES FOR 13 AUGUST 1981, 0400-0500 CST

| Compound | C_c/C_1 | B in Equation 9 | Q_1 ($g\ m^{-1}\ s^{-1}$) | $\frac{KQ_1 x^{0.9}}{\sin\phi}$ in Equation 11 | Estimated Emission Rates | | |
|--------------|-----------|----------------------|----------------------------------|---|---------------------------------------|--|--------------------------------|
| | | | | | Equation 9 ($g\ m^{-2}\ s^{-1}$) | Assuming area of $2.5 \times 10^4\ m^2$ ($g\ s^{-1}$) | Equation 11 ($g\ s^{-1}$) |
| CCl_4 | 15 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 2.2×10^{-5} | 0.6 | 1.5 |
| C_2Cl_4 | 0.6 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 8.8×10^{-7} | 0.02 | 0.06 |
| C_2HCl_3 | 0.3 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 4.4×10^{-7} | 0.01 | 0.03 |
| $C_2H_3Cl_3$ | 2 | 5.1×10^{-3} | 2.9×10^{-4} | 0.1 | 3.4×10^{-6} | 0.09 | 0.2 |

SECTION 7

SUMMARY AND RECOMMENDATIONS

ESTIMATED EMISSIONS

Table 19 summarizes the estimated emissions rates described in the preceding sections. It is immediately apparent from the table that the emission rates vary by more than two orders of magnitude. For the kinds of emissions that were measured, this does not seem unreasonable. Probably, the most frequently observed emissions would be comparable to those in the "minimum" columns of Table 19. It appears that some sporadic activities raise the emission rates appreciably for relatively short periods of time. It is not hard to imagine activities that could contribute to such elevated emissions: Drum filling, loading and unloading of containers, and other material transfer operations come immediately to mind.

SUGGESTED IMPROVEMENTS IN THE METHODOLOGY

The results obtained during this initial effort indicate that the methodology that has been developed has considerable promise, but that this first application did not always achieve that promise. It is not surprising that the potential of the method was not fully exploited in this effort, and future efforts should be able to profit by the errors made during this study. The following paragraphs present some suggestions for future efforts, based on our experience with the data collected during this study.

First, samples should be collected with greater spatial and temporal resolution. The data collected during this program suggest considerable variability in the emission rate. This means that there may be relatively short-term "puffs" of materials that come from different parts of the operation at different times during the hour-long sampling period. Closely spaced samplers would provide the spatial resolution necessary to resolve any such small-scale emissions. The closer spacing would also permit better definition of the peaks. Frequently the data collected in this study defined a peak with only a few observations. Of course, this problem was compounded by the difficulties that were encountered in some of the chemical analyses.

Finer temporal resolution; i.e., samples collected over a shorter period of time, would provide the information necessary to determine the short-term peak concentrations and the variability of emission rates.

TABLE 19. SUMMARY OF EMISSION RATE ESTIMATES
FOR VULCAN PLANT

| Compound | Rates Based on Equation 9 (kg h ⁻¹) | | | Rates Based on Equation 11 (kg h ⁻¹) | | |
|---|---|---------|---------|--|---------|---------|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| CCl ₄ | 30 | 0.1 | 11 | 20 | 0.4 | 9 |
| C ₂ Cl ₄ | 2 | 0.01 | 0.7 | 2 | 0.04 | 0.5 |
| C ₂ HCl ₃ | 20 | 0.04 | 6 | 20 | 0.1 | 5 |
| C ₂ H ₃ Cl ₃ | 2 | 0.01 | 0.7 | 2 | 0.04 | 0.7 |

For a line-source length comparable to that used in this study, it would be possible to get valid averages for time periods as short as about 10 min.

If the samples are collected at more closely spaced locations, then it will be very important to develop techniques to limit the number of samples that must be analyzed in order to reduce costs. This could be done in at least two different ways.

First, a screening technique could be developed. The SF₆ results were used to some extent during this study to decide which bags were to be analyzed for the chlorinated hydrocarbons. A rapid, inexpensive method sensitive to chlorinated hydrocarbons might improve the screening process even further. Another approach to reducing the number of samples would be to limit the extent of the sampling line itself. The results of this study have shown that the emissions and the tracer affect only a limited length of the total sampling line at a given hour. The problem, of course, is to determine ahead of time just where the effects will be felt or to make appropriate adjustments during the sampling operation. SRI recommends that as much use as possible be made of U.S. National Weather Service forecasts. Accurate forecasts of changes in wind direction would allow each field test to be planned in such a way that the samplers could be moved during the course of a test if necessary. On-site wind-direction observations are an obvious necessity. An attempt was made during this study to change the sampling array following changes in wind direction, but no plans for changes in deployment were formulated ahead of time, based on forecasted wind-direction changes. Any redeployment of samplers could probably be carried out more effectively if it were planned ahead of time, using U.S. National Weather Service forecasts.

