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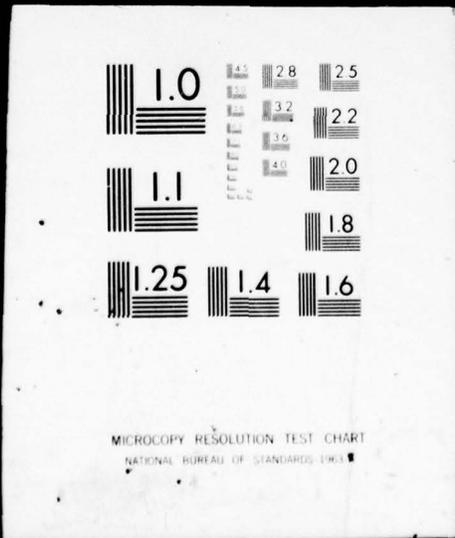
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STUDY OF DETECTION, IDENTIFICATION, AND QUANTIFICATION TECHNIQUES FOR SPILLS OF HAZARDOUS CHEMICALS



October 1976

FINAL REPORT

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**UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20590**

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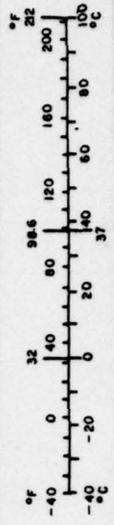
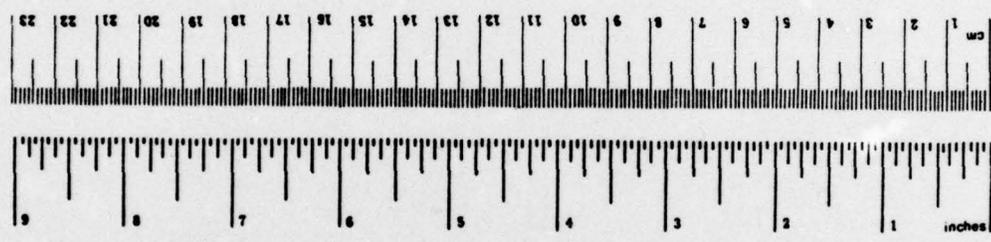
Administrative stamp with fields for 'DISTRIBUTION', 'REVISIONS', and 'APPROVED'. Includes checkboxes for 'This Section' and 'Not Section'. A large handwritten 'A' is present at the bottom of the stamp.

1. Report No. 18 25 CG D-114-76 ✓	2. Government Accession No.	3. Recipient's Catalog No.	
6 Title and Subtitle Study of Detection, Identification, and Quantification Techniques for Spills of Hazardous Chemicals.		5. Report Date October 1976	6. Performing Organization Code
7. Author 10 G. A. Sandness, J. F. Washburn, and S. B. Ailes		8. Performing Organization Report No. 12 196 P.	
9. Performing Organization Name and Address Battelle, Pacific Northwest Laboratories ✓ Richland, Washington		10. Work Unit No. (TRAIIS) 4241.5/1	11. Contract or Grant No. DOT-CG-54323-A <i>new</i>
12. Sponsoring Agency Name and Address Department of Transportation* U.S. Coast Guard Office of Research and Development Washington, D.C. 20590		13. Type of Report and Period Covered 9 Final Report. Jul 1975 - Oct 1976	
15. Supplementary Notes *This project was co-sponsored by the U.S. Environmental Protection Agency, National Environmental Research Center, Remote Sensing Branch, Las Vegas, Nevada 89114			
14. Abstract This study is intended to provide some of the initial technical data needed by the Coast Guard and the EPA for monitoring water pollution in inland and coastal waters. There are two major parts to this report. In the first part, twelve generalized remote and in situ water pollution sensing techniques are identified and discussed. Then the relative potential and current detectability, identifiability, and quantifiability of each of the first 400 chemicals in the Coast Guard's CHRIS list are estimated with respect to each of these techniques. The results are presented as numerical matrices or charts. Needs for further research and development of pollution sensing instrumentation are discussed. The second part of this report describes the design and testing of a prototype, active, aerial scanner system being developed by Battelle-Northwest for nighttime pollution detection. The feasibility of the design concept was demonstrated by laboratory and flight tests of the scanner together with laboratory measurements of the fluorescence spectra of fourteen oils and five other chemicals.			
17. Key Words Hazardous chemicals Water pollution Pollution detection Remote sensing Active scanner		18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 197	22. Price

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures			Approximate Conversions from Metric Measures					
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH								
in	inches	2.5	centimeters	mm	millimeters	0.04	inches	in
ft	feet	30	centimeters	cm	centimeters	0.4	inches	in
yd	yards	0.9	meters	m	meters	3.3	feet	ft
mi	miles	1.6	kilometers	km	kilometers	0.6	yards	yd
AREA								
sq in	square inches	6.5	square centimeters	cm ²	square centimeters	0.16	square inches	in ²
sq ft	square feet	0.09	square meters	m ²	square meters	1.2	square yards	yd ²
sq yd	square yards	0.8	square meters	m ²	square kilometers	0.4	square miles	mi ²
acres	square miles	2.6	hectares	ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)								
oz	ounces	28	grams	g	grams	0.035	ounces	oz
lb	pounds	0.45	kilograms	kg	kilograms	2.2	pounds	lb
	short tons	0.9	tonnes	t	tonnes (1000 kg)	1.1	short tons	st
VOLUME								
teaspoons	teaspoons	5	milliliters	ml	milliliters	0.03	fluid ounces	fl oz
tablespoons	tablespoons	15	milliliters	ml	liters	2.1	pints	pt
fluid ounces	fluid ounces	30	milliliters	ml	liters	1.06	quarts	qt
cups	cups	0.24	liters	l	liters	0.26	gallons	gal
pints	pints	0.47	liters	l	cubic meters	35	cubic feet	ft ³
quarts	quarts	0.96	liters	l	cubic meters	1.3	cubic yards	yd ³
gallons	gallons	3.8	liters	l				
cubic feet	cubic feet	0.03	cubic meters	m ³				
cubic yards	cubic yards	0.76	cubic meters	m ³				
TEMPERATURE (exact)								
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10-286.

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SECTION 1
INTRODUCTION

1.1 OBJECTIVES

The U.S. Coast Guard and the Environmental Protection Agency are both charged by Congress with responsibilities for monitoring the pollution of surface water within and adjacent to the United States.

This study, supported jointly by the Coast Guard and the EPA, is intended to provide some of the technical data that is required by both agencies in meeting their responsibilities for pollution monitoring and control.

More specifically, the objectives of this study, or the tasks that have been performed, can be listed as follows:

- Review scientific literature to assess the current state of knowledge on the physical, chemical, and spectral characteristics of the 400 chemicals listed in the first two volumes of the Coast Guard's Chemical Hazards Response Information System (CHRIS).
- Review scientific literature to determine the capabilities of currently available remote and in situ sensing instrumentation for detection, identification, and quantification of hazardous chemical spills.
- Identify those CHRIS chemicals which have physical, chemical, or spectral characteristics that will allow spills of the chemicals to be detected, identified, or quantified by remote and in situ sensing methods.
- Evaluate the various remote and in situ sensing techniques in terms of the number or range of chemicals which they may be capable of detecting, identifying, or quantifying.
- Correlate chemicals with appropriate sensing methods and assess the degree to which detection, identification, or quantification may be accomplished by currently available instrumentation.

- Assess the technical feasibility of the various techniques for immediate application to the detection, identification, and quantification of a limited number of chemicals.
- Estimate the scope of the research effort required to develop effective techniques and equipment for detection, identification, and quantification of those CHRIS chemicals which cannot be detected, identified, or quantified by currently available systems.

All of the above objectives or tasks involve the analysis of data and information obtained from scientific literature, government or industrial reports and brochures, and from individual researchers. Three additional tasks are directed toward evaluating the potential capabilities of an active, aerial imaging system, or scanner, developed by Battelle-Northwest. This system, which is intended for the nighttime detection, identification, and mapping of oil spills and other fluorescent or reflective materials, was constructed in prototype form and demonstrated in a preliminary manner prior to the initiation of this contract. The following tasks are intended to provide a more detailed evaluation of the potential of an imaging system of this type for detecting, identifying, and mapping spills of oil or other hazardous chemicals.

- Modify the existing prototype active scanner to maximize its performance, make laboratory measurements of arc lamp-stimulated oil fluorescence, and conduct controlled flight tests of the modified scanner to evaluate its potential capability for oil detection and identification.
- Perform laboratory fluorescence spectral measurements on a limited number of specified chemicals to determine if Battelle's active imaging system would provide a feasible means for detecting or identifying those chemicals.
- Test the modified active scanner at the site of a real oil spill. The primary emphasis in this task was the detection and areal display of the oil spill.

The active scanner system is described in detail in Section 7 of this report.

1.2 DISCUSSION OF THE PROBLEM

The problem of detecting, identifying, and quantifying spilled chemicals in large bodies of water such as rivers, lakes, and the oceans is enormously complex. This is due in part to the large number of chemicals that can potentially be spilled, and to the large diversity in the properties exhibited by those chemicals in water. It is also due to environmental factors such as the turbidity, turbulence, and roughness of the water, background pollutant concentration, and atmospheric conditions.

In recent years, rapid and significant advances have been made in the technology of remote sensing. As little as a decade ago, the state-of-the-art in remote sensing was largely represented by the techniques of aerial photography. Although photographic techniques can be highly effective in certain applications, their range of effectiveness is limited by the relatively narrow spectral range of available films and by the difficulty of quantitatively analyzing photographic imagery. The development of an optical-mechanical scanner by the University of Michigan in 1966 was an important step in remote sensing because it provided a means for quantitative data recording via magnetic tape as well as providing a wide-band multi-spectral capability. More recently, the availability of lasers, photon counters, optical multichannel analyzers and other advanced electro-optical devices have made possible further significant advances in remote sensing capabilities.

Nevertheless, no instrumentation system or sensing technique is yet available that can reliably detect any of the CHRIS chemicals under all normal environmental conditions, or detect all of the CHRIS chemicals even under ideal conditions. It is generally recognized that a multisensor approach is required to achieve a reasonably effective operational pollution monitoring capability. The Coast Guard's AOSS (Airborne Oil Spill Surveillance) system, utilizing radar, passive microwave, thermal infrared, and video (TV) sensors, is a good initial step in this direction. Much work remains to be done in the following areas:

- Research on the physical and chemical processes which affect the transport and dispersal of chemical spills in natural water bodies.
- Research on the physical, chemical, and optical properties of chemicals in water.
- Development of advanced sensor systems for remote and in situ applications.
- Research to determine the quantitative functional relationships between sensor response and environmental factors.
- Studies to determine optimum monitoring procedures and optimum sensor network configurations.

1.3 SELECTION OF SENSING TECHNIQUES

To conduct this study, it was necessary to identify, from a long list of analytical and remote sensing techniques, those techniques which could be both practical and effective in field applications to detect, identify, and quantify chemical spills in water bodies. Appropriate techniques should have several attributes, including the capability of detecting a broad range of chemicals, reliability, stability, capability for unattended or automatic operation, and low power requirements. For in situ sensing systems, an important consideration is that no sample preparation should be required.

Many standard laboratory analytical techniques, such as nuclear magnetic resonance, infrared absorption spectrometry, electron spin resonance, and chromatographic methods, are considered to be unsuitable for automatic sensing because they require special sample preparation or elaborate analysis procedures. However, this is basically an engineering (or cost) problem. If the need for automatic sensing systems which utilize these techniques is considered to be sufficiently acute, and if sufficient funding is made available, there is little doubt that effective operational systems could be developed.

Twelve generalized sensing techniques or classes of instrumentation have been selected for detailed consideration in this study:

- 1) Optical reflectance
- 2) Thermal infrared (passive sensors)
- 3) Passive microwave
- 4) Radar
- 5) Fluorescence
- 6) Raman scattering
- 7) Ion-selective electrodes
- 8) Electroconductivity
- 9) Reduction-oxidation potential
- 10) Optical absorptimetry
- 11) Dissolved oxygen
- 12) Total oxygen demand.

These types of instrumentation can be further categorized as either "in situ" or "remote" sensing systems.

In this report, in situ systems are taken to be those which operate in direct contact with the water. Remote sensing systems are those which operate at some distance from the water. Using these definitions, the first six techniques in the above list are primarily applicable to remote sensing. Fluorescence and Raman scattering techniques are exceptions in that they can also be implemented effectively for in situ applications. The last six techniques are limited to in situ applications.

SECTION 2
DATA ACQUISITION

2.1 CHRIS CHEMICALS

A data search was directed toward obtaining the types of data needed for field detection, identification, and quantification of spills of CHRIS chemicals in water. Data that are primarily useful in laboratory analytical methods were not actively sought. Emphasis was placed on data relating to the spectral reflectance, fluorescence, transmission and scattering properties of the chemicals in water.

Two principal sources were used to collect chemical, physical, and spectral data for the CHRIS chemicals. First, some of the physical data not already available in the CHRIS system were obtained from the OHM-TADS hazardous materials data file which has been established and maintained by Battelle under funds from the EPA. Second, a literature search was made to obtain spectral data and to identify data sources. Several compendia of spectral data were identified by this search. However, three of these compendia were not available locally. It was determined that the Linda Hall Library at the University of Missouri at Kansas City contained these volumes, and a graduate student was employed to make copies of the available data for the CHRIS compounds.

The results of this data search can be summarized as follows:

- Almost no reflectance data exist for either pure compounds or their water solutions.
- Fluorescence data are available for only a small number of the CHRIS compounds.
- Raman scattering data are available for almost half of the CHRIS compounds.
- Absorbance data are abundant in the infrared region above 2.5 microns. Data were obtained for nearly all of the pure compounds.

The data file has been submitted as a separate document to the Coast Guard and the EPA.

2.2 INSTRUMENTATION

The initial approach to the collection of information on remote and in situ sensing instrumentation was a literature search of available technical reports, abstracts, and journal articles. This yielded a significant amount of information, including the names of research organizations, industries, and researchers that have been active in the development of instrumentation for pollution detection and monitoring. Each of these individuals or organizations was initially contacted by a questionnaire and cover letter. This was done in order to make a large number of initial contacts quickly. Approximately 40% of the questionnaires were returned, and most of the responses were helpful in that they at least indicated the level of research effort being made by the responding researcher or research organization.

Most of the researchers identified by the literature search or by the returned questionnaire were directly contacted by telephone. This method provided information on developments which have been made since the publication of the available reports or articles.

The third method employed was a patent search conducted in the areas of remote and in situ sensing instrumentation. This search proved to be an economical means of gathering information, particularly for in situ instrumentation.

SECTION 3 SENSING TECHNIQUES

3.1 PURPOSE

The purpose of this section is to briefly introduce and discuss the twelve generalized sensing techniques that have been selected for this study. By "generalized" we mean that a variety of specific instrument types may be grouped together if there is a basic physical phenomenon or operating principle that is common to all of them. These basic principles will be outlined together with brief discussions of some of the factors that are involved in applying them to pollution monitoring. This section is intended to provide a background or a basis for the analyses of chemical detectability, identifiability, and quantifiability that follow in subsequent sections.

3.2 OPTICAL REFLECTANCE

3.2.1 BASIC CONCEPTS

Except at large angles of incidence, only a few percent of the light incident on a body of water is reflected by the surface of the water. The specular reflectivity of the water is a function of its index of refraction and the angle of incidence of the light. The index of refraction, in turn, depends on the wavelength of the light, as shown in Figure 3.1. In principle, if the addition of a pollutant sufficiently alters the index of refraction of the water, the polluted water may be detectable by virtue of a corresponding anomaly in the intensity of reflected light in that area. In practice, this method is insensitive because a high chemical concentration is needed to alter the reflectivity significantly in the presence of natural intensity variations caused by surface roughness fluctuations, sun glitter, clouds, haze and turbidity.

Reflectance anomalies produced by chemical films on the surface of the water are an important special case. Differences in the absorption spectra of a spilled chemical and water may result in detectable reflectivity contrasts in certain spectral regions. Oil spill detection in the IR and the near UV is an example of the utilization of this effect.

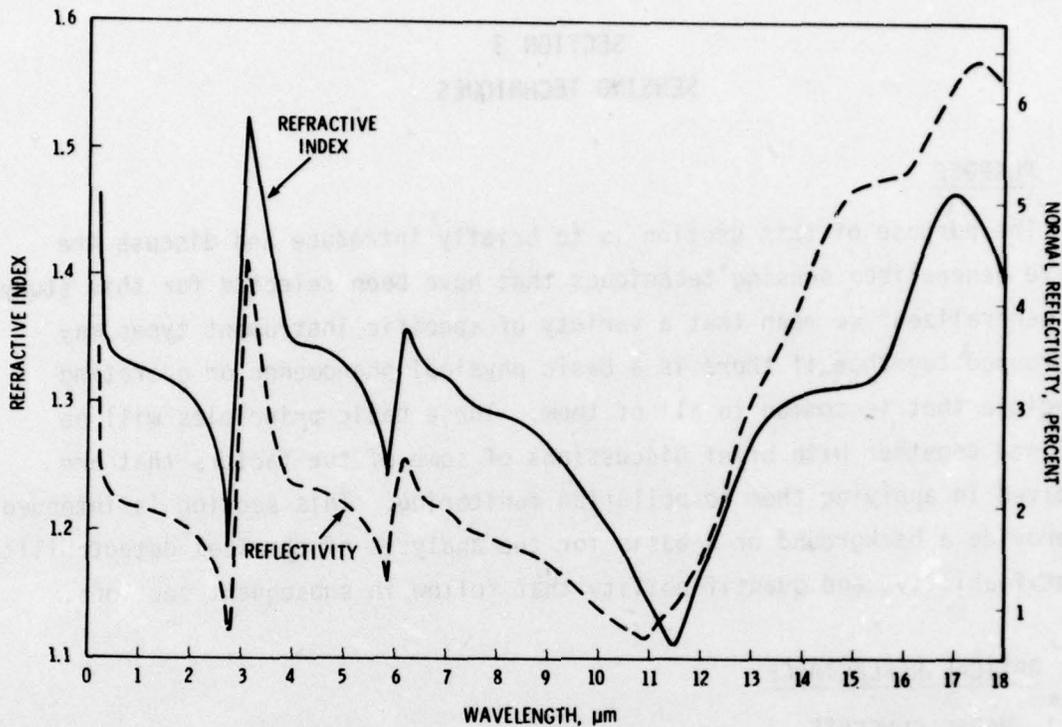


FIGURE 3.1. Refractive Index and Normal Reflectivity Versus Wavelength for Distilled Water. (Adapted From References 1 and 2.)