It should be noted that redeployment of samplers will introduce difficulties. Some data will be lost while samplers are being moved from place to place, but prior planning should reduce these losses. Serious complications will arise if records are not kept of the sampler locations at all times during a test. Careful bookkeeping with regard to sampler location will be absolutely essential. Again, prior planning based on weather forecasts should facilitate that bookkeeping.

There may be diurnal patterns of activity in a plant, so that data collected at night could be unrepresentative. Therefore, future tests should include daytime measurements. The methodology described in this report emphasized its application at night, but the method can be applied in the daytime as well. The best approach would be to apply the methodology only during periods of neutral atmospheric stability. Such stability conditions occur when skies are overcast, day or night. The techniques and equations described in this report could be applied in the daytime under neutral conditions. If tests were undertaken during periods of instability, it would be necessary to revise the equations. It is our recommendation that daytime applications of the method be limited to conditions of overcast skies with light winds.

The patterns of activity mentioned in the preceding paragraph could provide useful clues regarding specific sources of observed chlorinated hydrocarbon concentrations downwind of a plant. The plant studied in this program is arranged so that it is impossible to observe and record events at the plant from outside and the lack of such information has proved to be unfortunate. Such information might have provided reasons for the observed emission variability. At sites where it is possible, it would be desirable to have an observer recording information about:

- (1) Truck arrivals and departures
- (2) Movements of railroad tank cars
- (3) Outdoor drum-filling operations that might be visible
- (4) Changes in the visible emissions from the plant complex.

Such information is sometimes subjective and almost always difficult to incorporate into an automated data processing system, but as noted earlier, it can be very valuable to the interpretation of observed concentrations.

The original intent in developing this methodology was to release the tracer from within the plant complex by using some sort of extended manifold or multiple sources to simulate the areal extent of the fugitive sources. For reasons noted in Section 1, it was not possible to do this. However, SRI still believes that that approach would introduce the fewest uncertainties and would provide the most reliable results. Whenever it is possible to release tracers collocated with the sources of interest, the experiment should be conducted that way.

In summary, the methodology described in this report has been demonstrated to be workable, although it still needs improvement. The method has already provided some interesting estimates of emissions from a chlorinated hydrocarbon plant, by using only measurements made outside the plant area. If the recommended improvements are instituted, future programs using this methodology could provide even better estimates of emission rates.

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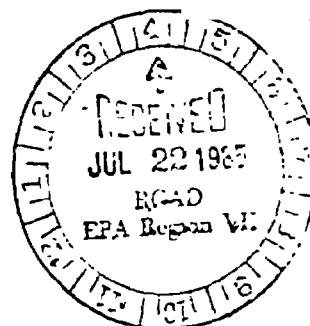
18 July 1985

Rural Route #1
Benton, Kansas 67017

Morris Kay, Administrator
USEPA Region VII
720 Minnesota
Kansas City, Kansas 66101

re: Vulcan Materials Company

Memo
Dear Mr. Kay:



I am enclosing a copy of testimony that I presented at a public hearing on 17 July 1985 regarding Vulcan's applications for repermitting of five underground injection wells at their Wichita plant.

I based my testimony on a review of a portion of the Vulcan files at the Kansas Department of Health and Environment. The Vulcan files are extensive and some of the information was withheld under a CBI claim. Evidently an attempt was made by Vulcan to also claim confidentiality on groundwater monitoring data but we did gain access to a limited amount of analyses. The groundwater monitoring information is spotty and according to the KDHE, no organized assimilation of the data is available at this time. Mrs. Donna Hinderliter had requested monitoring data from the EPA but none was available and at the suggestion of someone in the UIC branch, she contacted Mr. James Boyd of Vulcan for monitoring data--and was refused.

The situation at and around the Vulcan site is very serious. I had no idea of the magnitude of the problem until I reviewed the Vulcan documents and have to assume that you weren't aware of it either. The KDHE Oil Field and Geology Section has abused their UIC authority by allowing such conditions to prevail. As you will note, I have publicly petitioned the USEPA to conduct an environmental audit of the area.

I still haven't acquired the art of condensing information, so I will apologize in advance for asking you to personally review the enclosed statement that I presented at last evening's hearing--but please read it. We were pleased that EPA was represented by Ted Fritz last night. Mr. Fritz observed the meeting but did not testify.

Sincerely,

Sharilyn Dienst

Sharilyn Dienst

My name is Sharilyn Dienst. I am going to begin my statement with a request for an extension of the comment period. I appreciate the opportunity to voice my concerns with any repermitting of the Vulcan injection wells. I am opposed to the use of injection wells as a means of hazardous waste disposal. I have made that statement publicly numerous times based upon a general objection to industry's use of our natural resources as a sewer for chemical offage.

That argument is based upon the premise that the waste is actually going to get to the Arbuckle. After reviewing files on Vulcan's injection wells, I am also concerned with the effect that the Vulcan injection wells have had on the groundwater from the well head TO THE ARBUCKLE during the past several years.

A review of available material indicates that every environmental media has been contaminated in the Vulcan area. The extent of water and air contamination both on and off-site indicate that this may well be one of the major environmental problems in the state of Kansas. I am basing that statement on groundwater samples taken in April of 1985 and on an EPA study of air contamination conducted in 1981.

In 1976, the Vulcan site was found to be in a highly contaminated condition. An extensive amount of effort and money was reportedly expended in an attempt to "clean up the site". Three years later, Vulcan was pronounced a "CLEANED UP SITE" in an August 3, 1979 letter from Mel Gray of the KDHE to the Environmental Protection Agency. At that time, the Vulcan site was removed from the National Listing of Hazardous Waste sites. THAT IS AMAZING.

If the conditions that prevail today at the Vulcan site are what the regulatory agencies deem "CLEANED UP", I can foresee some great problems at Furley when it's time to decide whether the remedial work at that site is adequate.

Considering the air and water contamination from the Vulcan site -- and the fact that Vulcan has been identified by the USEPA as one of the sites in Region VII whose manufacturing operations have the potential to result in DIOXIN CONTAMINATION--and that Vulcan does produce high levels of PCBs in their perchloroethylene process--I publicly petition the United States Environmental Protection Agency to conduct an Environmental Audit of the Vulcan Materials site and surrounding area to determine the exact extent of water and air contamination and to assure the safety of the citizens who are being exposed to unknown contamination in their air and water.

Nobody should have to breathe chemically contaminated air and nobody should be deprived of the use of their natural water supply for industrial gain. I feel sure that our governmental agencies are knowingly condone such practices.

Considering the condition that the Vulcan area is in, I don't see how any assurance can be given that the Vulcan injection wells have had no detrimental effect on useable groundwater.

In March of 1985, extremely high levels of chemical contaminants--for instance 31,000 ppb of 2,4-D--were found in on-site monitoring wells in all three aquifers. I saw no monitoring results for PCBs or Dioxins--yet both are waste byproducts of Vulcan operations. Groundwater appears to be contaminated in all directions and in all water levels off-site. At least 15 private residence wells have been contaminated. I understand that Vulcan has financed water line installation from the city of Clearwater to most of these homes and installed carbon filters at a few others.

Carbon filters may or may not reduce chemical contaminant levels in drinking water. At best, filtered drinking water provides a false assurance to the affected user. Bathing in chemically contaminated water and inhalation of contaminated air reportedly provides a greater source of exposure than actual consumption of the water.

I would hope that the regulatory agencies do not consider such acquisition of contaminated property as an adequate method of dealing with ongoing water pollution from the Vulcan site. If so, Vulcan conceivably could become the landlord of a lot of property south of Wichita. PEOPLE ON THE OUTER EDGES OF EACH VULCAN ACQUIRED PROPERTY SHOULD BE ALERT TO THIS FACT.

In 1981, an Air Emissions study was performed for the USEPA outside the Vulcan site. The study revealed that Carbon Tetrachloride, Trichloroethylene, Methylene Chloride and Perchloroethylene were detected in all directions from the site for a distance up to 3 miles. The four chemicals were found in a range from Detectable to 36,200 parts of Trichloroethylene and up to 5,600 parts of Perchloroethylene. The higher levels were reported at a location near 55th Street between Hoover and Ridge Roads--approximately one-half mile due north of Vulcan.

The study noted that chemical emissions come from on-site operations such as LEAKS IN VALVES, INCOMPLETELY SEALED CONTAINERS, FILLING AND EMPTYING OPERATIONS AND TRANSPORT OF CHEMICALS FROM ONE PLACE TO ANOTHER ON SITE.

Neighbors of the site have complained of fumes resulting in headaches and respiratory distress. One recently described fumes at her home as having a "sweet" odor. I was interested to read in this morning's paper about a train accident that spilled Carbolic Acid near El Dorado. The chemicals were on their way to the Vulcan site and the Carbolic Acid was described as having a "sweet, tarry odor".

WHAT FOLLOW UP ACTIONS HAVE BEEN TAKEN BY THE REGULATORY AGENCIES REGARDING THE USEPA REPORT OF CONTAMINATED AIR IN THE VULCAN AREA?

INCINERATOR

Vulcan has proposed to meet Federal requirements for a test burn of their Wichita incinerator by submitting data from a test burn conducted in 1981 from a much larger incinerator at the Vulcan plant in Louisiana.

Vulcan became aware in 1979 that POLYCHLORINATED BIPHENYLS (PCBS) are present in their Perchloroethylene process waste streams. PCBS AVERAGING 300 PPM HAVE BEEN OBSERVED IN THEIR HEX WASTE STREAM. DOES VULCAN HAVE AN APPROVED PCB INCINERATOR? IT WAS MY UNDERSTANDING THAT PCB INCINERATORS ARE HIGHLY REGULATED AND FEW IN NUMBER.

IN THE STACK SAMPLING DATA, PCB DESTRUCTION EFFICIENCY IS RATED AT 99.99993% BASED ON LIMITS OF DETECTION. However, those limits of detection are shown at 10 parts per billion.