A second possible effect of a surface film is the formation of a slick due to the damping of high frequency wave components on the water surface.^{3,4} This increases the effective specular reflectivity of the film in comparison with the surrounding water, thereby increasing its detectability. It is well known that oil spills are detectable by virtue of their slick-forming properties. Presumably, other slick-forming chemical pollutants will be similarly detectable, depending on their viscosity and surface tension, but experimental observations are not available.

The large fraction of the incident light that is not reflected by the water surface is transmitted into the water where it is both scattered and absorbed. Figure 3.2 shows the absorption characteristics of water as a function of wavelength in the near UV to near IR spectral band.

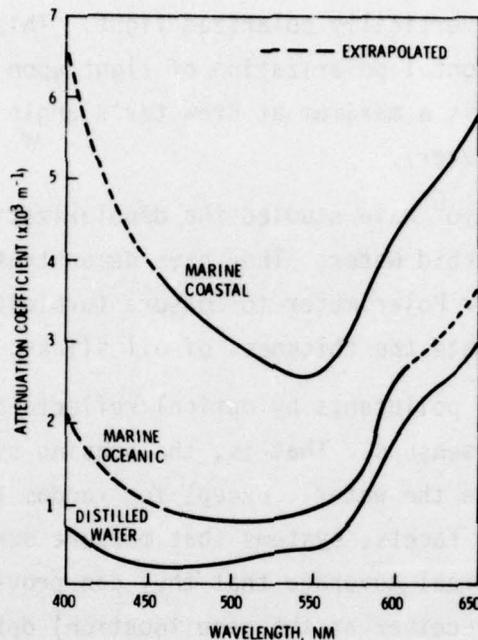


FIGURE 3.2. Attenuation Coefficient Versus Wavelength for Pure Water and Sea Water. (Adapted From Reference 5.)

A chemical pollutant having one or more strong absorption bands in the visible part of the spectrum may impart a coloration to the water which may be viewed from the surface as scattered or volume reflected light. Chemicals with absorption bands in the near UV or the near IR spectral regions are not detectable by means of their color since the absorption bands are outside the range of human perception, but they can be detected photographically or by a variety of electronic photodetectors.

The spectral intensity and distribution of incident sunlight and diffuse skylight are dependent on atmospheric conditions, as well as on sun elevation and azimuth. Light scattered from haze will strongly reduce apparent color or brightness differences (contrast) particularly in the blue portion of the spectrum.

It is often possible to enhance a surface reflection anomaly by observing only the horizontally polarized component of the light incident

on the detector. Similarly, the detection of subsurface pollutants can be enhanced by observing only vertically polarized light. This effect is a result of the partial horizontal polarization of light upon reflection from the water surface and is a maximum at Brewster's angle (approximately 53° from vertical for sea water).

Sheives, Rouse, and Mayo⁶ have studied the depolarization of back-scattered laser light in turbid water. They have demonstrated the feasibility of using a Lidar Polarimeter to measure turbidity and to detect, identify, and estimate the thickness of oil slicks.

Nighttime detection of pollutants by optical reflectance methods requires the use of active sensors. That is, the sensing system must include a light source to illuminate the water. Except for random reflections from properly oriented wave facets, systems that measure surface reflectivity are limited in the areal coverage that they can provide. Monostatic systems (light source and receiver at the same location) detect back-scattered light and are effective primarily near normal incidence. Bistatic systems allow the use of oblique viewing angles, but do not greatly enlarge the areal coverage unless multiple-sensor configurations are employed.

3.2.2 APPLICATION TO CHEMICAL DETECTION

Oil slick detection based on reflectivity effects has been successfully and routinely accomplished by photographic methods,⁷⁻⁹ optical-mechanical scanners,^{7,10} television systems,¹¹ and other opto-electronic sensors.^{6,12} Various combinations of spectral and polarization filtering have been used. The effectiveness of any given technique depends on geometrical and environmental parameters such as the relative positions of the sun, the slick, and the sensor; the directions of the wind and swells; the roughness of the water; turbidity; thickness and areal extent of the slick; and atmospheric conditions.

Chemical discharges which discolor the water have also been detected photographically¹³⁻¹⁵ and by multispectral scanners.¹⁶ But systematic studies to determine detection limits for chemical pollutants other than oils have not yet been conducted.

Clarke, Ewing, and Lorenzen¹⁷ have measured the spectrum of volume-scattered light to detect and estimate chlorophyll concentrations. Reflections from the water surface were minimized by observing only vertically polarized light at Brewster's angle. McCormack, Fournier, and Knight¹⁸ and Rambie¹⁹ have described an oil sensor which utilizes differences in the shapes of oil and water reflectance curves in two wavelength bands in the IR to detect oil. The sensor remotely measures the ratio of the reflected signal at 3.4 μm to the signal at 3.8 μm . For a hydrocarbon reflector, the ratio is approximately 1.0, and for water, approximately 1.5. An internal light source is used to obtain a day and night operating capability at a height of 10 to 100 feet. However, in a monostatic configuration, near-vertical operation is required. Other floating pollutants, in addition to oils, should be detectable by this method.

3.2.3 APPLICATION TO CHEMICAL IDENTIFICATION

Optical reflectance spectra for most chemicals are not highly distinctive in the UV and visible bands. However, under favorable environmental conditions, remote sensing techniques in these spectral bands may allow a significant narrowing of the range of possibilities for chemicals which display strong selective absorption.

Reflection and absorption spectra in the IR region are chemical-specific, but unique identification, if it can be accomplished, usually requires detailed spectral data in the "fingerprint" region, 6.7-14. μm . Techniques for remote or in situ measurements of IR spectra in the necessary spectral range have been mentioned in the literature²⁰, and are probably feasible, but they have apparently not yet been fully studied or developed.

3.2.4 APPLICATION TO CHEMICAL QUANTIFICATION

Under favorable conditions, it may be possible to estimate the concentration of certain known chemicals in the UV and visible regions of the spectrum. Research is required to determine these capabilities.

3.3 THERMAL INFRARED

3.3.1 BASIC CONCEPTS

Solids or liquids at finite temperature emit a continuous spectrum of electromagnetic energy. The spectral emittance of a blackbody is given by Planck's law:²¹

$$W_{\lambda} = \frac{C_1 \lambda^{-5}}{\exp(C_2/\lambda T) - 1}$$

where

the units of W_{λ} are Watts/m²/unit wavelength (m),

λ \equiv wavelength (m),

T \equiv absolute temperature (K),

C_1 \equiv 3.740 (10⁻¹⁶) (Watt·m²), and

C_2 \equiv 1.4385 (10⁻²) (m·K).

Figure 3.3 shows the spectral emittance of a blackbody at a temperature of 300 K. Material surfaces, however, can only approximate a blackbody. At a given wavelength the emittance of a real surface is proportional to the emittance of a blackbody of the same temperature. The constant of proportionality is called the emissivity of the surface.

Figure 3.4 shows the transmissivity of the atmosphere in the visible and infrared spectral regions. A major transmission window in the 8-14 μ m band corresponds closely to the maximum of the spectral emittance curve of Figure 3.3. A smaller window exists in the 3-5 μ m range. In the 8-14 μ m band, the emissivity of water is greater than .99;²²⁻²⁵ therefore, at these wavelengths the thermal IR emission spectrum of water closely approximates that of a blackbody.

Water strongly absorbs energy in the 8-14 μ m range and is essentially opaque to those wavelengths in thicknesses greater than approximately 0.02 mm.²⁶ Consequently, the thermal IR radiance of a water body is representative of the temperature of a thin surface layer.

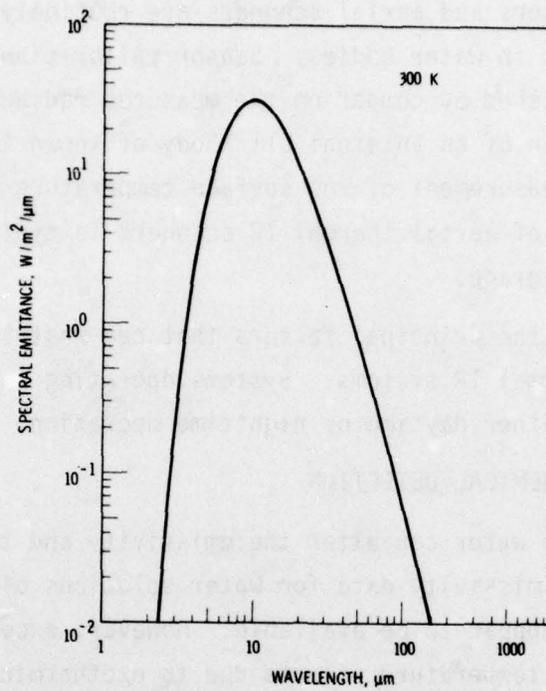


FIGURE 3.3. Blackbody Emission Spectrum at 300 K

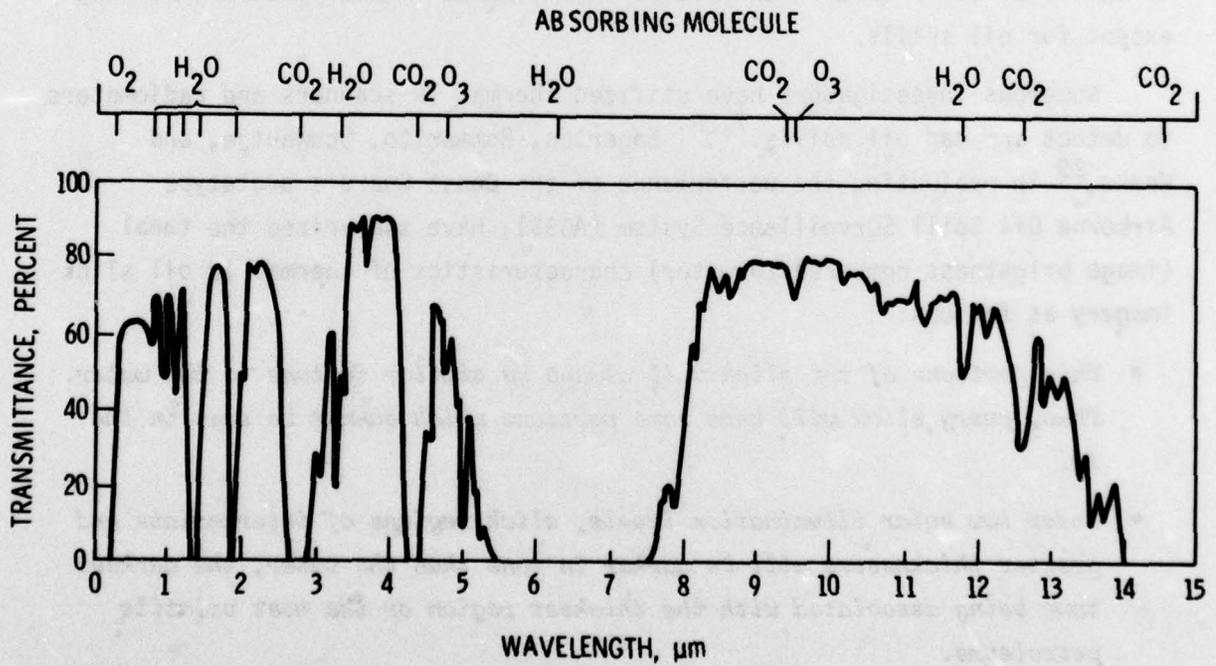


FIGURE 3.4. IR Transmittance Through the Earth's Atmosphere (Horizontal Path at Sea Level, Length 1828 m). (Adapted from Reference 27.)

Thermal IR radiometers and aerial scanners are routinely used for mapping thermal patterns in water bodies. Sensor calibration for temperature measurements is accomplished by comparing the measured radiance of the surface with the emission of an internal blackbody of known temperature, or by utilizing a direct measurement of the surface temperature at a known point. The sensitivity of aerial thermal IR scanners is typically a few tenths of a degree centigrade.

Fog and clouds are the principal factors that can restrict the operation of aerial thermal IR systems. Systems operating in the 8-14 μm band are effective in either daytime or nighttime operation.

3.3.2 APPLICATION TO CHEMICAL DETECTION

A chemical spill in water can alter the emissivity and the temperature of the water surface. Emissivity data for water solutions of most of the CHRIS chemicals do not appear to be available. However, except for rare but possible transitory temperature effects due to exothermic reactions of spilled chemicals, cases of practical importance are likely to be limited to spills of slick forming chemicals. Again, experimental data are lacking except for oil spills.

Numerous investigators have utilized thermal IR scanners and radiometers to detect and map oil spills.^{7,28} Edgerton, Bommarito, Schwantje, and Meeks,²⁹ in evaluating the performance of the Coast Guard's prototype Airborne Oil Spill Surveillance System (AOSS), have summarized the tonal (image brightness compared to water) characteristics of thermal IR oil slick imagery as follows:

- *Thin portions of the slick will always be similar in tone to the water. Thus, every slick will have some portions which cannot be seen in the IR.*
- *Under low solar illumination levels, slick regions of intermediate and greater thicknesses will be darker in tone than the water, the darkest tone being associated with the thickest region or the most volatile petroleums.*

- *Under high solar illumination conditions, slick regions of intermediate thickness will be darker in tone than the water. Thicker regions may be either lighter or darker in IR tone, depending upon whether the petroleum is highly absorbing to solar illumination or not, respectively.*

The minimum oil slick thickness detectable in thermal IR imagery appears to be on the order of 10 μm . Observable thermal patterns unrelated to oil or other chemicals can give false indications of spills. These can occur for several reasons, particularly in inland and coastal waters:

- Vertical mixing of water by waves, tidal currents, and ships.
- Effluent discharges.
- Flow of river water into the sea or a lake, or the confluence of rivers.
- Discharge of groundwater into surface water bodies.

3.3.3 APPLICATION TO CHEMICAL IDENTIFICATION

Thermal IR radiometry and imaging techniques do not appear to be capable of chemical identification except for inferences that can be drawn from the tone, shape, and texture of the imagery.

3.3.4 APPLICATION TO CHEMICAL QUANTIFICATION

Present capabilities are limited to estimating the areal distribution and location of the thicker parts of an oil spill.

3.4 PASSIVE MICROWAVE

3.4.1 BASIC CONCEPTS

As discussed in Section 3.3, all materials continuously emit electromagnetic energy throughout a broad range of the electromagnetic spectrum. Part of this energy is emitted in the microwave region of the spectrum; that is, at frequencies of approximately 1-300 GHz (or wavelengths in the range .1-30 cm). Microwave radiometers to detect this energy are calibrated in terms of a brightness temperature, T_B . The measured brightness temperature of a water surface is approximated by the expression:³⁰

$$T_B = \epsilon T_W + (1-\epsilon)T_S,$$

where ϵ is the effective emissivity of the surface, T_W is the thermometric temperature of the water, and T_S is the brightness temperature of the sky. The second term on the right side of this expression represents incident energy from the sky that is reflected from the water surface (the reflectivity of the surface is given by the term, $1-\epsilon$). Emission and absorption by the atmosphere along the path from the surface to the radiometer have been neglected in this expression.

In order to be detectable by a microwave radiometer, a spilled chemical must alter the product of the effective emissivity of the water and the thermometric temperature of the water surface. Either or both of these parameters can be affected by a pollutant in the water.

In microwave sensing of a natural body of water, the effective emissivity is not necessarily equivalent to the inherent emissivity of an undisturbed sample of the water. For an undisturbed sample containing a dissolved pollutant, the emissivity is a function of the dielectric constant of the water, the dielectric constant and concentration of the pollutant, the polarization of the emitted radiation, and the zenith angle at which the water surface is viewed. In the natural environment, the roughness of the surface and the presence of whitecaps and foam can also strongly affect the intensity and angular distribution of emitted microwave radiation, and therefore the measured brightness temperature of the surface.

If the pollutant forms a film on the surface of the water, the emissivity of the film is of primary importance. Also, in this case, interference effects due to reflections within the film can occur.

3.4.2 APPLICATION TO CHEMICAL DETECTION

Three cases are distinctive: 1) A dissolved or suspended chemical in fresh water; 2) A dissolved or suspended chemical in sea water; and 3) A floating chemical on either fresh or salt water.