IS THE PCB BURN DATA FROM THE WICHITA INCINERATOR OR FROM THE LOUISIANA INCINERATOR? IF THE DATA IS FROM THE LOUISIANA INCINERATOR, DOES THAT MEAN THAT THE WICHITA VULCAN PLANT IS AND HAS BEEN USING THEIR INCINERATOR FOR PCB INCINERATION BASED UPON DATA FROM ANOTHER PLANT IN ANOTHER STATE?

HAS ANY AMBIENT AIR MONITORING BEEN CONDUCTED IN THE VULCAN VICINITY SPECIFICALLY FOR PCBS OR FOR ANY OF THE OTHER CHEMICALS AT THE VULCAN PLANT?

I've been to several deepwell hearings in the past couple of years. I've seen sketches of injection wells drawn on a blackboard showing three protective casings--corrosion resistant cement bonding around the casing--corrosion resistant tubing. At a hearing three weeks ago, I listened to the KDHE staff explain how mechanical integrity tests are conducted to assure foolproof operation of injection wells. I've heard about the importance of compatibility between the receiving formation and the injection wastes.

After reading the history of the Vulcan injection wells--I have come to the conclusion that the KDHE and I are in great disagreement as to what constitutes a problem.

-I would like to ask what the requirements for Mechanical Integrity Tests have been in the past for the Vulcan wells?

A note from a Vulcan meeting says: "LOGS ON WELLS SUBSTITUTE FOR M.I.T.S.". Is that correct? Are MITs required prior to problems or only as a reaction to problems?

Another memo from a Vulcan meeting with EPA last year notes that new integrity testing of the casing is required. Vulcan claimed that they had done an equivalent assurance of the integrity of the casing and asked if this would suffice. Vulcan threatened to appeal the requirement.

-Why does the Vulcan Draft Permit allow a 50% reduction in annulus pressure when the KDHE required notification of a 25% reduction by the High Plains well?

-Senate Bill #120 has been signed into law by the Governor. This bill requires an application fee of \$10,000 per well for existing wells.

Has Vulcan submitted the \$50,000 in application fees?

-Has a current review of disposal alternatives been provided? The document that I saw was undated but dwelled mainly on the financial feasibility of alternatives.

-What studies have been undertaken to protect oil and gas production in the Vulcan area? Has the impact of lateral displacement of brine in the injection zone been investigated fully? Oil production exists within 3 miles of Vulcan. A well in Florida caused pressure effects 40 miles away from the site.

-Considering the existing contamination of air and water from the Vulcan site, how are the requirements of Section 213 of the RCRA Reauthorization going to be met?

In the recently released USGCRP report to Congress on Underground Injection Wells in the United States, a statement was made that sticks in my mind:

THE COMMON PRACTICE AT A FEW OF THE FACILITIES HAS BEEN TO REWORK AN INJECTION WELL ONLY AFTER LEAKS ARE DETECTED.

Vulcan was not among those sites visited but it is apparent that Vulcan falls into that category--and has been allowed to do so by the state regulatory agency.

The history of the Vulcan wells is abysmal and a far cry from what is presented by deepwell proponents.

THE WELL CASING IS USED TO PREVENT CONTAMINATION OF UNDERGROUND SOURCES OF DRINKING WATER BY CONFINING THE INJECTION FLUID INSIDE. A CRUCIAL INDICATOR OF WELL FAILURE IS THE ANNULUS PRESSURE. LEAKS IN THE CASING CAN BE DETECTED BY A DROP IN ANNULUS PRESSURE. EVEN A VULCAN REVIEW OF THEIR WELLS NOTES THE FOLLOWING REGARDING THE IMPORTANCE OF THE ANNULUS ZONE:

"THE ANNULUS PRESSURE ASSURES THAT, SHOULD A LEAK OCCUR IN THE INJECTION STRING, NO WASTEWATER COULD FLOW INTO THE ANNULUS. THE WASTEWATER WOULD REMAIN CONTAINED."

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The following is a brief summary of six of Vulcan's wells, including the five for which they seek repermitting.

VULCAN WELL #3

3-29-77: ANNULUS PRESSURE VARIED ERRATICALLY AND DROPPED TO ZERO. When the well was pulled, several deteriorated gaskets, thread imperfections on casing joints and EXTENSIVE CASING CORROSION WAS FOUND. THE CASING REVEALED DAMAGE AND LEAKS FROM THE 500 TO 700 FOOT LEVEL.

3-31-77: TUBING REINSTALLED BUT COULD NOT RE-ESTABLISH ANNULAR PRESSURE. The following is a direct quote from a letter from Vulcan to Bryson of KONE:

NEVERTHELESS, THE LARGE VOLUME OF IMPOUNDED WASTEWATER REQUIRED THAT WE RETURN THE WELL TO SERVICE.