In cases 1 and 2, chemical detectability is based primarily on the ionic or conductive properties of the chemical in water. Strongly ionic

compounds such as acids or bases will lower the emissivity of the water, thereby lowering its brightness temperature. Figure 3.5 illustrates the effect of the conductivity of NaCl in water at several microwave frequencies. Long wavelengths provide the greatest sensitivity for the detection of soluble, conductive pollutants.

However, microwave detection systems are insensitive to soluble pollutants in sea water because of its high natural conductivity, but microwave systems may be useful for the detection of soluble pollutants in inland waters.

In case 3, chemical detectability depends on the emissivity of the pollutant and on the damping effect that the polluting surface film may have on the roughness of the water. Field tests of airborne microwave imaging systems^{29,31} and profiling radiometers^{30,32} have shown that oil slicks as thin as a few micrometers can sometimes be detected.

In calm water, because of the high effective emissivity of oil, an oil slick on the order of a millimeter in thickness can have a brightness temperature that is 80 K or more above that of the surrounding unpolluted water.³² The minimum detectable temperature anomaly for existing microwave radiometers is typically on the order of few kelvins, corresponding to a minimum detectable slick thickness of a few tenths of a millimeter.

The probability of detecting a thick oil slick or a thick portion of an oil slick in rough water also appears to be high. However, an oil slick may be undetectable for the following reasons:

- The effective emissivity of unpolluted water is increased by surface roughness, particularly by high frequency waves and ripples. But the high frequency components are strongly damped by even a thin oil film.³⁰ The resulting negative temperature anomaly in the area of the oil slick may counterbalance the positive anomaly produced by the high emissivity of the oil, thereby making the oil slick indistinguishable from the surrounding water.

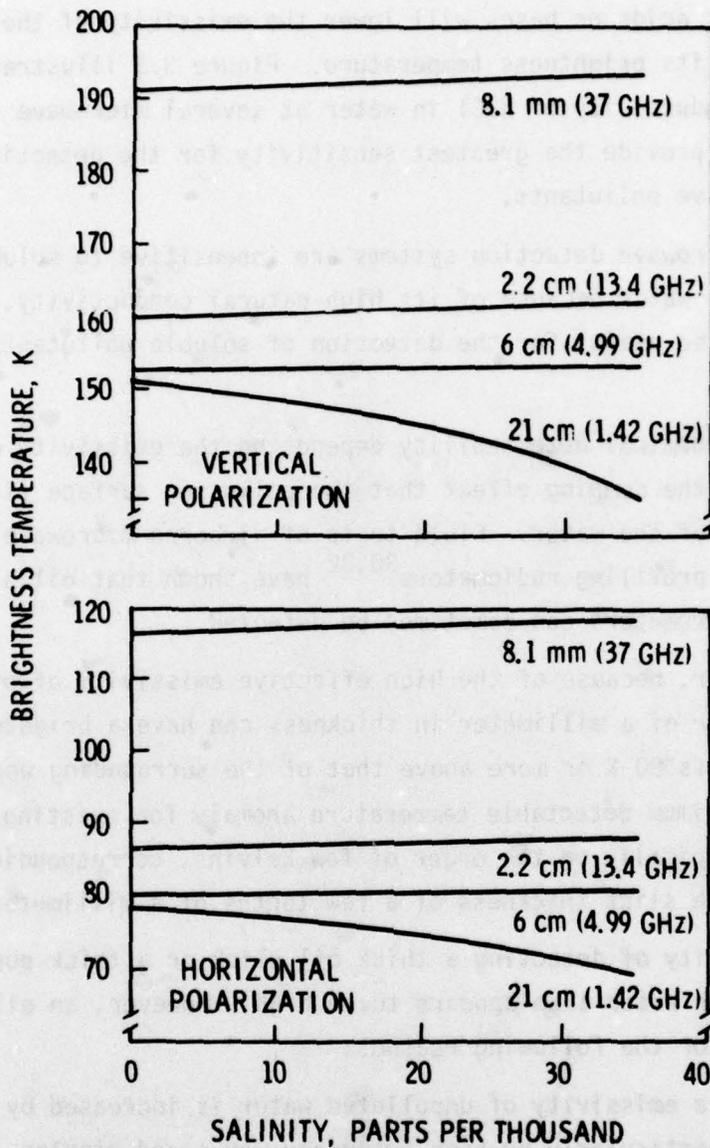


FIGURE 3.5. Theoretical Brightness Temperature Versus Salinity at Various Wavelengths per 50° View Angle, Constant 239 K Water Temperature and Vertical and Horizontal Polarization. Values Include a T_s Contribution Based on a Standard Atmospheric Profile with a 25% Ground Relative Humidity (After Edgerton et al., Reference 31.)

- The wind-induced roughness of a large body of water is highly variable spatially, temporally, and spectrally. Corresponding variations in brightness temperature may obscure the signal produced by an oil slick.
- If foam is present on the water in sufficient quantities, its high emissivity (approximately .8)³³ in comparison with the emissivity of sea water (approximately .4) can result in the occurrence of positive temperature anomalies that may be confused with, or obscure temperature anomalies related to oil spills.

Additional sources of noise or signal degradation are electronic noise in the receiver, spurious energy received in the side lobes of the antenna, and poor spatial resolution due to wide beamwidth.

On the positive side, passive microwave systems are capable of day or night operation as well as operation in fog, moderate rain, snow, and clouds.³⁴

Perhaps the most effective utilization of passive microwave sensors would be to install fixed systems at key on-shore locations. Large, slowly scanning antennas and long integration times could be used to achieve good resolution and signal-to-noise ratios.

3.4.3 APPLICATION TO CHEMICAL IDENTIFICATION

Passive microwave sensing systems appear to have no significant capabilities for chemical identification.

3.4.4 APPLICATION TO CHEMICAL QUANTIFICATION

In some cases it may be possible to estimate the near-surface concentration of soluble, conductive chemical spills. This capability has been demonstrated by profiling salinity gradients in the ocean.^{35,36} Experimental results are not available for other chemicals.

Interference effects in surface films may be used to estimate film thickness if the chemical has been identified. As the thickness of the

film increases, the intensity of the emitted radiation passes through a series of maxima and minima. The period of the oscillation, measured in terms of film thickness, is a frequency-dependent function of the dielectric constant of the film. Hollinger³² has used this effect at three microwave frequencies to unambiguously determine the thickness of oil slicks for thicknesses greater than .05 mm. In calm seas, the measured volume of the spilled oil was within 25% of the known volume. System noise, spurious signals, nonuniform slicks, whitecaps, foam, and roughness variations appear to be limiting factors.

3.5 RADAR

3.5.1 BASIC CONCEPTS

Side looking radar systems have been successfully used to detect and map oil spills on water. The method is based on the fact that a radar beam incident on a water surface is partially backscattered by the short wavelength components of the surface roughness. The essentially random character of water waves gives the backscattered signal the appearance of noise or "clutter". Because oil strongly damps the high frequency components of the water wave spectrum, the effect of an oil slick is to reduce the strength of the backscattered radar signal. A slick is thus visible in radar imagery as a dark pattern in a brighter background.

Oil has been shown to have a damping effect on capillary waves and gravity waves up to 5 m in length, but the effect is most pronounced for short wavelengths.^{3,4,30}

For a given radar frequency, and for small grazing angles, the primary contribution to the backscattered signal is provided by water waves having wavelengths close to the wavelength defined by the Bragg condition for diffraction:³⁷

$$L = \frac{\lambda}{2} \sec \theta$$

where L is the wavelength of the water wave, λ is the radar wavelength, and θ is the grazing angle of the transmitted beam. X-band (approximately 10 GHz) radar is often used for oil detection. At grazing angles between 2° and 20° , the resonant water waves will have a wavelength of approximately 1.5 cm.

3.5.2 APPLICATION TO CHEMICAL DETECTION

Oil slicks as thin as a monomolecular layer are theoretically capable of damping water waves. In practice, oil films less than $1 \mu\text{m}$ thick have been detected by radar.^{29,37-39} Other significant results are as follows:

- Vertically polarized signals provide greatest image contrasts between oil and water.
- Detection ranges greater than 10 miles are apparently feasible.
- Detection range increases with wind speed.
- Thin slicks are most readily detected at moderate wind speeds. In high sea states, thin slicks may be broken up and undetectable.
- Radar detection requires some surface roughness to produce a back-scattered signal. Slick detection is not possible in a calm sea.
- Radar signals are only weakly attenuated by fog, clouds, or precipitation. Radar therefore provides an all-weather, day or night detection capability.

Test data do not appear to be available for the detection of chemical pollutants other than oil. However, other slick forming chemicals with properties similar to oil are probably detectable. It is unlikely that soluble substances will be detectable except under special circumstances. For example, it may be possible to detect an electrically conductive chemical spill in fresh water by means of a downward looking, low frequency radar.

3.5.3 APPLICATION TO CHEMICAL IDENTIFICATION

Radar systems do not provide data suitable for chemical identification, although it may be possible to infer certain gross physical characteristics of a slick-forming chemical from the behavior of the slick.

3.5.4 APPLICATION TO CHEMICAL QUANTIFICATION

Imaging radar systems can provide data on the areal distribution of a pollutant slick, but thickness information is not generally available. However, it is known that the distance that a water wave can travel into a slick before being damped is a function of the product of the viscosity and the thickness of the slick. It has been suggested that the value of this product may be estimated from measurements of the damping distance at two widely separated radar wavelengths.³⁸

3.6 FLUORESCENCE

3.6.1 BASIC CONCEPTS

Fluorescence is the emission of electromagnetic radiation resulting from absorption of electromagnetic radiation from some other source. For purposes of environmental monitoring, the excitation (absorbed electromagnetic radiation) wavelengths are normally between 200 and 400 nanometers. The fluorescent radiation is due to electronic relaxation of the molecule, and is normally of a longer wavelength than the excitation energy.

Electronic transition energies are usually greater than the energy of ultraviolet photons in the 200-400 nm spectral region. Therefore, in order to fluoresce, a substance must have a low electronic transition energy. This requirement is filled by the $\pi \rightarrow \pi^*$ transition found in organic aromatic ring structures (e.g., benzene, styrene). Occasionally, other transitions such as $n \rightarrow \pi^*$ and $\pi \rightarrow \sigma^*$ are of interest. However, an aromatic ring structure is not a sufficient characteristic. Substituents on an aromatic ring can either enhance or suppress fluorescence. In general, substituents which are ortho- and para-directing will increase fluorescence, while meta-directing

groups decrease fluorescence. For example, nitrobenzene does not fluoresce because the nitro-group is meta-directing. On the other hand, the ortho- and para-directing group on benzene enhances its fluorescence.

The environment of a fluorescent molecule can significantly affect its fluorescent intensity. As a general rule, the more rigid the system in which the molecule exists, the greater the fluorescence. Therefore, solids fluoresce better than liquids, solutions at low temperature are superior to those at high temperature, and viscous solutions fluoresce better than nonviscous solutions. This behavior is due to the fact that there is a reduced chance of losing the absorbed energy through collision with another molecule (this loss is normally called external conversion).

3.6.2 APPLICATION TO CHEMICAL DETECTION

There are several methods for employing fluorescence for the detection of hazardous chemical spills. The geometry of the various systems depends on whether the system is for remote sensing or in situ sensing. Remote sensing systems use a backscatter geometry, while in situ systems can use either the backscatter geometry or a ninety degree angle from the source to the object to the detector. Sources include xenon flash lamps, mercury-xenon arc lamps, UV lasers, and the sun itself. Detectors used are usually photomultiplier tubes.

A major factor affecting the potential application of fluorescence detection methods is the accessibility of the spilled chemical. For remote fluorescence detection, the optimum distribution of the pollutant is a film floating on the surface of the water. Chemicals which dissolve, sink, vaporize, or react with the water are inaccessible in varying degrees to a remote fluorescence sensor. Water-soluble or floating fluorescent compounds are optimally accessible to in situ fluorescence sensors.

The development of a remote fluorosensor has received much attention in the last several years. A system of this kind, capable of operating at an altitude of 1000 feet or more, would have great potential for conducting rapid surveys of large areas. Several prototype or developmental systems

have been tested.^{40,41} Most of these, including the Coast Guard's ERODAC⁴² (Experimental Remote Oil Detection and Classification) system, have utilized UV lasers to produce the necessary excitation energy. But other sources of excitation energy have been successfully used. For example, Baird-Atomic has used a xenon flash lamp in a prototype shore mounted oil spill detector for harbor surveillance.⁴³ Battelle's active scanner utilizes the UV mercury lines produced by a mercury-xenon arc lamp as a continuously-operating source for two-dimensional nighttime imaging.

A laser source can have at least two important attributes: 1) It can produce a well collimated illuminating beam. A receiver optical system with a small field of view can therefore be used to obtain good spectral resolution and a minimum background signal as well as a maximum utilization of the source energy. 2) When used in a pulsed mode, the peak power can be very high, on the order of a few megawatts. At this power level, the instantaneous optical intensity of the laser beam greatly exceeds the intensity of sunlight in the same spectral band. Daylight fluorosensor operation in the active mode is therefore possible.

Lasers also have several properties which limit their effectiveness in fluorosensor applications: 1) Existing high-power UV lasers require large power sources, power supplies, and cooling systems. Airborne fluorosensor systems therefore require large aircraft. 2) Practical UV lasers operating in a continuous (CW) mode have low output power levels, typically a maximum of a few watts. 3) At the present time, because of their high peak power capabilities and because of their limitations in the CW mode, lasers are best suited to profiling operations (i.e., to making periodic measurements along a line on the water surface) or to slow-scan surveys from a fixed platform. An airborne mapping scanner, capable of producing a two-dimensional picture of the fluorescence intensity distribution on the ground at normal aircraft speeds, requires a continuous, high intensity, UV light source. An appropriate laser is not yet available.

The most effective potential application of fluorescence detection methods is probably the detection and mapping of oil spills. Because most oils float on water, they are optimally accessible to both remote and in situ fluorescence

sensors. Also, most petroleum oils have relatively high quantum efficiencies in comparison with the other fluorescent CHRIS chemicals.

Using a nitrogen laser at 3371 Å, the Coast Guard's ERODAC system has measured oil spectra in a profiling mode, both during the day and at night, from an altitude of 400 feet.⁴²

Baird-Atomic's shore mounted MAPS (Multispectral Active/Passive Scanner) system⁴³, with two detector channels, has been shown to be capable of detecting oil at night and discriminating between oil fluorescence and natural seawater fluorescence, at a slant range of about 600 feet. This is a low resolution, slow-scan system for oil spill detection in a harbor or channel.

In initial tests with two detector channels, Battelle's active scanner mapped a 2-gallon oil slick at night from an altitude of 1000 feet. Operating with four detector channels, it has detected an 8-gallon oil spill from an altitude of 100 feet. This system is described in detail in a later section of this report.

Other active remote fluorosensors have been tested in experimental programs, but none appears to have chemical detection capabilities superior to those just described.

Strongly fluorescent materials such as fluorescent dyes can be readily detected in daylight by means of a passive sensor which is bandpass filtered at the fluorescent wavelength. In clean water, Rhodamine can be routinely detected by passive optical-mechanical scanners at a concentration of 1 ppb.⁴⁴ An experimental Fraunhofer Line Discriminator (FLD),⁴⁵ developed by the USGS and the Perkin-Elmer Corporation, utilizes a very narrow bandpass filter at the wavelength of a suitable Fraunhofer atmospheric absorption line to discriminate against reflected sunlight. A prototype version of this device has detected Rhodamine WT dye at a concentration of 5 ppb in San Francisco Bay. A later model with an order of magnitude improvement in sensitivity has been tested and has detected oil in the Santa Barbara Channel.⁴⁶

Weather is a limiting factor in the operation of any remote fluorescence detection system. Attenuation of the transmitted beam or the fluorescent light by rain, snow, or fog will greatly reduce the operating range. Low clouds will also restrict aerial survey operations.

3.6.3 APPLICATION TO CHEMICAL IDENTIFICATION

Laboratory analytical procedures using highly diluted samples yield fluorescence spectra that are characteristic of chemical type. It is often possible in the laboratory to match the spectrum of a spilled chemical to the spectrum of a sample from a suspected source.

Equivalent specificity does not appear to be generally obtainable in field measurements of the fluorescence spectra of oils and other spilled chemicals. There are several possible reasons:

- Natural waters may contain substances which produce a background fluorescence or phosphorescence. Possible contributing substances include living organisms and other organic material, chemical pollutants, previously spilled oils, natural oils, dissolved minerals, and suspended sediments.
- The horizontal and vertical distribution of the spilled chemical may be highly irregular and nonuniform. This can be due to the manner in which the spill is created, as well as to the subsequent actions of wind, waves, boats, and currents.
- Petroleum oils are mixtures of many distinct molecular compounds. In an oil spill, a natural, partial, horizontal separation of these components occurs. Because each component has its own characteristic fluorescence spectrum, the measured fluorescence spectrum will be a function of location within the slick.
- Fluorescence spectra may change with time as a result of chemical changes caused by exposure to sunlight, biological decomposition, vaporization of volatile components, selective absorption of components by suspended solids in the water, or by interactions with other pollutants.

- Fluorescence spectra from soluble spilled chemicals may be distorted by wavelength-dependent attenuation of the incident light and/or the fluorescent light by other suspended or dissolved materials in the water.

Remote or in situ measurements of fluorescence emission spectra will provide a classification or coarse identification capability for oils and other chemical pollutants, but other data will probably be necessary in most cases to make a positive identification of chemical species.

Additional information may be provided by the measurement of fluorescence decay times. Fantasia, Hard, and Ingrao⁴⁷ have shown that light oils (high API gravity) tend to have longer fluorescent lifetimes than do heavy oils. Measures, Houston, and Stephenson⁴⁸ have suggested that a fluorescence decay spectrum, a curve of decay time versus fluorescence wavelength, may be more diagnostic for oil identification than the emission spectrum itself. Fluorescence decay spectra are measurable by means of a pulsed laser fluorosensor.

3.6.4 APPLICATION TO CHEMICAL QUANTIFICATION

Remote and in situ measurements of film thickness or chemical concentration are possible by fluorescence techniques provided that calibration data are obtained. However, remote measurements of the volume of spilled, soluble, fluorescent materials are limited in accuracy by the difficulty of determining the depth distribution of the material in the water. This problem is aggravated by turbidity.

3.7 RAMAN SCATTERING

3.7.1 BASIC CONCEPTS

In the Raman scattering process,⁴⁹ an absorbed photon raises the vibrational energy of a molecule. The energy is then re-emitted as a photon, usually of longer wavelength than the exciting photon (Stokes lines), but sometimes at a shorter wavelength (anti-Stokes lines). Rayleigh scattering occurs when the same frequency is re-emitted.

Like infrared absorption, Raman scattering is a function of the vibrational modes of a molecule. However, infrared absorption requires that the molecular dipole moment change in phase with the vibration of the molecule, whereas Raman scattering requires that the polarizability of the molecule change in phase with the vibration of the molecule.

Intensities of Raman peaks depend in a complex manner on the polarizability of the molecule, the concentration of the active molecule, and the intensity of the source. In the absence of absorption, Raman intensities increase with the fourth power of the frequency of the source. However, this cannot be carried too far since molecular bonds begin to rupture at an excitation wavelength of about 200 nm. The intensity of Raman scattering is also directly proportional to the concentration of the molecule. The efficiency of the Raman scattering process is one to several orders of magnitude smaller than that of fluorescence.

3.7.2 APPLICATION TO CHEMICAL DETECTION

Since the Raman scattering process is similar to fluorescence, methods for detecting Raman scattering are similar to those used to detect fluorescence. However unlike fluorescence it is possible to detect scattering at shorter wavelengths by anti-Stokes Raman spectroscopy. This method has the potential advantage that since fluorescence is always at longer wavelengths, the scattering in the anti-Stokes region is relatively free from background fluorescence. This method, however, requires further development before it can be applied to detection, identification or quantification of hazardous chemical spills in the field.

Raman systems are limited in range by the weakness of the signal, and in sensitivity by fluorescence of resident biota and background pollutants. Turbidity of the water can also affect detection. Signal averaging and background subtraction can reduce these problems.⁵⁰ However, 100 feet appears to be the current maximum range because of low scattering intensities. Both Raman and resonance Raman spectroscopy have been experimentally applied to detection of hazardous chemicals by Davis, Bristow, and Koningstein,⁵¹ Baldwin and Brown,⁵² Ahmadjian and Brown,⁵³ Hirschfield and Klainer,⁵⁴ and others.

3.7.3 APPLICATION TO CHEMICAL IDENTIFICATION

Identification of hazardous chemical spills appears to be the potential forte of Raman spectroscopy. A Raman spectrum is chemical specific because the molecular polarizability is a distinctive function of the excitation wavelength. This fact makes Raman scattering techniques potentially valuable for identification of chemicals both in the laboratory and in the field. However, much development needs to be done before this capability can be exploited.

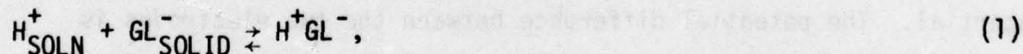
3.7.4 APPLICATION TO CHEMICAL QUANTIFICATION

Quantification by Raman spectroscopy is possible in clean water, but turbidity and resident biota may produce too large a background for good quantification of spilled chemicals. Presently, the minimum concentration for Raman detection of any of the CHRIS chemicals is about one part per million.

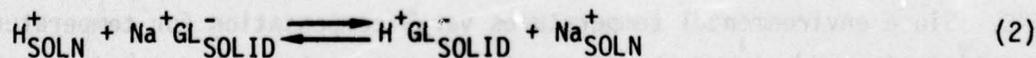
3.8 ION-SELECTIVE ELECTRODES

3.8.1 BASIC CONCEPTS

Ion-selective electrodes measure the activity of the ion in solution. This activity is measured by the electrical potential developed across a membrane which isolates a solution of known activity from the sample. The potential is not caused by penetration of the membrane by the ion to be measured, but by an ion exchange reaction on the surface of the membrane. In the case of the glass electrode for measuring pH, the reaction is:



where a gel-like substance, silicic acid, forms on the surface from the reaction:⁵²



Therefore, when the activities of the known and sample solution are different, a charge distribution will result from the different equilibrium positions of the two solutions, thereby causing a potential difference. That potential difference is described by Nernst's equation:⁵⁵

$$E = \frac{RT}{F} \ln \frac{a_1}{a_2},$$

which reduces to:

$$E = \text{constant} + \frac{RT}{F} \ln a_1,$$

where

E = potential difference

R = gas constant

F = Faraday's constant

T = temperature, K

a_1 = activity of species 1

a_2 = activity of species 2.

The measurement of specific ions in solution is accomplished by immersing a special electrode and a reference electrode in the sample solution. The potential developed at the special electrode is dependent upon the activity of the ion of interest. The reference electrode completes the circuit and supplies a stable reference potential to compare with the specific-ion potential. The potential difference between the two electrodes is proportional to the ion concentration, provided the concentration is low.⁵⁶

The activity of an ion is dependent on the temperature of the solution, and most activity measurements are taken at a standard temperature of 25°C. Since environmental temperatures vary, compensation for temperature variations is made with a thermistor in order to relate the activity measurements to the standard. Once an activity measurement is made at a standard temperature, it is then possible to relate that activity to the concentration of the ion of interest.

3.8.2 APPLICATION TO CHEMICAL DETECTION

In terms of the numbers of CHRIS chemicals each could detect, the most useful ion-selective electrodes would be:

BROMIDE (BR^-)

CHLORIDE (CL^-)

CYANIDE (CN^-)

FLUORIDE (F^-)

IODIDE (I^-)

NITRATE (NO_3^-)

POTASSIUM (K^+)

SODIUM (NA^+)

HYDROGEN ION (H^+ , pH).

For example, there is only one cadmium compound in the CHRIS list, whereas there are more than 20 chloride compounds including cadmium chloride ($CdCl_2$).

These specific-ion electrodes could be used in particular circumstances, but in many cases a sensor is needed which responds to a broad range of chemicals. The hydrogen ion (pH electrode) electrode satisfies this requirement for compounds which alter hydrogen ion concentrations (e.g., acids like sulfuric, hydrochloric, acetic and bases like sodium hydroxide, ammonium hydroxide, organic amines, etc.). Any spilled chemical causing a change in pH can be detected if the sensor is at the right location (e.g., 20 miles down river is too far). The other specific-ion electrodes do not have this versatility. For instance, the cyanide electrode can detect hydrogen cyanide and potassium cyanide spills, whereas the pH electrode can detect both of these as well as several others.

At present, ion-selective electrodes are technically feasible for immediate application to detection of hazardous chemical spills. Ion-selective electrodes, particularly the pH electrode, have been used

extensively in industry. While a river can have significantly more interferences than a process stream, selectivity constants for most interfering ions are low enough to permit adequate detection of ions of interest.

3.8.3 APPLICATION TO CHEMICAL IDENTIFICATION

A single ion-specific electrode can detect only the anion or the cation of a compound. It would be possible, for example, to identify a spilled chemical as a chloride compound, but a second ion-specific electrode is needed to determine the cation. Similarly, the pH electrode cannot identify the cause of a hydrogen ion concentration change except to indicate that a spill was an acid or a base. A set of ion-selective electrodes will provide enough information to greatly reduce a list of possible chemicals, but usually cannot uniquely identify a chemical.

3.8.4 APPLICATION TO CHEMICAL QUANTIFICATION

Since ion-selective electrodes are specific to one ion, they have the best capability of the in situ systems for quantification of hazardous chemical spills. Concentrations can be monitored on a real-time basis because of that specificity so that actual concentration data can be recorded rather than interpreted from laboratory calibration curves. The use of ion-selective electrodes is definitely feasible for immediate application to quantification of hazardous chemical spills.

3.9 ELECTROCONDUCTIVITY

3.9.1 BASIC CONCEPTS

When an ionic solution is placed in an electric field, ions are accelerated toward the electrode of the opposite charge. The rate of migration is suppressed by frictional losses and is a linear function of the applied potential. Therefore, an ionic current in a solution obeys Ohm's law.

Four factors affect the mobility of an ion: 1) As discussed above, the ionic mobility is proportional to the applied potential. 2) Frictional

losses reduce the ionic mobility due to the molecular vibration of the solvent and solute. At very low concentrations, these losses control ion mobility, but at finite concentrations the electrophoretic effect and the relaxation effect begin to play a strong role. 3) The electrophoretic effect arises from the motion of ions opposite in charge to the ion of interest. These ions carry with them molecules of the solvent; thus, the ion of interest is slowed by the motion of the solvent. 4) The relaxation effect occurs when the ion of interest is slowed by a buildup of oppositely charged ions behind it. The last three factors are temperature dependent.

Electroconductivity is measured by creating an electric field between two plates or in an inductor and then measuring the resistance of the solution, or the change in inductance produced by an ionic current. Strongly ionic solutions are more conductive and are therefore easier to detect than weakly ionic solutions. Nonionic compounds probably are undetectable in solution.

3.9.2 APPLICATION TO CHEMICAL DETECTION

Application of electroconductivity is technically feasible for detection of hazardous chemical spills in fresh water. The electroconductivity probe is sensitive to a broad spectrum of compounds, all of the strong electrolytes and many of the weak ones. Within the stated limitations, electroconductivity has sufficient sensitivity to detect hazardous chemical spills.

Since the electroconductivity probe is sensitive to a broad spectrum of compounds, detection of hazardous chemical spills is difficult in sea water. The electrical conductivity of sea water is already high, and unless the concentration of a spilled chemical is high, the chemical is not likely to produce a significant change in electrical conductivity.⁵⁶

3.9.3 APPLICATION TO CHEMICAL IDENTIFICATION

Identification by electroconductivity is not feasible for chemicals in the CHRIS list. Electroconductivity is a measure of the conductance or resistance of a solution, and therefore cannot differentiate between chemicals.

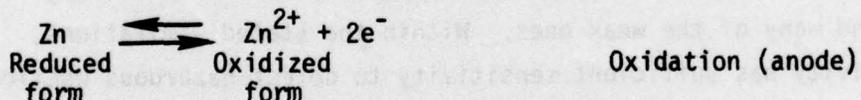
3.9.4 APPLICATION TO CHEMICAL QUANTIFICATION

Quantification is possible with electroconductivity measurements, although probably not practical. Electroconductivity measurements respond not only to the spilled hazardous chemical, but also to ions existing in natural waters. In sea water, for instance, it would be difficult to detect changes in electrical conductance as a result of a spill, much less obtain quantitative results. In fresh water, quantification would be easier, but in order to quantify the spill, it would be necessary to determine the possible interactions of the spilled chemical with the local environment.

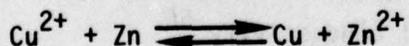
3.10 REDUCTION-OXIDATION POTENTIAL

3.10.1 BASIC CONCEPTS

In an electrochemical cell, an electric current is produced between two electrodes by a chemical reaction. The chemical reaction has two parts, an oxidation reaction occurring at the anode, and a reduction reaction at the cathode. Oxidation is the giving up of electrons by a reduced compound to produce an oxidized form, and reduction is the taking up of electrons by an oxidized form to produce a reduced form. For example:



Adding these half reactions together yields the actual reaction:



Since this reaction produces an electric current, there is a corresponding potential across the electrodes--the reduction-oxidation potential (ROP).

A reduction-oxidation (redox) reaction, like any other chemical reaction, is affected by the thermodynamics of its state. The redox reaction is

affected by pressure, temperature and chemical concentration. The most significant factor for environmental monitoring is concentration. Because potentials become lower for lower concentrations, reduction-oxidation potential measurements require significant concentrations of ions. It can be shown from thermodynamics that:⁵⁵

$$E = E_o - \frac{RT}{nF} \ln \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

where

E_o = a constant characteristic of a specific half reaction

R = gas constant = 8.314 volt coulombs /K/mole

F = the Faraday = 96,493 coulombs

T = absolute temperature

A = concentration in moles/liter of species A

n = number of electrons participating in the half-cell reaction.

The measurement of reduction-oxidation potential is made in much the same way that pH and specific ion potential measurements are made. A reference electrode is used in conjunction with a metallic electrode made of a noble metal such as gold or platinum. The major difference between pH and ROP measurements is that the ROP electrode is not selective to any particular ion. As in the measurement of specific ion concentrations, temperature variations are compensated for by thermistors.

3.10.2 APPLICATION TO CHEMICAL DETECTION

Measurement of reduction-oxidation potential is a feasible means for detecting hazardous chemical spills in fresh water. The chemicals detectable by ROP are mainly inorganic compounds in solution. Currently available systems can detect these compounds in fresh water. At present, the accuracy of redox analyzers is approximately 1% of a 1200 mv scale. Natural redox processes can account for at least 12 mv signal variations, so concentration changes must produce a fairly large signal change to

detect a spill of a hazardous chemical. Therefore, system sensitivities are greater than the sensitivity required for unattended in situ water quality monitors.

Sea water presents problems to ROP detection of chemical spills. ROP, like electroconductivity, is sensitive to many ions, including the natural ions in sea water. If used in sea water, ROP measurement would monitor natural reduction-oxidation processes going on all the time. The question is whether or not a measurable difference occurs when a hazardous chemical is spilled. ROP is probably not practical for application to detection of hazardous chemical spills in salt water.

3.10.3 APPLICATION TO CHEMICAL IDENTIFICATION

Identification of a specific chemical by an unattended, in situ ROP system is not yet possible, although a narrowing of choices can be made. The ROP electrodes are not chemical specific, but are specific to a class of compounds, namely, soluble electrolytes. Therefore, only a reduction in the number of possible compounds can be accomplished.

3.10.4 APPLICATION TO CHEMICAL QUANTIFICATION

An estimate of chemical concentration may be possible once a spilled chemical has been identified and contributions from all naturally occurring redox processes have been determined. The problem which arises is that natural redox reactions can contribute significantly to the recorded signal. It may not be enough to measure a background signal, because there may be interactions between the spilled chemical and compounds already existing at the site. These possible complex interactions make quantification by measuring redox potentials impractical.

3.11 OPTICAL ABSORPTIMETRY

3.11.1 BASIC CONCEPTS

As electromagnetic radiation passes through a layer of a solid, liquid, or gas, certain wavelengths of light may be selectively removed by absorption. The absorbed energy is transferred to the atoms or molecules

of the sample. As a result the energy state of the atoms or molecules is altered from a low energy or ground state to a higher energy or excited state.

The energy is retained for approximately 10^{-8} seconds before the atom returns to its ground state. The energy is usually released in the form of heat, but as discussed earlier, in some cases the excited atom or molecule may emit electromagnetic radiation in the form of fluorescence or phosphorescence. In other cases, the absorbed energy causes a chemical reaction which absorbs the energy.

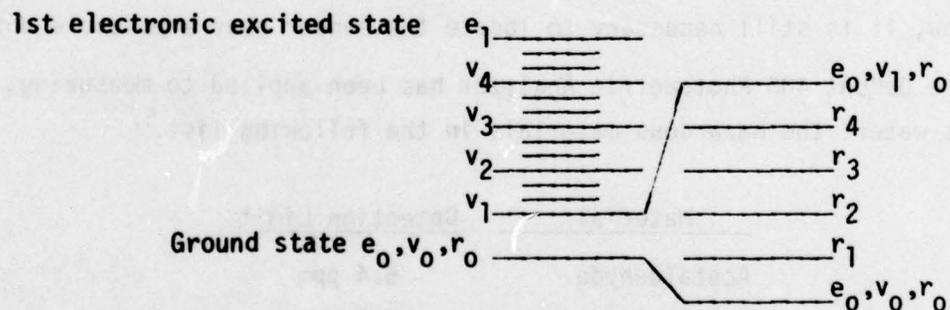
A molecular energy state is a combination of three components of energy; electronic, vibrational, and rotational. The total energy of a molecule is therefore:

$$E_{\text{molecule}} = E_{\text{electronic}} + E_{\text{vibrational}} + E_{\text{rotational}}$$

where

$$E_{\text{electronic}} > E_{\text{vibrational}} > E_{\text{rotational}}$$

A diagram of the energy levels appears like this:



For a transition from the ground state to the first electronic excited state to occur, a molecule must absorb energy equal to that energy difference. Electronic transitions are produced by ultraviolet or visible electromagnetic radiation. Vibrational and rotational excitations are produced by photons in the infrared and microwave spectral regions.

Absorbance measurements are made by illuminating a sample with a light source and measuring the output signal of a photodetector placed on the opposite side of the sample from the source.

The absorbance of the sample is determined by comparing the sample with a suitable standard (usually water). Flow-through systems are normally used for environmental monitoring. Ideally, detection of a hazardous chemical spill occurs when the absorption of the sample suddenly changes; identification is accomplished by comparing the unknown sample spectrum with spectra of known compounds; and concentrations can be determined for a known chemical by comparing absorbance data from a sample with standard curves of concentration versus absorbance at the appropriate wavelengths.