THE WELL WAS USED FOR 18 DAYS WITH NO ANNULUS PRESSURE and WITH NO REPAIR. Although no firm conclusion was ever reached as to the problem, well #3 was put back into service.

1-19-80: TUBING PULLED BECAUSE OF BRINE SLUDGE BLOCKAGE.

TWO MONTHS LATER (APRIL 1980): TUBING PULLED DUE TO BRINE SLUDGE BLOCKAGE.

SIX MONTHS LATER (OCTOBER 1980): WELL SUFFERING REDUCED FLOW OWING TO BOTTOM HOLE BLOCKAGE.

FOUR MONTHS LATER (FEBRUARY 1981): TUBING PLUGGED AND DRILLED THROUGH HARD BLOCKAGE AT 3980'.

LATER THAT MONTH: ANOTHER BLOCKAGE DEVELOPED IN TUBING STRING.

IN 1983, 141,900,000 GALLONS OF WASTE WAS INJECTED THROUGH THIS WELL.

VULCAN IS SEEKING REPERMIT FOR WELL #3

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WELL #4

JULY 1982: REDUCTION IN ANNULUS PRESSURE. The repair work is as follows:

-The 141st joint of tubing had separated leaving the remaining 57 joints of tubing in the bottom of the hole.

-Fibercast tubing covered with very thick, black sludge--apparently the result of chemical contamination of the annulus oil below the tubing leak.

-Reference is made to damaged bottom hole conditions.

-Hole in joint at 2074' and at 2850' depths.

-Several thread failures.

-Older pipe very badly deteriorated inside and at the ends.

On July 14, 1982 several new areas of possible casing damage were revealed--most significant being at 2076 and 2857' depths.

-Other areas of metal loss at depths of 2273, 2292 and 2601'.

-A blockage was noted at 3413' depth and it was noted that PREVIOUS LOGS HAVE SHOWN SEVERE DAMAGE BELOW THIS DEPTH.

On July 12, 1982 during reinstallation of the tubing, the tubing stopped at the 196th joint. "ALTHOUGH THE TUBING IS HUNG UP DOWNHOLE, IT IS NOT ACTUALLY ANCHORED AT BOTH ENDS". After unsuccessfully attempting to free the string, a meeting was held with KDHE and PERMISSION WAS GRANTED TO RETURN THIS FAULTY WELL TO SERVICE.

IN 1983, 109,600,000 GALLONS OF CHEMICAL WASTE WAS INJECTED THROUGH WELL #4. VULCAN SEEKS REPERMITTING OF THIS WELL.

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WELL #6

7-5-78: ANNULUS PRESSURE FELL. PRESSURE TEST REVEALED LEAKS AND DAMAGED THREADS OR LINER. ONLY 39 OF 196 JOINTS FIT FOR REUSE.

8-14-79: ANNULUS PRESSURE FELL. "THE NEXT DAY ACID SERVICE WAS TERMINATED". I ASSUME THAT THIS MEANS THAT FOR A FULL DAY, THE

ACID SERVICE WAS CONTINUED ALTHOUGH A LEAK IN THE WELL WAS INDICATED BY THE DROP IN ANNULAR PRESSURE.

OCTOBER 1979: CASING DAMAGE WAS FOUND AT THE FOLLOWING INTERVALS:

| | |
|-----------|--|
| 3150-3175 | <u>SLIGHT</u> |
| 3215-3238 | <u>SLIGHT</u> |
| 3238-3254 | <u>COMPLETE FAILURE</u> |
| 3254-3278 | <u>SEVERE DAMAGE TO COMPLETE FAILURE</u> |
| 3278-3295 | <u>COMPLETE FAILURE</u> |
| 3295-3352 | <u>SEVERE</u> |
| 3352-3357 | <u>COMPLETE FAILURE</u> |
| 3357-3458 | <u>SEVERE TO MODERATE</u> |
| 3458-3590 | <u>MODERATE TO SLIGHT</u> |
| 3590-3600 | <u>COMPLETE FAILURE</u> |
| 3600-3745 | <u>SEVERE DAMAGE TO COMPLETE FAILURE</u> |
| 3745-3938 | <u>NO STEEL CASING PRESENT</u> |
| 3938 | MECHANICAL CALIPER TOTAL DEPTH |

Vulcan met with KDHE's Oil Field and Geology staff and it was decided to repair the casing damage.

- The first cement squeeze would not hold pressure.
- They had trouble with the third squeeze.
- The inflatable Lynes plug partially deflated and moved down the hole for 9 feet.
- Attempts to pull or push the plug resulted in getting it stuck in the hole.
- While drilling out the cement, the formation cuttings at 3949' depth changed. The author notes: "I believe that we started drilling a new hole at this point. Circulation was lost at 3970' and never regained. A new hole was drilled to 4072'."

12-28-79: Fibercast tubing eventually landed at 3965' and disposal of contaminated water began. The consultant noted: "THE PROBLEM WITH USING THIS WELL FOR ACID SERVICE IS THAT FIBERCAST TUBING FAILURE IN THE LOWER PORTION OF THE HOLE IS HARD TO DETECT. THERE ARE HOURLY FLUCTUATIONS IN ANNULUS PRESSURE AND THESE CHANGES COULD 'MASK' A TUBING FAILURE."