3.11.2 APPLICATION TO CHEMICAL DETECTION

Optical absorbance measurements can be used for the detection of hazardous chemical spills. Because water scatters ultraviolet light and strongly absorbs infrared, the most useful band for detection is the near ultraviolet-visible region (~200 nm - 700 nm). Detectable solutions are, therefore, usually colored. Normal detection limits for optical absorbance measurements are in the range of 0.1 to 1 ppm.⁵⁵ Even at concentrations that low, it is still necessary to locate the sensor near a possible outfall.

The DuPont 400 Photometric Analyzer has been applied to measuring, in process water, the hazardous materials in the following list.⁵⁷

<u>Material</u>	<u>Detection Limit</u>
Acetaldehyde	5.4 ppm
Acetic Acid	25.0 ppm
Copper (as Cu ²⁺)	42.0 ppm
Dimethylformamide	~1.0 ppm
Ferrous Sulfate	380.0 ppm
Furfural	6.2 ppb

Hydrazine	8.3 ppm
Hydrogen Peroxide	163.0 ppb
Nickel Sulfate	235.0 ppm
Nitric Acid	14.5 ppm
Nitroaniline	30.4 ppb
Phenol	72.0 ppb
Sodium Sulfide	55.0 ppb
Sodium Sulfate	668.0 ppb

Although optical absorbance measurements have been applied to measuring these compounds in process solutions, it does not mean similar detection limits can be reached in natural waters. The complicating problem is that concentrations of naturally occurring compounds can cause significant interferences, especially for organic compounds because of their abundance in natural waters.

3.11.3 APPLICATION TO CHEMICAL IDENTIFICATION

The most chemical-specific section of an absorbance spectrum is in the infrared from 2.5-40 microns. However, water strongly absorbs infrared radiation, making this range unusable for in situ optical absorbance. The remaining range is the near UV-visible.

The certainty of identifying any compound by absorbance measurements is directly related to the number of separate spectral features present in the unknown compound's absorbance spectrum. In the UV-visible region, the number of spectral features is limited and the peaks are usually quite broad. Therefore, in an unattended in situ system only a narrowing of the list of possible chemicals can be accomplished. Unique identification of the spilled hazardous chemical requires either additional data from a different type of field sensor, or laboratory analysis.

3.11.4 APPLICATION TO CHEMICAL QUANTIFICATION

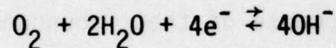
Since it is not possible to quantify a compound without first identifying it, quantification is not possible on a real-time basis. For

identified chemicals, it is possible to use recorded data to quantify the hazardous chemical spill by constructing a calibration curve of absorbance or transmission versus concentration. In this sense, quantification by optical absorptimetry is technically feasible.

3.12 DISSOLVED OXYGEN

3.12.1 BASIC CONCEPTS

The measurement of dissolved oxygen is a specific application of reduction-oxidation potentials. As measured now, dissolved oxygen (DO) is allowed to diffuse across a thin membrane of Teflon* after which it comes into contact with the cathode. A potential applied between the two electrodes causes oxygen to be reduced at the cathode by the reaction:



There are a few variations for the anode, but the most common is the silver chloride electrode. Its half-cell reaction is:



The current produced by these half-cell reactions is proportional to the dissolved oxygen concentration. Parameters which affect DO concentrations include:

1. Pressure
2. Temperature
3. Ionic Strength of the solution
4. Quantity of biodegradable material
5. The diurnal cycle
6. Stream characteristics (e.g., gradient, rapids, pools, etc.)⁵⁸

Dissolved oxygen is an important parameter in determining surface water quality. Not only is it important for the survival of aquatic life, including micro-organisms which biologically decompose organic pollutants,

*Trade name of DuPont de Nemours

it is also important for the direct oxidation of pollutants. Spilled pollutants can significantly and quickly alter dissolved oxygen concentrations.

3.12.2 APPLICATION TO CHEMICAL DETECTION

Monitoring of dissolved oxygen concentrations is a technically feasible method for detection of hazardous chemical spills, but not immediately. Some complications involving detection of hazardous chemical spills include:

- Dissolved oxygen concentrations vary diurnally.
- It is not clear how each of the CHRIS chemicals affects dissolved oxygen concentrations.
- How fast does each chemical cause a change in dissolved oxygen concentration?

To operate in an alarm mode, upper and lower limits of DO concentration must be set outside the range of normal variations. Chemically produced DO changes within that range will not be detected.

3.11.3 APPLICATION TO CHEMICAL IDENTIFICATION

A measurement of dissolved oxygen concentration is not sufficient in itself to permit the identification of a spilled hazardous chemical.

3.11.4 APPLICATION TO CHEMICAL QUANTIFICATION

Quantification is not technically feasible because of the complications mentioned above. If equilibrium between dissolved oxygen and the polluted water could be assumed, quantification might be possible by a DO concentration versus pollutant concentration calibration curve. However, not knowing the transient response of DO concentration to a step input of one of the CHRIS chemicals makes quantification difficult.

3.13 TOTAL OXYGEN DEMAND

3.13.1 BASIC CONCEPTS

Total oxygen demand (TOD) is a measure of the rate at which a volume of natural water uses dissolved oxygen. Waters containing pollutants use

oxygen at different rates than do unpolluted waters. Chemicals "demand" oxygen in the process of oxidation to a more stable form. Micro-organisms "demand" oxygen for the biological decomposition of the polluting chemical, normally producing CO_2 , CO and H_2O for organic pollutants. Thus, detection occurs if oxygen is used at different rates by either bio-organisms or by polluting chemicals.

3.13.2 APPLICATION TO CHEMICAL DETECTION

Total oxygen demand is measured by introducing a water sample along with a metered air stream into a combustion chamber. When the impurities in the water are fully oxidized, the depleted oxygen is measured. The total oxygen demand of the water solution is directly proportional to the amount of depleted oxygen in the air stream.

The ability of a TOD analyzer to detect hazardous chemical spills is good for those chemicals that are degradable in the natural environment. Instrumentation available today can continuously monitor TOD and detect changes as small as 2 ppm dissolved oxygen. Therefore, a small change in organic content will produce a detectable change in the TOD.

Measurement of biological oxygen demand has been used extensively in water and sewage treatment plants to monitor organic content of effluent streams. For water quality monitoring and spill detection, it is also necessary to take into account chemical oxygen demand. The two quantities are combined into a measurement of total oxygen demand.

3.13.3 APPLICATION TO CHEMICAL IDENTIFICATION

TOD analyzers respond to many compounds, both organic and inorganic. However, a measured TOD value depends not only on the chemical type, but also on its concentration. Another complication is that the measurements are affected by other compounds in the sample volume; further analyses must be made to isolate the contribution of a specific polluting chemical to the signal.

3.13.4 APPLICATION TO CHEMICAL QUANTIFICATION

Due to the non-specificity of TOD measurements, quantification of hazardous chemical spills cannot be done on a real-time basis. However, after identification, a concentration versus TOD calibration curve could be used to determine concentrations of a hazardous chemical spill.

SECTION 4
CHEMICAL DETECTABILITY, IDENTIFIABILITY, AND QUANTIFIABILITY

4.1 DISCUSSION

Numerous factors will affect the detectability, identifiability, and quantifiability of a given spilled chemical. The nature and degree of influence of these factors will depend on the type of instrumentation system used. A list of important factors would include:

- type of sensing system - remote or in situ;
- distance from the sensor to the water;
- zenith angle of the observation;
- system sensitivity;
- distance from the source of the spill;
- time since the spill;
- concentration of the chemical;
- turbidity of the water;
- turbulence and surface roughness of the water;
- salinity of the water;
- water depth;
- density of biological organisms;
- background pollutant concentration;
- weather conditions; and
- ambient lighting.

It is not the intent of this study, nor is it feasible, to perform an analysis which takes into account all of these factors. The ways that they individually and in combinations affect remote and in situ sensing measurements could constitute numerous profitable research topics.

Our analysis approach utilizes generalized sensing system characteristics and the gross physical, chemical, and optical properties of the CHRIS chemicals to sort out the chemicals that are likely to be detectable, identifiable, and quantifiable by each of the twelve sensing methods. This approach yields an estimate of the relative potential detectability, identifiability,

and quantifiability of each of the CHRIS chemicals for the twelve sensing techniques. It also yields an estimated, relative, broad-spectrum effectiveness ranking for each of the sensing techniques. Without precisely defining acceptable ranges for environmental conditions, we have assumed that a favorable set of environmental conditions exists for each sensing system. The following additional assumptions were made in the analysis:

- 1) The sensor design, placement, and mode of operation are optimum.
- 2) The sensitivity of a given sensing technique is unspecified.
- 3) The concentration or volume of the spilled chemical is also unspecified. It is assumed to be equal to an easily detectable concentration or volume of a chemical that is readily detectable by the sensing method being considered. Approximate concentration ranges for the twelve sensing methods are given in Section 5.1.
- 4) The inherent sensitivity of the sensing method to environmental variations (primarily the last seven factors in the above list) was considered in estimating the probability of detecting, identifying, and quantifying a given chemical under the range of environmental conditions that would be encountered in normal field operations.

The results are presented in chart form in Sections 4.2, 4.3, and 4.4.

4.2 DETECTABILITY

The first basic consideration in this analysis is the accessibility of the chemical to the sensing system. For example, a floating chemical is accessible to a thermal infrared detection system, but a sinking chemical is not. We have used the following numerical scale:

- 2 = probably accessible;
- 1 = possibly accessible, or accessible under some conditions; and
- 0 = probably not accessible.

The chemical properties that most directly determine accessibility are density, solubility, volatility, and reactivity. Using the first two of these properties, we derive four accessibility groups:

Accessibility Group	Floats	Soluble
1	Yes	Yes
2	Yes	No
3	No	Yes
4	No	No

Accessibility values are assigned to each accessibility group/sensing system combination. These values are listed in Table 4.1. A chemical is considered to be soluble if 1 pound or more dissolves in 100 pounds of water. Volatility and reactivity have not been included in the accessibility groupings. Notations referring to these characteristics are included in the Detectability, Identifiability, and Quantifiability Charts.

TABLE 4.1. Accessibility Factors

ACCESSIBILITY GROUP	REMOTE OR IN SITU INSTRUMENTATION						IN SITU INSTRUMENTATION					
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTRO-CONDUCTIVITY	REDUCTION-OXIDATION POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND
1	2	1	2	1	2	1	2	2	2	2	2	2
2	2	2	2	2	2	2	0	1	0	0	0	0
3	1	0	1	1	2	1	2	2	2	2	2	2
4	0	0	0	0	1	1	0	0	0	0	0	0

The second basic consideration in this analysis is that in order to be detected by a given sensing system, a spilled chemical must possess specific optical or electrochemical characteristics. Each chemical has been evaluated with respect to these characteristics, and numerical system applicability values, or detectability factors, have been assigned to each chemical/sensing system combination according to the following criteria:

Optical Reflectance

- 2 -- Probably applicable
 - Chemicals with strong absorption peaks in the near UV-visible spectral region.
 - Hydrophobic chemicals with strong absorption peaks within the atmospheric windows of the IR.
- 1 -- Possible, limited applicability
 - Chemicals with weak absorption peaks in the UV-visible.
 - Hydrophobic chemicals with strong absorption peaks outside the atmospheric windows in the IR.
- 0 -- Not applicable
 - Chemicals with no absorption peaks
 - No coloration

Thermal Infrared

- 2 -- Probably applicable
 - Viscous hydrophobic compounds
 - Volatile compounds
- 1 -- Possible, limited applicability
 - Chemicals having exothermic reactions with water
- 0 -- Not applicable
 - All others

Passive Microwave

- 2 -- Probably applicable
 - Viscous hydrophobic compounds
 - Strongly conductive compounds (fresh water)

- 1 -- Possible, limited applicability
 - Weakly electrolytic or conductive compounds (fresh water)
- 0 -- Not applicable
 - Nonelectrolytes
 - All others

Radar

- 2 -- Probably applicable
 - Viscous hydrophobic compounds
- 1 -- Possible, limited applicability
 - Strong electrolytes (fresh water)
- 0 -- Not applicable
 - All others

Fluorescence

- 2 -- Probably applicable
 - Chemicals having aromatic ring structures, with exceptions
 - Other strongly fluorescent compounds
- 1 -- Possible, limited applicability
 - Weakly fluorescent compounds
- 0 -- Not applicable
 - Nonfluorescent, structurally incapable compounds

Raman Scattering

- 2 -- Probably applicable
 - Compounds with known strong Raman spectra
 - Compounds with known strong IR absorption spectra
- 1 -- Possible, limited applicability
 - Compounds with known weak Raman spectra
 - Compounds with weak IR absorption spectra
 - Fluorescent compounds
 - Most other compounds are possible

0 -- Not applicable

- Substances with no chemical bonds.

Ion-Selective Electrodes

2 -- Probably applicable

- Strong electrolytes

1 -- Possible, limited applicability

- Weak electrolytes

0 -- Not applicable

- Nonelectrolytes

Electroconductivity

2 -- Probably applicable

- Strong electrolytes

1 -- Possible, limited applicability

- Weak electrolytes
- Include viscous, insoluble, floating compounds (assume skimmer)

0 -- Not applicable

- Nonelectrolytes

Reduction-Oxidation Potential

2 -- Probably applicable

- Strong oxidizers or reducers

1 -- Possible, limited applicability

- Weak oxidizers or reducers

0 -- Not applicable

- Nonoxidizers and nonreducers

Optical Absorptimetry

2 -- Probably applicable

- Compounds with strong UV or visible absorption peaks, strongly colored.

1 -- Possible, limited applicability

- Compounds with weak UV and/or visible absorption peaks, weakly colored

0 -- Not applicable

- All others

Dissolved Oxygen

2 -- Probably applicable

- Strong acids and bases

1 -- Possible, limited applicability

- Weak acids and bases

0 -- Not applicable

- Nonelectrolytes

Total Oxygen Demand

2 -- Probably applicable

- Easily degradable compounds

1 -- Possible, limited applicability

- Moderately degradable compounds

0 -- Not applicable

- Persistent or nondegradable compounds

The following Chemical Detectability Chart, Table 4.2, incorporates in numerical matrix form all pertinent chemical characteristics, including the accessibility factors, in an evaluation of the potential effectiveness of each of the twelve sensing techniques for detecting each of the CHRIS chemicals. The numerical values assigned to the matrix elements are products of the accessibility factor, A, and the appropriate chemical-specific detectability factor, D. The values of both A and D are integers in the range 0-2. For example, the combination of a strongly fluorescing chemical and a fluorescence detection system would be assigned a D value of 2. If, in addition, the chemical forms a surface slick, the product of

TABLE 4.2. Chemical Detectability Chart

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEMICAL DETECTABILITY	COMMENTS	
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RFID/RF	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			ROW SUMS
ACETALDEHYDE	3	0	0	1	0	0	2	2	2	0	2	2	4	15	.31	
ACETIC ACID	3	1	0	1	0	0	2	2	2	0	4	2	4	18	.37	
ACETIC ANHYDRIDE	3	1	0	1	0	0	2	2	2	2	4	2	4	20	.41	
ACETONE	1	2	0	0	0	0	2	0	0	0	4	0	4	12	.25	
ACETONE CYANOHYDRIN	1	0	0	2	0	0	1	2	2	0	0	2	2	11	.22	
ACETONITRILE	1	2	0	0	0	0	2	0	0	0	2	0	2	8	.16	
ACETOPHENONE	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06	
ACETYLENE	2	0	0	0	0	0	4	0	0	0	0	0	0	4	.08	BP*-84 C
ACRYLIC ACID	3	1	0	1	0	0	2	2	2	0	2	2	0	12	.25	
ACRYLONITRILE	1	2	0	0	0	0	1	0	0	0	2	0	2	7	.14	
ADIPONITRILE	2	4	0	2	2	0	2	0	1	0	0	0	0	11	.22	
ALDRIN	4	0	0	0	0	1	1	0	0	0	0	0	0	2	.04	
ALLYL ALCOHOL	1	0	0	0	0	0	2	2	2	0	0	0	0	6	.12	
ALLYL CHLORIDE	2	2	2	0	0	0	2	0	1	0	0	0	0	7	.14	BP*45 C
ALUMINUM CHLORIDE	3	0	0	1	1	0	0	4	4	4	0	4	0	18	.37	VIOLENT REACTION WITH WATER
ALUMINUM FLUORIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
AMINOETHYLETHANOLAMINE	3	0	0	1	0	0	2	2	2	0	0	2	2	11	.22	
AMMONIA, ANHYDROUS	1	0	1	0	1	0	1	4	4	2	0	4	2	19	.39	BP*-39.4 C
AMMONIUM HYDROXIDE (<28% AQUEOUS AMMONIA)	1	0	0	4	1	0	1	4	4	2	0	4	2	22	.45	
AMMONIUM NITRATE	3	1	0	1	0	0	1	2	2	0	2	2	0	11	.22	
AMMONIUM PERCHLORATE	3	2	0	1	0	0	1	2	2	0	4	2	0	14	.29	
AMMONIUM SULFATE	3	2	0	1	0	0	1	2	2	0	4	2	0	14	.29	
AMYL ACETATE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP*106 C
N-AMYL ALCOHOL	1	0	0	0	0	0	2	0	2	0	0	0	0	4	.08	
ANILINE	3	1	0	0	0	4	1	2	2	0	2	2	0	14	.29	
ANTIMONY TRIFLUORIDE	3	2	0	1	0	0	1	2	2	2	4	2	2	18	.37	
ASPHALT	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06	
ASPHALT BLENDING STOCKS+ ROOFERS FLUX	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06	

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PRDRR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ION SUMS	BLIND/BLINDING POSSIBLE (IN VALUE (RELATIVE DETECTABILITY))		
ASPHALT BLENDING STOCKS* STRAIGHT RUN RESIDUE	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06		
BARIUM CARBONATE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
BENZALDEHYDE	2	4	2	2	2	2	0	1	0	0	0	0	0	15	.31		
BENZENE	2	4	0	0	0	4	2	0	1	0	0	0	0	11	.22	BP=80.1 C	
BENZENE HEXACHLORIDE	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06		
BENZOIC ACID	4	0	0	0	0	2	2	0	0	0	0	0	0	4	.08		
BENZOYL CHLORIDE	4	0	0	0	0	2	2	0	0	0	0	0	0	4	.08	REACTS SLOWLY	
BISPHENOL A	4	0	0	0	0	2	2	0	0	0	0	0	0	4	.08		
BROMINE	3	2	0	1	0	0	0	2	2	4	4	2	0	17	.35		
BUTADIENE, INHIBITED	2	4	4	4	4	0	2	0	1	0	0	0	0	19	.39	BP=4.4 C	
BUTANE	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43	BP=0.68 C	
1,4-BUTANEDIOL	3	0	0	0	0	0	2	0	0	0	0	0	2	4	.08		
1,4-BUTENEDIOL	3	1	0	0	0	0	2	0	0	0	2	0	2	7	.14		
N-BUTYL ACETATE	1	2	0	0	0	0	2	0	2	0	0	0	2	8	.16		
SEC-BUTYL ACETATE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP=112 C	
N-BUTYL ACRYLATE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP=148.8 C	
ISO-BUTYL ACRYLATE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP=137.9 C	
N-BUTYL ALCOHOL	1	0	1	2	1	0	2	0	0	0	0	0	4	10	.20	BP=117 C	
SEC-BUTYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	4	6	.12	BP=98.5 C	
TEAT-BUTYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.08	BP=82.6 C	
BUTYLENE	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43	BP=6.3 C	
TEAT-BUTYL HYDROPEROXIDE	1	0	2	0	0	0	2	0	2	4	2	0	4	16	.33	DECOMPOSES	
1,4-BUTYNEEDIOL	3	2	0	0	0	0	2	0	0	0	4	0	2	10	.20		
N-BUTYRALDEHYDE	1	0	1	0	0	0	2	0	2	2	0	0	2	9	.18	BP=74.8 C	
ISO-BUTYRALDEHYDE	1	0	1	0	0	0	2	0	0	0	0	0	2	5	.10	BP=64.1 C	
CADMIUM CHLORIDE	3	0	0	1	0	0	0	2	2	2	0	2	2	11	.22		
CALCIUM CARBIDE	3	1	0	0	0	0	2	0	0	0	0	0	2	5	.10	REACTIVE, FORMS GAS AND WHITE PPT	
CALCIUM FLUORIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION			CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PMAPP	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	NON SUNS	SUNS/MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)	
CALCIUM HYDROXIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
CALCIUM HYPOCHLORITE	3	0	0	1	0	0	1	2	2	2	0	2	4	14	.29	
CALCIUM OXIDE	3	1	0	1	0	0	1	4	4	2	0	4	4	21	.43	REACTS VIOLENTLY WITH WATER
CAMPOR OIL	2	4	2	2	4	2	2	0	1	0	0	0	0	17	.35	
CARBARYL	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06	
CARBOLIC OIL	3	1	0	0	0	4	1	0	0	0	2	0	0	6	.16	
CARBON BISULFIDE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
CARBON TETRACHLORIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
CAUSTIC POTASH SOLUTION	3	0	0	1	0	0	0	4	4	4	0	4	0	17	.35	
CAUSTIC SODA SOLUTION	3	0	0	1	0	0	0	4	4	4	0	4	0	17	.35	
CHLORINE	3	2	0	1	0	0	1	2	2	2	4	2	0	16	.33	BP=94.1 C
CHLOROBENZENE	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06	
CHLOROFORM	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
CHLOROHYDRINS (CRUDE)	3	1	0	0	0	2	1	0	0	0	2	0	0	6	.12	
CHLOROSULFONIC ACID	3	0	0	2	1	0	1	4	4	4	0	4	4	24	.50	REACTS VIOLENTLY WITH WATER
CHROMIC ANHYDRIDE	3	2	0	2	1	0	1	4	4	4	4	4	2	28	.58	
COPPER SULFATE	3	2	0	1	0	0	1	2	2	0	4	2	0	14	.29	
CORN SYRUP	3	0	0	0	0	2	1	0	0	0	0	0	2	5	.10	
CRESOLS	3	2	0	0	0	4	1	0	0	0	4	0	2	13	.27	
CRONALDEHYDE	1	4	0	0	0	0	2	0	0	0	4	0	2	12	.25	BP=102.2 C
CUMENE	2	4	0	0	0	4	2	0	1	0	0	0	0	11	.22	BP=152.4 C
CYANOGEN BROMIDE	3	0	0	0	0	0	1	2	2	2	0	2	0	9	.18	
CYANOGEN CHLORIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP=13.1 C
CYCLOHEXANE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP=98.7 C
CYCLOHEXANOL	1	4	0	0	0	0	2	0	0	0	2	0	0	6	.16	
CYCLOHEXANONE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
CYCLOHEXYLAMINE	1	0	0	0	0	0	2	4	4	2	0	4	0	16	.33	
DDT	4	0	0	0	0	1	1	0	0	0	0	0	0	2	.04	

TABLE 4.2. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP		REMOTE OR IN-SITU INSTRUMENTATION								IN-SITU INSTRUMENTATION				CHEMICAL DETECTABILITY		COMMENTS
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE INFRARED	PRDRR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ION SUMS	SUMS/PRIORITY	POSSIBLE VALUE (RELATIVE DETECTABILITY)		
DECALDEHYDE	2	4	2	2	4	0	4	0	1	0	0	0	0	17	.35		
1-DECENE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18		
N-DECYL ALCOHOL	2	4	2	2	2	0	2	0	1	0	0	0	0	13	.27		
DEXTRASE SOLUTION	3	0	0	0	0	0	2	0	0	0	0	0	4	6	.12		
DIACETONE ALCOHOL	1	0	0	0	0	0	2	0	0	0	2	0	2	6	.12		
DIBENZOYL PEROXIDE	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06	REACTIVE WITH SUSPENDED SOLIDS	
DIBUTYL PHTHALATE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
O-DICHLOROBENZENE	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06		
P-DICHLOROBENZENE	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06		
DICHLORODIFLUOROMETHANE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP*-29.6 C	
DICHLOROMETHANE	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
2,4-DICHLOROPHENOL	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06		
DICHLOROPROPANE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
DICHLOROPROPENE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
DICYCLOPENTADIENE	2	4	0	0	0	0	2	0	0	0	0	0	0	6	.12		
DIETANOLAMINE	3	0	0	1	0	0	2	2	2	0	0	2	2	11	.22		
DIETHYLAMINE	2	4	4	0	0	0	4	0	1	0	0	0	0	13	.27	BP*55.5 C	
DIETHYLBENZENE	2	4	0	0	0	4	2	0	1	0	0	0	0	11	.22		
DIETHYLCARBONATE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.16	BP*126.6 C	
DIETHYLENE GLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
DIETHYLENE GLYCOL DIMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.06		
DIETHYLENE GLYCOL MONOETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.06		
DIETHYLENE GLYCOL MONOMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.06		
1,1-DIETHYLENETRIAMINE	1	2	0	0	0	0	2	2	2	0	2	2	0	12	.25		
DIISOBUTYL CARBINOL	2	2	2	2	4	0	2	0	1	0	0	0	0	13	.27		
DIISOBUTYLENE	2	2	0	0	4	0	2	0	1	0	0	0	0	9	.16	BP*101.5 C	
DIISOPROPANOLAMINE	1	0	0	0	0	0	1	2	2	0	0	2	2	9	.16		
DIMETHYLAMINE	1	0	2	2	0	0	2	2	2	0	0	2	0	12	.25	BP*6.9 C	

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													IN-SITU INSTRUMENTATION		CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PRDRA	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	POW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)			
DIMETHYLFORMAMIDE	1	4	0	0	0	0	2	2	2	0	4	2	0	16	.33			
1,1-DIMETHYLHYDRAZINE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04			
DIMETHYL SULFATE	3	0	0	0	0	0	1	2	2	0	0	2	4	11	.22			
DIMETHYL SULFOXIDE	3	0	0	0	0	3	2	0	0	0	0	0	0	2	.04			
2,4-DINITROANILINE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04			
2,4-DINITROPHENOL	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04			
DIOCTYL ADIPATE	2	2	2	2	4	0	4	0	1	0	0	0	0	15	.31			
DIOCTYL PHTHALATE	2	2	2	2	4	2	2	0	1	0	0	0	0	15	.31			
1,4-DIOXANE	3	0	0	0	0	2	2	0	0	0	0	0	0	4	.08			
DIPHENYLMETHANE-DIISOCYANATE	4	0	0	0	0	1	1	0	0	0	0	0	0	2	.04			
DIPROPYLENE GLYCOL	3	0	0	0	0	0	1	0	0	0	0	0	2	3	.06			
DISTILLATES-FLASHED FEED STOCKS	2	2	2	0	0	2	2	0	0	0	0	0	0	8	.16	BP*14-135 C		
DISTILLATES STRAIGHT RUN	2	2	2	0	0	2	2	0	0	0	0	0	0	8	.16	BP*14-135 C		
DODECANOL	2	4	0	0	2	0	4	0	1	0	0	0	0	11	.22			
DODECENE	2	4	0	0	0	0	4	0	0	0	0	0	0	8	.16			
1-DODECENE	2	4	0	0	0	0	4	0	0	0	0	0	0	8	.16			
DOWTHERM	2	4	2	0	2	4	2	0	0	0	0	0	0	14	.29			
EPICHLOROHYDRIN	3	0	0	0	0	0	1	2	0	0	0	2	4	9	.18	BP*115.2 C		
EPOXIDIZED VEGETABLE OILS	2	4	4	4	4	2	2	0	1	0	0	0	0	21	.43			
ETHANE	2	2	4	4	4	0	2	0	0	0	0	0	0	16	.33	BP*-88.6 C		
ETHOXYLATED DODECANOL	1	2	0	0	0	0	1	0	0	0	2	0	2	7	.14			
ETHOXYLATED PENTADECANOL	1	2	0	0	0	0	1	0	0	0	2	0	2	7	.14			
ETHOXYLATED TETRADECANOL	1	2	0	0	0	0	1	0	0	0	2	0	2	7	.14			
ETHOXYLATED TRIDECANOL	1	2	0	0	0	0	1	0	0	0	2	0	2	7	.14			
ETHOXY TRIGLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	2	4	.08			
ETHYL ACETATE	1	0	0	0	0	0	1	0	0	0	0	0	2	3	.06	BP*77 C		
ETHYL ACRYLATE	1	0	0	0	0	0	1	0	2	0	0	0	2	5	.10	BP*98.6 C		
ETHYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	4	5	.10			

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													IN-SITU INSTRUMENTATION		CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RFIDAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)			
ETHYLBENZENE	2	4	0	0	0	4	2	0	0	0	0	0	0	10	.20	BP*136.2 C		
ETHYL BUTANOL	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP*146 C		
ETHYL CHLORIDE	2	4	4	4	0	0	4	0	0	0	0	0	0	16	.33	BP*12.2 C		
ETHYLENE	2	4	4	4	4	0	4	0	0	0	0	0	0	20	.41	BP*-183.7 C		
ETHYLENE CYANOHYDRIN	3	1	0	0	0	0	1	0	0	0	2	0	2	6	.12			
ETHYLENEDIAMINE	1	0	1	0	0	0	2	2	2	2	0	4	4	17	.35			
ETHYLENEDIAMINE TETRACETIC ACID	2	4	4	2	0	0	2	0	1	0	0	0	0	13	.27			
ETHYLENE DIBROMIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02			
ETHYLENE DICHLORIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02			
ETHYLENE GLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	4	6	.12			
ETHYLENE GLYCOL DIMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.08	BP*85.2 C		
ETHYLENE GLYCOL MONOBUTYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.08			
ETHYLENE GLYCOL MONOETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	4	5	.10			
ETHYLENE GLYCOL MONO-ETHYL ETHER ACETATE	1	2	0	0	0	0	1	0	0	0	0	0	2	5	.10			
ETHYLENE GLYCOL MONOETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04			
ETHYLENEIMINE	1	0	0	4	1	0	2	4	4	4	0	4	2	25	.52			
ETHYLENE OXIDE	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.08	BP*18.6 C		
ETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP*34.6 C		
2-ETHYL HEXANOL	2	4	2	2	4	0	2	0	1	0	0	0	0	15	.31			
ETHYL HEXYL TALLATE	2	4	2	2	4	0	2	0	1	0	0	0	0	15	.31			
2-ETHYL-3-PROPYLACROLEIN	2	4	0	0	0	0	2	0	1	0	0	0	0	7	.14			
FERROUS SULFATE	3	1	0	1	0	0	1	2	2	2	2	2	0	19	.27			
FLUORINE	1	2	2	2	0	0	1	4	4	4	0	4	4	27	.56	BP*-188 C REACTS		
FORMALDEHYDE SOLUTION	3	0	0	0	0	0	1	0	0	0	0	0	4	5	.10			
FORMIC ACID	3	0	0	1	0	0	2	4	4	2	0	4	2	19	.39			
FURFURAL	3	2	0	0	0	0	2	0	0	0	4	0	4	12	.25			
GAS OIL- CRACKED	2	4	2	0	2	2	2	0	1	0	0	0	0	13	.27			
GASOLINES AUTOMOTIVE (<4.250 LEAD/GAL)	2	4	2	0	0	0	4	0	1	0	0	0	0	11	.22	BP*68-199 C		

TABLE 4.2. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP		REMOTE OR IN-SITU INSTRUMENTATION							IN-SITU INSTRUMENTATION				CHEMICAL DETECTABILITY		COMMENTS
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE INFRARED	RF/MRA	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	POV SUMS	SUMS MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)		
GASOLINES* AVIATION (<4.860 LEAD/GAL)	2	4	2	0	0	0	4	0	1	0	0	0	0	11	.22	BP*71-171 C
GASOLINES* CASINGHEAD	2	4	2	0	0	0	4	0	1	0	0	0	0	11	.22	BP*14-135 C
GASOLINES* POLYMER	2	4	2	0	0	0	4	0	1	0	0	0	0	11	.22	BP*14-135 C
GASOLINES* STRAIGHT RUN	2	4	2	0	0	0	4	0	1	0	0	0	0	11	.22	BP*14-135 C
GASOLINE BLENDING STOCKS* REFORMATES	2	4	2	0	0	0	4	0	1	0	0	0	0	11	.22	BP*14-135 C
GASOLINE BLENDING STOCKS* ALKYLATES	2	4	2	0	0	0	4	0	1	0	0	0	0	11	.22	BP*14-135 C
GLYCERINE	3	0	0	0	0	0	2	0	0	0	0	0	2	4	.08	
GLYCIDYL METHACRYLATE	2	4	2	2	4	0	2	0	1	0	0	0	0	15	.31	
HEPTANE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*98.4 C
HEPTANOL	2	4	2	2	4	0	4	0	0	0	0	0	0	16	.33	
1-HEPTENE	2	2	4	2	2	0	2	0	1	0	0	0	0	13	.27	BP*93.6 C
HEXAMETHYLENEDIAMINE	1	0	0	0	0	0	2	2	2	0	0	2	0	8	.16	
HEXAMETHYLENETETRAMINE	3	1	0	1	0	0	2	2	2	0	2	2	0	12	.25	
HEXANE	2	2	2	0	0	0	4	0	1	0	0	0	0	9	.18	BP*68.7 C
HEXANOL	2	4	0	0	0	0	2	0	1	0	0	0	0	7	.14	
1-HEXENE	2	2	2	0	0	0	4	0	1	0	0	0	0	9	.18	BP*63.5 C
HEXYLENE GLYCOL	1	0	0	0	0	0	1	0	0	0	0	2	4	7	.14	
HYDRAZINE	3	0	0	1	0	0	1	2	2	2	0	2	4	14	.29	
HYDROCHLORIC ACID	3	0	0	2	1	0	0	4	4	4	0	4	0	19	.38	
HYDROFLUORIC ACID	3	0	0	2	1	0	0	4	4	4	0	4	0	19	.39	
HYDROGEN CHLORIDE	3	0	0	1	1	0	0	4	2	4	0	4	0	16	.33	BP*-85 C REACTS
HYDROGEN CYANIDE	1	2	0	0	0	0	1	2	2	2	2	2	0	13	.27	BP*25.7 C MODERATE REACTION
HYDROGEN FLUORIDE	1	0	1	2	0	0	1	4	2	4	0	2	0	16	.33	BP*18.5 C
HYDROGEN PEROXIDE	3	0	0	0	0	0	0	2	2	2	0	2	0	8	.16	
HYDROGEN SULFIDE	2	0	4	4	4	0	2	0	1	0	0	0	0	15	.31	BP*-88.4 C
ISOMYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.08	
ISOBUTANE	2	2	4	4	4	0	4	0	0	0	0	0	0	18	.37	BP*-11.8 C
ISOBUTYL ACETATE	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08	BP*117.3 C