The well was returned to service for "primarily" "essentially" neutral or basic wastewater. A profound statement was made at this point: "DIFFICULTIES WILL ARISE ONLY AFTER THE TUBING FAILS".

3-29-80: ANNULUS PRESSURE AND TUBING PRESSURE EQUALIZED AND THEY THOUGHT THE TUBING WAS EITHER PINCHED OR COLLAPSED AT ABOUT 3800 FEET.

A year later a KDHE geologist drove by the Vulcan plant and noticed that a "rig was positioned over Vulcan #6". He stopped to confer with Vulcan officials. It is noted that Well #6 had been down for approximately 60 days with no evident notification to the Department.

Well #6 had STOPPED TAKING FLUID IN MAY 1981. When the tubing was retrieved, the lower part was badly twisted.

The KDHE geologist notes that he thinks that the CASING HAS PARTED AND IS OFFSET.

An inspection log clearly showed extensive casing damage above 190'. The 7" casing was completely gone from a depth of 82' to 109'

Maintenance on Well #6 was finally discontinued and the well was abandoned--NEARLY TWO YEARS AFTER A CASING INSPECTION REVEALED EVERYTHING FROM SEVERE DAMAGE TO NO CASING AT ALL NEARLY 1000 FEET ABOVE THE DISPOSAL ZONE.

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WELL #8

December 1983: LOSS IN ANNULUS PRESSURE AND MAJOR MAINTENANCE.

-COMPLETE SEPARATION AT 30TH JOINT OF TUBING STRING.

-SOME TUBING LEFT IN OPEN HOLE.

MAJOR MAINTENANCE CONTINUED THRU EARLY JANUARY 1984.

85,400,000 GALLONS OF WASTE WAS INJECTED INTO WELL #8 IN 1983.

ON MAY 16, 1985: LOSS IN ANNULUS PRESSURE. AFTER LOADING ANNULUS SEVERAL TIMES AND CONTINUING TO LOSE PRESSURE, VULCAN CONCLUDED THAT THEY PROBABLY HAVE A HOLE IN THE TUBING. SEVERAL ATTEMPTS WERE MADE TO FIND THE PROBLEM AND IT WAS FINALLY DECIDED THAT THE ANNULUS OIL HAD WATER IN IT. THE OIL WAS REPLACED AND THE WELL RETURNED TO SERVICE ON JUNE 4, 1985--A MONTH AGO.

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CEMENTING

THE MAJOR FUNCTIONS OF THE CEMENT THAT IS APPLIED BETWEEN THE OUTER WALLS OF THE CASING AND THE BOREHOLE OR OTHER CASING ARE TO RESTRICT MOVEMENT OF FLUIDS BETWEEN THE SURFACE AND THE SUBSURFACE OR BETWEEN DIFFERENT STRATA IN THE SUBSURFACE, TO SUPPORT THE CASING, TO PREVENT POLLUTION OF UNDERGROUND SOURCES OF DRINKING WATER AND TO PREVENT CASING CORROSION.

THE USEPA REPORT ON UNDERGROUND INJECTION STATES THAT IN ALL CASES, CEMENT IS APPLIED IN AT LEAST ONE STRING, FROM THE SURFACE TO BELOW THE BASE AND AT THE CONFINING ZONE ABOVE THE INJECTION ZONE.

THE REPORT NOTES THAT WHEN THE WELL IS DRILLED, A CONDUIT IS CREATED FOR COMMUNICATION BETWEEN THE DIFFERENT STRATA AND UNLESS AN ADEQUATE CEMENTING PROGRAM IS FOLLOWED, MOVEMENT OF FLUIDS COULD OCCUR AT THE INJECTION ZONE INTO OTHER FORMATIONS OR BETWEEN FORMATIONS PENETRATED BY THE WELL.

THE EPA REPORT ERRONEOUSLY LISTED ALL FIVE OF THE VULCAN WELLS AS BEING CEMENTED TO THE SURFACE. WELLS #7 AND #9 ARE NOT.

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WELL #7

In September 1976, KDHE granted Vulcan permission to construct Well #7 for use of highly acidic waste. Well #7 receives acid waste with a pH of .1 to .7.

(The information in the USEPA Report erroneously showed this well as receiving waste with pH of 1.5 to 13.0.)

A letter written TWO MONTHS AFTER PERMISSION TO CONSTRUCT REPORTS THAT THE CEMENTING PROCESS ON WELL #7 FAILED AT A DEPTH OF 2400'.

DOCUMENTS NOTE THAT CEMENT BONDING BETWEEN THE 7" CASING AND THE FORMATION IS NOT CONTINUOUS THROUGHOUT THE ENTIRE LENGTH OF THE HOLE. A CONSULTANT NOTES: "even if the cement bond were to fail and fluid from the Arbuckle comes in contact with outside of casing, ONLY CORROSION WOULD RESULT."