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEMICAL DETECTABILITY	COMMENTS	
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS		SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)
ISOBUTYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	4	6	.12	
ISOBUTYLENE	2	2	4	4	4	0	2	0	0	0	0	0	0	16	.33	BP*-6.8 C
ISODECYL ALCOHOL	2	4	2	2	4	0	2	0	1	0	0	0	0	15	.31	
ISODECALDEHYDE	2	2	2	2	4	0	2	0	1	0	0	0	0	13	.27	
ISOHEXANE	2	2	2	0	0	0	2	0	0	0	0	0	0	6	.12	BP*60.3 C
ISOOCTYL ALCOHOL	2	0	2	2	4	0	2	0	1	0	0	0	0	11	.22	
ISOOCTALDEHYDE	2	2	0	0	0	0	2	0	1	0	0	0	0	5	.10	BP*153-178 C
ISOPENTANE	2	4	4	4	0	0	4	0	0	0	0	0	0	16	.33	BP*27.9 C
ISOPRENE	2	4	4	4	0	0	4	0	0	0	0	0	0	16	.33	BP*34.1 C
ISOPROPYL ACETATE	1	2	0	0	0	0	2	0	2	0	0	0	0	6	.12	BP*88.5 C
ISOPROPYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	4	6	.12	
JET FUELS* JP-1 (KEROSENE)	2	4	0	0	2	2	2	0	0	0	0	0	0	10	.20	
JET FUELS* JP-3	2	4	0	0	0	2	2	0	0	0	0	0	0	8	.16	
JET FUELS* JP-4	2	4	0	0	0	2	2	0	0	0	0	0	0	8	.16	
JET FUELS* JP-5 (KEROSENE HEAVY)	2	4	2	0	2	2	2	0	0	0	0	0	0	12	.25	
KEROSENE	2	4	0	0	2	2	2	0	0	0	0	0	0	10	.20	
LATEX LIQUID SYNTHETIC	3	2	0	0	0	0	1	0	0	0	4	0	2	9	.18	
LAURYL MERCAPTAN	2	4	2	0	2	0	2	0	1	0	0	0	0	11	.22	
LEAD ARSENATE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
LINEAR ALCOHOLS (12-15 CARBONS)	2	4	2	2	4	0	4	0	1	0	0	0	0	17	.35	
LIQUEFIED NATURAL GAS	2	2	4	4	4	0	4	0	1	0	0	0	0	19	.39	BP*-161 C
LIQUIFIED PETROLEUM GAS	2	2	4	4	4	0	2	0	1	0	0	0	0	17	.35	BP*-60 C
LITHIUM ALUMINUM HYDRIDE	1	0	1	2	0	0	0	4	4	4	0	4	4	23	.47	REACTS VIOLENTLY WITH WATER
MALATHION	4	0	0	0	0	2	1	0	0	0	0	0	0	3	.06	
MALEIC ANHYDRIDE	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
MERCURY	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
METHANE	2	2	4	4	4	0	2	0	0	0	0	0	0	16	.33	BP*-161.5 C
METHANESULFONIC ACID, SODIUM SALTS	1	2	0	2	0	0	1	2	2	0	2	2	0	13	.27	

TABLE 4.2. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION		CHEMICAL DETECTABILITY		COMMENTS
		OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PROPR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	RON SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)	
METHYL ACRYLATE	1	0	0	0	0	0	2	0	0	0	0	0	2	.04	BP*88.6 C	
METHYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	4	6	.12		
METHYL AMYL ACETATE	2	2	2	0	2	0	2	0	0	0	0	0	8	.16	BP*146.2 C	
METHYL AMYL ALCOHOL	1	0	0	0	0	0	1	0	2	0	0	2	5	.10	BP*131.8 C	
METHYL BROMIDE	4	0	0	0	0	0	2	0	0	0	0	0	2	.04	BP*9.6 C	
METHYL CHLORIDE	2	4	4	4	4	0	4	0	0	0	0	0	20	.41	BP*-24.2 C	
METHYL ETHYL KETONE	1	0	0	0	0	0	2	0	0	0	0	4	6	.12		
METHYLETHYLPYRIDINE	1	0	0	0	0	0	1	2	2	0	0	2	7	.14		
METHYL ISOBUTYL CARBINOL	1	0	0	0	0	0	1	0	0	0	0	2	3	.06	BP*131.8 C	
METHYL ISOBUTYL KETONE	1	2	0	0	0	0	2	0	0	0	0	4	8	.16	BP*116.2 C	
METHYL METHACRYLATE	1	2	0	0	0	0	2	0	0	0	0	2	6	.12	BP *101 C	
METHYL PARATHION	4	0	0	0	0	1	1	0	0	0	0	0	2	.04		
MINERAL SPIRITS	2	2	2	2	4	2	2	0	0	0	0	0	14	.29		
MONOCHLORODIFLUOROMETHANE	4	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP*-48.5 C	
MONOETHANOLAMINE	3	0	0	1	0	0	1	4	4	2	0	2	4	.37		
MONOISOPROPANOLAMINE	1	0	0	2	0	0	1	4	4	2	0	2	2	.35		
MORPHOLINE	1	2	0	2	0	2	1	4	4	2	0	4	2	.47		
MOTOR FUEL ANTI-KNOCK COMPOUNDS*LEAD ALKYLs	4	0	0	0	0	1	1	0	0	0	0	0	2	.04		
NAPHTHA* COAL TAR	2	2	2	2	4	4	2	0	0	0	0	0	16	.33	BP*93-260 C	
NAPHTHA* SOLVENT	2	2	2	2	4	2	2	0	0	0	0	0	14	.29	BP*130-155 C	
NAPHTHA* STANDARD SOLVENT	2	2	2	2	4	2	2	0	0	0	0	0	14	.29	BP*100-199 C	
NAPHTHA* VMAP (75% NAPHTHA)	2	2	2	2	4	2	2	0	0	0	0	0	14	.29	BP*93-149 C	
NAPHTHALENE, MOLTEN	4	0	0	0	0	2	1	0	0	0	0	0	3	.06		
NICKEL SULFATE	3	1	0	0	0	0	2	2	2	2	2	0	13	.27		
NITRIC ACID	3	1	0	2	1	0	2	4	4	4	4	0	26	.54		
NITROBENZENE	4	0	0	0	0	0	2	0	0	0	0	0	2	.04		
NITROGEN TETROXIDE	3	1	0	2	1	0	1	4	4	4	2	4	23	.47	REACTS WITH WATER	
NITROMETHANE	3	1	0	0	0	0	1	2	2	0	2	2	10	.20		

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PMOIR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	RON SUMS	SUMS OF MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)		
NITROSYL CHLORIDE	1	4	0	2	0	0	1	4	4	2	4	2	2	25	.52	BP*-5.8 C REACTS	
NONANOL	2	4	2	2	4	0	4	0	1	0	0	0	0	17	.35		
NONENE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP*135-140 C	
1-NONENE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP*147 C	
NONYLPHENOL	2	4	4	4	4	2	2	0	1	0	0	0	0	21	.43		
OCTANOL	2	4	2	2	4	0	4	0	1	0	0	0	0	17	.35		
1-OCTENE	2	4	0	0	0	0	4	0	1	0	0	0	0	9	.18	BP*121.3 C	
OILS* CLARIFIED	2	4	2	2	4	4	2	0	1	0	0	0	0	19	.39		
OILS* CRAUDE	2	4	2	2	4	4	2	0	1	0	0	0	0	19	.39		
OILS* DIESEL	2	4	2	2	4	4	2	0	1	0	0	0	0	19	.39		
OILS,EDIBLE*CASTOR	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS,EDIBLE* COTTONSEED	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS,EDIBLE* FISH	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS,EDIBLE*OLIVE	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS,EDIBLE* PEANUT	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS,EDIBLE* SOYA BEAN	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS,EDIBLE* VEGETABLE	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS,FUEL* NO.1 (KEROSENE)	2	4	2	0	2	4	2	0	1	0	0	0	0	15	.31		
OILS,FUEL* NO.1-D	2	4	2	0	2	4	2	0	1	0	0	0	0	15	.31		
OILS FUEL* NO. 2	2	4	2	0	2	4	2	0	1	0	0	0	0	15	.31		
OILS, FUEL* NO. 2-D	2	4	2	0	2	4	2	0	1	0	0	0	0	15	.31		
OILS, FUEL* NO. 4	2	4	4	2	4	4	2	0	1	0	0	0	0	21	.43		
OILS, FUEL* NO. 5	2	4	4	4	4	4	2	0	1	0	0	0	0	23	.47		
OILS, FUEL*NO. 6	2	4	4	4	4	4	2	0	1	0	0	0	0	23	.47		
OILS, MISCELLANEOUS* ABSORPTION	2	4	4	4	4	4	2	0	1	0	0	0	0	23	.47		
OILS, MISCELLANEOUS* COAL TAR	2	4	2	2	4	4	2	0	1	0	0	0	0	19	.39	BP*106-167 C	
OILS, MISCELLANEOUS* LUBRICATING	2	4	4	4	4	4	2	0	1	0	0	0	0	23	.47		
OILS, MISCELLANEOUS* MINERAL	2	4	4	4	4	4	2	0	1	0	0	0	0	23	.47		

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SENSITIVITY/RELATIVE DETECTABILITY		
OILS, MISCELLANEOUS* MINERAL SEAL	2	4	2	2	4	4	2	0	1	0	0	0	0	19	.39		
OILS, MISCELLANEOUS* MOTOR	2	4	4	4	4	4	2	0	1	0	0	0	0	23	.47		
OILS, MISCELLANEOUS* NEATSFOOT	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
OILS, MISCELLANEOUS* PENETRATING	2	4	2	2	4	4	2	0	1	0	0	0	0	19	.39		
OILS, MISCELLANEOUS* RANGE	2	4	2	0	2	4	2	0	1	0	0	0	0	15	.31		
OILS, MISCELLANEOUS* RESIN	2	4	4	4	4	2	2	0	1	0	0	0	0	21	.43		
OILS, MISCELLANEOUS* ROAD	2	4	2	2	4	4	2	0	1	0	0	0	0	19	.39		
OILS, MISCELLANEOUS* ROSIN	2	4	4	4	4	2	2	0	1	0	0	0	0	21	.43		
OILS, MISCELLANEOUS* SPERM	2	4	4	2	4	0	4	0	1	0	0	0	0	19	.39		
OILS, MISCELLANEOUS* SPINDLE	2	4	4	2	4	4	2	0	1	0	0	0	0	21	.43		
OILS, MISCELLANEOUS* SPRAY	2	4	2	0	4	4	2	0	1	0	0	0	0	17	.35		
OILS, MISCELLANEOUS* TALL	2	4	4	4	4	2	2	0	1	0	0	0	0	21	.43		
OILS, MISCELLANEOUS* TANNER'S	2	4	2	2	4	0	4	0	1	0	0	0	0	17	.35		
OILS, MISCELLANEOUS* TRANSFORMER	2	4	4	4	4	4	2	0	1	0	0	0	0	25	.47		
OLEUM	3	0	0	2	1	0	2	4	4	4	0	4	0	21	.43	HIGHLY EXOTHERMIC DISSOLUTION	
OXALIC ACID	3	1	0	1	0	0	2	4	4	4	2	4	2	24	.50		
PARAFORMALDEHYDE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
PENTACHLOROPHENOL	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
PENTADECANOL	2	4	2	0	2	0	4	0	1	0	0	0	0	13	.27		
PENTANE	2	4	4	2	0	0	4	0	0	0	0	0	0	14	.29	BP=36.1 C	
1-PENTENE	2	4	4	2	0	0	4	0	0	0	0	0	0	14	.29	BP=29.9 C	
PETROLATUM	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
PETROLEUM NAPHTHA	2	4	2	2	4	0	4	0	0	0	0	0	0	16	.33	BP=97.2 C	
PHENOL	3	1	0	0	0	4	1	0	0	0	4	0	4	14	.29		
PHOSGENE	3	0	0	2	1	0	0	4	4	4	0	4	0	19	.39	BP=8.2 C REACTS	
PHOSPHORIC ACID	3	0	0	1	0	0	2	2	2	2	0	2	0	11	.22	BP=130 C	
PHOSPHORUS, RED	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
PHOSPHORUS, WHITE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RF/RRR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROV SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)		
PHOSPHORUS OXYCHLORIDE	3	0	0	2	1	0	0	4	4	4	0	4	0	10	.39	REACTS WITH WATER	
PHOSPHORUS PENTASULFIDE	3	0	0	1	0	0	0	2	2	2	0	2	0	9	.18	REACTS WITH WATER	
PHOSPHORUS TRICHLORIDE	3	0	0	2	1	0	0	4	4	4	0	4	0	19	.39	REACTS VIOLENTLY WITH WATER	
PHTHALIC ANHYDRIDE	4	0	0	0	0	1	1	0	0	0	0	0	0	2	.04		
POLYBUTENE	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
POLYCHLORINATED BIPHENYL	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
POLYPHOSPHORIC ACID	3	0	0	1	0	0	0	2	2	2	0	2	0	9	.18	REACTS WITH WATER	
POLYPROPYLENE GLYCOL METHYL ETHER	3	0	0	0	0	0	2	0	0	0	0	0	2	4	.08		
POTASSIUM CYANIDE	3	1	0	1	1	0	1	4	4	4	2	4	0	22	.45	REACTS WITH WATER	
POTASSIUM DICHROMATE	3	2	0	1	0	0	2	2	2	4	4	2	0	19	.39		
POTASSIUM HYDROXIDE	3	0	0	2	1	0	0	4	4	4	0	4	0	19	.39	EXOTHERMIC	
POTASSIUM IODIDE	3	1	0	0	0	0	0	2	2	2	2	2	0	11	.22		
POTASSIUM PERMANGANATE	3	2	0	0	0	0	2	2	2	2	4	2	2	18	.37		
PROPANE	2	4	4	4	4	0	4	0	0	0	0	0	0	20	.41	BP = -42.1 C	
PROPIONALDEHYDE	1	0	0	0	0	0	2	0	0	0	0	0	4	6	.12		
PROPIONIC ACID	1	2	0	0	0	0	2	0	0	2	2	0	4	12	.25		
N-PROPYL ACETATE	1	2	0	0	0	0	2	0	0	0	0	0	2	6	.12	BP = 101.6 C	
N-PROPYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	4	6	.12		
PROPYLENE	2	4	4	4	4	0	4	0	0	0	0	0	0	20	.41	BP = -47.7 C	
PROPYLENE BUTYLENE POLYMER	2	4	4	2	4	0	4	0	0	0	0	0	0	18	.37		
PROPYLENE GLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	4	6	.12		
PROPYLENE GLYCOL METHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	2	4	.08		
PROPYLENE OXIDE	1	0	0	0	0	0	2	0	0	0	0	0	4	6	.12	BP = 34.3 C	
PROPYLENE TETRAMER	2	4	4	2	4	0	4	0	0	0	0	0	0	18	.37		
PYRIDINE	1	4	0	0	0	0	2	0	0	0	4	0	4	14	.28		
SILVER NITRATE	3	1	0	0	0	0	2	0	0	2	2	2	0	9	.18		
SODIUM	3	0	0	1	0	0	0	4	4	4	0	4	0	17	.35	REACTS VIOLENTLY WITH WATER	
SODIUM ALKYL-BENZENESULFONATES	1	2	0	2	0	2	1	4	4	4	2	4	0	25	.52		

TABLE 4.2. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP			REMOTE OR IN-SITU INSTRUMENTATION							IN-SITU INSTRUMENTATION				CHEMICAL DETECTABILITY		COMMENTS
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	RDV SUNS	SUNS/MINIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)			
SODIUM ALKYL SULFATES	1	2	0	0	0	0	2	4	4	4	2	4	4	26	.54		
SODIUM AMIDE	3	0	0	1	0	0	0	4	4	4	0	4	0	17	.35	REACTS VIOLENTLY WITH WATER	
SODIUM BISULFITE	3	1	0	2	1	0	2	4	4	2	0	4	0	20	.41		
SODIUM BOROHYDRIDE	3	0	0	1	0	0	0	4	4	4	0	4	0	17	.35	REACTS	
SODIUM CHLORATE	3	1	0	2	1	0	2	4	4	4	2	4	0	24	.50		
SODIUM CYANIDE	3	1	0	1	1	0	1	4	4	4	2	4	0	22	.45	MILD REACTION	
SODIUM DICHROMATE	3	2	0	1	0	0	2	2	2	2	4	2	0	17	.35		
SODIUM FERROCYANIDE	3	2	0	1	0	0	1	2	2	0	4	2	0	14	.29		
SODIUM FLUORIDE	3	0	0	2	1	0	0	4	4	0	0	4	0	15	.31		
SODIUM HYDRIDE	3	0	0	1	0	0	0	4	4	4	0	4	0	17	.35	VIGOROUS REACTION	
SODIUM HYDROXIDE	3	0	0	1	0	0	0	4	4	4	0	4	0	17	.35	VIGOROUS REACTION	
SODIUM HYPOCHLORITE	3	2	0	2	1	0	0	4	4	4	4	4	0	25	.52		
SODIUM SILICATE	3	0	0	2	1	0	1	4	4	0	0	4	0	16	.33		
SODIUM SULFIDE	3	2	0	2	1	0	0	4	4	0	4	4	0	21	.43		
SODIUM SILFITE	3	2	0	1	0	0	1	2	2	0	4	2	0	14	.29		
SORBITOL	3	0	0	0	0	0	2	0	0	0	0	0	2	4	.06		
STYRENE	2	4	0	0	0	4	2	0	0	0	0	0	0	10	.20	BP=145.2 C	
SULFOLANE	3	0	0	0	0	0	2	0	0	0	0	0	2	4	.06		
SULFUR (LIQUID)	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
SULFUR DIOXIDE	3	0	0	2	1	0	2	4	4	4	0	4	2	23	.47	BP=-10 C REACTS	
SULFUR MONOCHLORIDE	3	0	0	2	1	0	0	4	4	4	0	4	0	19	.39	REACTS VIOLENTLY WITH WATER	
SULFURIC ACID	3	0	0	2	1	0	2	4	4	4	0	4	0	21	.43	REACTS	
SULFURIC ACID, SPENT	3	1	0	2	1	0	2	4	4	4	2	4	0	24	.50		
SULFURYL CHLORIDE	3	0	0	2	1	0	2	4	4	4	0	4	0	21	.43	VIGOROUS REACTION	
TALLOW	2	4	4	4	4	0	4	0	1	0	0	0	0	21	.43		
TETRACHLOROETHYLENE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TETRADECANOL	2	4	4	4	4	0	4	0	0	0	0	0	0	20	.41	FP=37.0 C	
1-TETRADECENE	2	4	0	0	2	0	4	0	0	0	0	0	0	10	.20		