MARCH 1977: PRIOR to use of Well #7, a letter from KDHE notes:

"We were quite concerned, although not surprised, to learn that Well #7 has developed a STATIC COLUMN OF FLUID WHICH HAS A LOW PH. THIS OF COURSE SUBSTANTIATES THAT COMMUNICATION EXISTS WITHIN THE ARBUCKLE FORMATION BETWEEN WELL #7 AND ONE OR MORE OF THE DISPOSAL WELLS IN CURRENT USE..A STATIC COLUMN OF ACIDIC FLUID WOULD HASTEN PIPE CORROSION AND THEREFORE JEOPARDIZE THE INTEGRITY OF THE CASING."

One month later (4-77) the KDHE approved Vulcan's application to use the well and approved the casing EVEN WITH THE LACK OF TOP TO BOTTOM CEMENTING.

SIXTEEN MONTHS LATER; (AUGUST 1978) THE FEED PIPING WOULD ONLY TAKE FEED AT 250 GPM.

NINE MONTHS LATER (MAY 1979): A DECREASE IN ANNULUS PRESSURE WAS REPORTED. INSTEAD OF SHUTTING THE WELL DOWN, THE COMPANY MERELY SWITCHED WASTE STREAMS AND CONTINUED TO USE THE WELL FOR TWO MORE WEEKS.

WHEN THE TUBING WAS FINALLY PULLED, A DAMAGED SECTION WAS FOUND AT 1480 FEET DEPTH. THE WELL WAS RETURNED TO SERVICE 3 DAYS LATER.

FIFTEEN MONTHS LATER (SEPTEMBER 1980): ANNULUS PRESSURE DROPPED. As the string was removed, IT PARTED AT THE 6TH JOINT WHERE IT HAD UNDERGONE CORROSION.

IN 1983, 151,800,000 GALLONS OF WASTE WAS DISPOSED OF THRU THIS WELL.

APRIL 1985: LOST ANNULUS PRESSURE.

-HOLES PRESENT IN 7" CASING FROM 3868' AND BELOW.
 -A TWO-FOOT SPLIT WAS OBSERVED IN 5TH AND 8TH JOINTS FROM BOTTOM.
 -FOUR MORE JOINTS SPLIT DURING PRESSURE TEST.
 -LEAKS IN THREADS OF 168TH JOINT FROM BOTTOM.
 -ELECTRONIC CASING CALIPER LOG INDICATED POSSIBLE DAMAGE IN BOTTOM 100 FOOT OF HOLE.

AFTER A KDHE-VULCAN MEETING, LARRY KNOCHE OF KDHE SAID IF THE WELL COULD PASS A PRESSURE TEST, IT COULD BE RETURNED TO SERVICE. THE WELL PASSED THE TEST AND WAS BACK IN SERVICE ON MAY 14, 1985--TWO MONTHS AGO.

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WELL #9

(NOTE: FROM VULCAN'S DESCRIPTION OF THEIR WELLS: "OUR DESIGN CONSISTS OF 3 SEPARATE STEEL CASINGS, EACH OF WHICH IS ANCHORED BY CEMENT FROM THE BOTTOM OF THE HOLE TO THE SURFACE. THIS EFFECTIVELY SEALS AND PROTECTS THE ONLY POTABLE WATER PRODUCING ZONES WHICH ARE AT 50-100 FEET FROM THE SURFACE.")

6-8-82: CEMENT BOND LOG SHOWED ABSENCE OF CEMENT FROM 420' TO 250'--WHICH IS THE FLUID LEVEL OF THE ARBUCKLE.

Vulcan notes that the amplitude of the ring of the pipe SUGGESTS PRACTICALLY FREE PIPE, SUCH THAT NO INTERPRETATION OF ANNULAR CONTENT IS POSSIBLE.

A conference call was held between KDHE and Vulcan--after which VULCAN WAS GIVEN VERBAL APPROVAL TO USE THE WELL AS WAS--VOID OF CEMENT FROM 420' UP.

IN 1983, 9,000,000 GALLONS OF WASTE WAS INJECTED INTO THIS WELL.

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THE USEPA REPORT detailed conditions at twenty injection sites. I might add that there IS NO RECORD OF VIOLATIONS IN KANSAS. The states of Louisiana, North Carolina, Texas, Ohio, Alabama, Arkansas and Florida considered the following as more than "OPERATIONAL PROBLEMS".

1. DISREGARD FOR COMPATIBILITY BETWEEN WASTES AND TUBING, PACKER AND CASING.
2. INADEQUATE CEMENT IN BOREHOLE
3. CORRODED TUBING AND CASING
4. CASING CRIMPED
5. ACIDIC WASTE DISSOLVED PART OF INJECTION ZONE
6. ANNULUS AND INJECTION FLUID COMMUNICATION
7. INCONSISTENCY IN ANNULUS PRESSURE

8. pH VIOLATION CAUSING CORROSION OF WELL

ALL OF THESE THINGS HAPPEN RATHER ROUTINELY WITH THE VULCAN WELLS
AND YET VULCAN IS LISTED AS HAVING NO PROBLEMS.

WHERE DID THE USEPA OBTAIN THE INFORMATION REGARDING THE VULCAN
WELLS?

GROUNDWATER

As the largest generator of hazardous waste in the state of Kansas, Vulcan manufactures ammonia, chlorine, caustic soda, hydrogen, chloroform, carbon tetrachloride, methylene chloride, perchloroethylene and Pentachlorophenol. Wastes from the Vulcan plant include all of the above and hexachlorobenzene, solvents, PCBs, Dioxins and other assorted hazardous wastes.

With the limited information available from groundwater monitoring, it isn't possible to take a comprehensive look at the groundwater conditions. What I can see is that most of the aforementioned chemicals -- along with several others-- have been detected in three levels of groundwater as recently as four months ago.

Intercept wells, designed to retrieve the contaminated groundwater, have been operated for several years on and near the site. The highly contaminated water pumped from the ground is then injected into the Arbuckle along with Vulcan's chemical waste.

The Vulcan site has a 41.6 acre chemical waste landfill which has been covered with six feet of clay and "is monitored extensively". Scientific studies have found that chemicals attack soils, causing dissolution of the clay, and allowing the chemical waste to enter the groundwater. It has become commonly known that landfills leak. The state of Kansas found that out in 1982. Putting a top on a leaking landfill does not prevent the migration of chemicals from the clay sides and bottom of the landfill. Vulcan has stated that their concern is not with the groundwater On the site but beyond their boundaries. It would be nice if the chemicals in the groundwater WOULD remain at the fence line, but they haven't, they don't and they won't.

In March of 1985, some of the chemicals found in the groundwater on site, in all levels of groundwater include:

| | |
|-----------------------|----------|
| ORTHO-CLOROPHENOL | 3800 PPB |
| 2,4 DICHLOROPHENOL | 7500 |
| 2,4,6 TRICHLOROPHENOL | 5300 |
| 2,6 DICHLOROPHENOL | 1200 |
| 2,4-D | 31,000 |
| 2,6-D | 22,000 |
| 2,4,6-T | 4500 |
| BENZENE | 386 PPB |
| TETRACHLOROETHYLENE | 241 |
| CHLOROPHENOL | 5600 |

THIS IS NOT A LIST OF CHEMICALS FOUND PRIOR TO THE "CLEAN UP" OF THE VULCAN SITE. THIS IS A MONITORING REPORT FROM APRIL OF 1985.

HAVE ANY PCB ANALYSES BEEN CONDUCTED ON THE GROUNDWATER ON AND OFF OF THE VULCAN SITE? UP TO 300 PARTS PER MILLION OF PCBS ARE FOUND IN THE PERCHLOROETHYLENE PROCESS WASTE STREAMS.

The condition of the groundwater beyond the Vulcan boundaries is alarming. Groundwater appears to be contaminated in all directions in all three water levels.

SOUTHEAST OF VULCAN, the aquifers contain 8 of the chemicals found in on-site wells.

SOUTHWEST of Vulcan, the groundwater contains ten of the chemicals.

Northeast of Vulcan, analyses reveal 12 of those chemicals. The carbon tetrachloride levels in that area are nearly 8 TIMES HIGHER THAN IN 1984 despite the use of interceptor wells.

Twenty-eight chemicals were found in shallow and deep aquifers SOUTH of Vulcan. This well appears to be at the south end of the landfill and would create a reasonable conclusion that the landfill is leaking.

At least 15 PRIVATE RESIDENCES HAVE CONTAMINATED WELL WATER. The wells contain up to NINE CHEMICAL CONTAMINANTS ranging from less than 1 PPB to 35 parts per billion of individual chemicals--the same chemicals in the aforementioned groundwater samples. It is my understanding that Vulcan has purchased property with contaminated groundwater and financed water line installation from the city of Clearwater to supply these contaminated homes. A memo titled Vulcan Meeting Notes states that "Carbon filters installed on many residents' well water. Carbon filters may or may not reduce chemical contaminant levels in the drinking water. At the best, filtering drinking water provides a false assurance to the affected citizens. According to the National Journal of Public Health, skin absorption and inhalation represent a significant route of exposure to chemicals. In other words, if it is indeed possible to filter chemicals from drinking water--bathing in contaminated water and inhalation of contaminated air apparently provides a greater source of exposure than actually consuming the water.

While that may be a responsible action for the company to take, I would hope that the regulatory agencies do not consider such acquisition of contaminated property as an adequate method of dealing with ongoing water pollution from the Vulcan site. If so, Vulcan conceivably could become the landlord of a lot of property south of Wichita. PEOPLE ON THE OUTER EDGES OF EACH VULCAN ACQUIRED PROPERTY SHOULD BE ALERT TO THIS FACT.