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													IN-SITU INSTRUMENTATION													CHEMICAL DETECTABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE DETECTABILITY)														
TETRAETHYL LEAD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00			
TETRAHYDROFURAN	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	.04			
TETRAHYDRONAPHTHALENE	2	4	0	0	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	.25			
TETRAMETHYL LEAD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00			
TITANIUM TETRACHLORIDE	9	0	0	2	1	0	0	4	4	4	0	4	0	19	0	0	0	0	0	0	0	0	0	0	19	0	.39	REACTS	
TOLUENE	2	4	0	0	0	4	2	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	10	0	.20	BP=110.6 C	
TOLUENE 2,4-DIISOCYANATE	4	0	0	0	0	1	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04		
TOXAPHENE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04	FP=88-95 C	
TRICHLOROETHANE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04		
TRICHLOROETHYLENE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04		
TRICHLOROFLUOROMETHANE	4	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04	BP=29.0 C	
TRICHLOROPHENOL	4	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04		
TRICRESYL PHOSPHATE	4	0	0	0	0	1	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04		
TRIDECANOL	2	4	4	4	4	0	4	0	1	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	21	0	.43		
1-TRIDECENE	2	4	0	0	0	0	4	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	8	0	.16		
TRIETHANOLAMINE	3	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04		
TRIETHYLAMINE	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.04		
TRIETHYLBENZENE	2	4	0	0	2	4	2	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	12	0	.25		
TRIETHYLENE GLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.08		
TRIETHYLENETETRAHINE	1	4	0	0	0	0	2	2	2	0	4	0	2	16	0	0	0	0	0	0	0	0	0	0	16	0	.33		
TRIMETHYLAMINE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	.08	BP=2.9 C	
TURPENTINE	2	4	0	0	2	2	2	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	10	0	.20	BP=150-160 C	
UNDECANOL	2	4	4	4	4	0	4	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	20	0	.41	FP=15.0 C	
1-UNDECENE	2	4	0	0	0	0	4	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	8	0	.16		
UREA	3	1	0	0	0	0	2	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3	0	.06		
VALEVALDEHYDE	1	4	0	0	0	0	2	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	6	0	.12	BP=103 C	
VINYL ACETATE	1	4	1	0	0	0	2	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	7	0	.14	BP=72.9 C	
VINYL CHLORIDE	2	4	4	4	4	0	4	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	20	0	.41	BP=-13.0 C	

TABLE 4.2. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													ROW SUMS	CHEMICAL DETECTABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RF/MW	FLUORESCENCE	RF/MW SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			
VINYLDIENE CHLORIDE, INHIBITED	4	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
VINYLTOLUENE	2	4	0	0	0	4	2	0	0	0	0	0	0	10	.20	BP=167.7 C
WAXES* CARNAUBA	2	4	4	4	4	2	2	0	1	0	0	0	0	21	.43	
WAXES* PARAFFIN	2	4	4	4	4	2	2	0	1	0	0	0	0	21	.43	
M-XYLENE	2	4	0	0	0	4	2	0	0	0	0	0	0	10	.20	BP=131.9 C
O-XYLENE	2	4	0	0	0	4	2	0	0	0	0	0	0	10	.20	BP=144 C
P-XYLENE	2	4	0	0	0	4	2	0	0	0	0	0	0	10	.20	BP=136.3 C
ZINC CHLORIDE	3	0	0	1	0	0	1	2	2	2	0	2	0	10	.20	
COLUMN SUMS	691	350	383	391	256	771	294	483	224	162	268	272				
SUMS/MAXIMUM POSSIBLE VALUE	.43	.21	.23	.24	.16	.46	.18	.25	.14	.11	.16	.17				
SUMS/MAXIMUM VALUE	.69	.45	.49	.50	.33	1.0	.36	.52	.29	.23	.37	.35		RELATIVE SYSTEM EFFECTIVENESS		
NUMBER OF CHEMICALS PROBABLY DETECTABLE	133	56	48	79	40	69	50	48	40	28	47	37				

A and D would be $2 \times 2 = 4$. If the chemical sinks and is insoluble, the ranking would be $0 \times 2 = 0$. In this chart, a 4 indicates that detection is probable; a 1 or a 2 indicates that detection may be possible under certain circumstances; and a 0 indicates that detection is unlikely.

Wherever pertinent, a note has been made of the boiling point or reactivity of the chemical to indicate that its residence time on or in the water is limited. If the compound reacts with water, the detectability of that compound was considered to be the detectability of the reaction products. For example, chlorosulfonic acid reacts violently to produce hydrochloric and sulfuric acids. Thus, the detection of chlorosulfonic acid spills is based on the detectability of hydrochloric and sulfuric acids.

The matrix elements are summed across the rows and the sums are listed in the column labeled ROW SUMS. The maximum possible value is 48. This would correspond to a chemical that is potentially detectable by all of the twelve sensing techniques. In the column labeled SUMS/MAXIMUM POSSIBLE VALUE, the row sums are divided by 48 to provide a numerical ranking of the relative potential detectabilities of the chemicals on a scale from 0 to 1.

Similarly, the column sums and the normalized values listed at the bottom of the last page of the chart provide a ranking of the maximum, relative effectiveness of each of the sensing techniques for the complete range of CHRIS Chemicals. The maximum possible column sum is 1600, corresponding to a sensing system which can potentially detect all 400 of the chemicals listed. Values for the row labeled NUMBER OF CHEMICALS PROBABLY DETECTABLE were derived by counting the 4's in each of the system columns.

On the basis of this analysis, it is apparent that optical reflectance, radar, and Raman sensing systems are potentially the most effective systems for detecting these chemicals. Other considerations, such as sensitivity and operating environment, may modify these relative system rankings. It should be noted that a Raman system designed to detect light at the wavelengths of the Stokes scattering lines will also be capable of detecting light emitted by fluorescent chemicals. Therefore, about 40 fluorescent chemicals can be added to the list of chemicals probably detectable by a

Raman system. It may also be true that a laser fluorosensor may be capable of detecting certain chemicals by means of their Raman scattering, but because of the greater quantum efficiency of fluorescence in comparison with Raman scattering, an effective fluorosensor may have a sensitivity lower than that necessary for effective operation of a Raman sensor. Similar considerations apply to identification and quantification of spilled chemicals by these two types of systems. However, except by utilizing the weak anti-Stokes scattering lines, or some other special technique, it is unlikely that a fluorescent chemical can be identified by its Raman spectrum.

4.3 IDENTIFIABILITY

In order to identify a spilled chemical, it is first necessary to detect it. Thus, the probability of identifying a chemical depends on the probability of detecting it. As described above, each of the detectability values in the preceding chart is the product of an accessibility factor, A, and a chemical-specific detection factor, D. To determine identifiability, a third term was defined, namely, an identification factor, I. The values of I are again integers in the range 0-2:

- 2 = probably effective for chemical identification;
- 1 = possibly effective for chemical identification; and
- 0 = probably ineffective for chemical identification.

For a given sensing system, the value of I depends on the accessibility group of the chemical to be identified. The assigned values of I for all system/accessibility group combinations are given in Table 4.3.

The following Chemical Identifiability Chart, Table 4.4, presents, in the form of a numerical matrix, estimates of the relative potential effectiveness of each of the twelve sensing techniques for identifying each of the CHRIS chemicals. Each matrix element is the product of the corresponding element in the Detectability Chart and the appropriate value of I. In addition, each of the products has been divided by 2 in order to make the range of the possible values (0,1,2,4) equal to the range of values in the Detectability Chart. A 4 indicates that identification is

TABLE 4.3. Identification Factors

ACCESSIBILITY GROUP	REMOTE OR IN SITU IN SITU INSTRUMENTATION							IN SITU INSTRUMENTATION				
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTRO-CONDUCTIVITY	REDUCTION-OXIDATION POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND
1	1	0	0	0	1	2	1	0	0	1	0	0
2	1	0	0	0	1	2	0	0	0	0	0	0
3	1	0	0	0	1	2	1	0	0	1	0	0
4	0	0	0	0	1	1	0	0	0	0	0	0

probable; a 1 or a 2 indicates that identification may be possible under certain circumstances; and a 0 indicates that identification is unlikely.

The matrix elements are summed across the rows. In the column labeled SUMS/MAXIMUM POSSIBLE VALUE, the rows sums are divided by 48 to provide a numerical ranking of the relative potential identifiabilities of the chemicals on a scale from 0 to 1.

The column sums and the normalized values listed at the bottom of the last page of the chart provide a ranking of the relative effectiveness of each of the sensing techniques for the complete range of CHRIS chemicals. The maximum possible column sum is 1600, corresponding to a sensing system which can potentially identify all 400 of the chemicals listed. Values for the row labeled NUMBER OF CHEMICALS PROBABLY IDENTIFIABLE were derived by counting the 4's in each of the system columns.

In this analysis, only Raman scattering systems are considered to be "probably" capable of identifying any of the CHRIS chemicals. The other

TABLE 4.4. Chemical Identifiability Chart

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEM. IDENTIFIABILITY	COMMENTS	
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			ROW SUMS
ACETALDEHYDE	3	0	0	0	0	0	2	1	0	0	1	0	0	4	.06	
ACETIC ACID	3	0	0	0	0	0	2	1	0	0	2	0	0	5	.10	
ACETIC ANHYDRIDE	3	0	0	0	0	0	2	1	0	0	2	0	0	5	.10	
ACETONE	1	1	0	0	0	0	2	0	0	0	2	0	0	5	.10	
ACETONE CYANOHYDRIN	1	0	0	0	0	0	1	1	0	0	0	0	0	2	.04	
ACETONITRILE	1	1	0	0	0	0	2	0	0	0	1	0	0	4	.08	
ACETOPHENONE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
ACETYLENE	2	0	0	0	0	0	4	0	0	0	0	0	0	4	.08	BP*-84.C
ACRYLIC ACID	3	0	0	0	0	0	2	1	0	0	1	0	0	4	.08	
ACRYLONITRILE	1	1	0	0	0	0	1	0	0	0	1	0	0	3	.06	
ADIPONITRILE	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08	
ALDRIN	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
ALLYL ALCOHOL	1	0	0	0	0	0	2	1	0	0	0	0	0	3	.06	
ALLYL CHLORIDE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*45 C
ALUMINUM CHLORIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	VIOLENT REACTION WITH WATER
ALUMINUM FLUORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
AMINOETHYLETHANOLAMINE	3	0	0	0	0	0	2	1	0	0	0	0	0	3	.06	
AMMONIA, ANHYDROUS	1	0	0	0	0	0	1	2	0	0	0	0	0	3	.06	BP*-33.4 C
AMMONIUM HYDROXIDE (<28% AQUEOUS AMMONIA)	1	0	0	0	0	0	1	2	0	0	0	0	0	3	.06	
AMMONIUM NITRATE	3	0	0	0	0	0	1	1	0	0	1	0	0	3	.06	
AMMONIUM PERCHLORATE	3	1	0	0	0	0	1	1	0	1	2	0	0	5	.10	
AMMONIUM SULFATE	3	1	0	0	0	0	1	1	0	0	2	0	0	5	.10	
AMYL ACETATE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*146 C
N-AMYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
ANILINE	3	0	0	0	0	2	1	1	0	0	1	0	0	5	.10	
ANTIMONY TRIFLUORIDE	3	1	0	0	0	0	1	1	0	0	2	0	0	5	.10	
ASPHALT	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
ASPHALT BLENDING STOCKS+ ROOFERS FLUX	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEM. IDENTIFIABILITY	COMMENTS	
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE INFRARED	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			POV SUMS
ASPHALT BLENDING STOCKS+ STRAIGHT RUN RESIDUE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
BARIUM CARBONATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
BENZALDEHYDE	2	2	0	0	0	1	2	0	0	0	0	0	0	5	.10	
BENZENE	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	BP*66.1 C
BENZENE HEXACHLORIDE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
BENZOIC ACID	4	0	0	0	0	1	1	0	0	0	0	0	0	2	.04	
BENZOYL CHLORIDE	4	0	0	0	0	1	1	0	0	0	0	0	0	2	.04	REACTS SLOWLY
BISPHENOL A	4	0	0	0	0	1	1	0	0	0	0	0	0	2	.04	
BROMINE	3	1	0	0	0	0	0	1	0	0	2	0	0	4	.06	
BUTADIENE, INHIBITED	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.06	BP*-4.4 C
BUTANE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*-0.48 C
1,4-BUTANEDIOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
1,4-BUTENEDIOL	3	0	0	0	0	0	2	0	0	0	1	0	0	3	.06	
N-BUTYL ACETATE	1	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	
SEC-BUTYL ACETATE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*112 C
N-BUTYL ACRYLATE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*146.6 C
ISO-BUTYL ACRYLATE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*137.9 C
N-BUTYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP*117 C
SEC-BUTYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP*99.5 C
TEAT-BUTYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP*82.6 C
BUTYLENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*-6.3 C
TEAT-BUTYL HYDROPEROXIDE	1	0	0	0	0	0	2	0	0	0	1	0	0	3	.06	DECOMPOSES
1,4-BUTYNEEDIOL	3	1	0	0	0	0	2	0	0	0	2	0	0	5	.10	
N-BUTYRALDEHYDE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP*74.6 C
ISO-BUTYRALDEHYDE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP*64.1 C
CADMIUM CHLORIDE	3	0	0	0	0	0	0	1	0	0	0	0	0	1	.02	
CALCIUM CARBIDE	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	REACTIVE. FORMS GAS AND WHITE PPT
CALCIUM FLUORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	

TABLE 4.4. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP	REMOTE OR IN-SITU INSTRUMENTATION							IN-SITU INSTRUMENTATION					CHEM. IDENTIFIABILITY	COMMENTS	
		OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			ROW SUMS
CALCIUM HYDROXIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
CALCIUM HYPOCHLORITE	3	0	0	0	0	0	1	1	0	0	0	0	0	2	.04	
CALCIUM OXIDE	3	0	0	0	0	0	1	2	0	0	0	0	0	3	.06	REACTS VIOLENTLY WITH WATER
CAMPOR OIL	2	2	0	0	0	1	2	0	0	0	0	0	0	5	.10	
CARBARYL	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
CARBOLIC OIL	3	0	0	0	0	2	1	0	0	0	1	0	0	4	.08	
CARBON BISULFIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
CARBON TETRACHLORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
CAUSTIC POTASH SOLUTION	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	
CAUSTIC SODA SOLUTION	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	
CHLORINE	3	1	0	0	0	0	1	1	0	0	2	0	0	5	.10	BP=34.1 C
CHLORO BENZENE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
CHLOROFORM	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
CHLOROHYDRINS (CRUDE)	3	0	0	0	0	1	1	0	0	0	1	0	0	3	.06	
CHLOROSULFONIC ACID	3	0	0	0	0	0	1	2	0	0	0	0	0	3	.06	REACTS VIOLENTLY WITH WATER
CHROMIC ANHYDRIDE	3	1	0	0	0	0	1	2	0	0	2	0	0	6	.12	
COPPER SULFATE	3	1	0	0	0	0	1	1	0	0	2	0	0	5	.10	
CORN SYRUP	3	0	0	0	0	1	1	0	0	0	0	0	0	2	.04	
CRESOLS	3	1	0	0	0	2	1	0	0	0	2	0	0	6	.12	
CROTONALDEHYDE	1	2	0	0	0	0	2	0	0	0	2	0	0	6	.12	BP=102.2 C
CUMENE	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	BP=152.4 C
CYANOGEN BROMIDE	3	0	0	0	0	0	1	1	0	0	0	0	0	2	.04	
CYANOGEN CHLORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP=13.1 C
CYCLOHEXANE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=98.7 C
CYCLOHEXANOL	1	2	0	0	0	0	2	0	0	0	1	0	0	5	.10	
CYCLOHEXANONE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
CYCLOHEXYLAMINE	1	0	0	0	0	0	2	2	0	0	0	0	0	4	.08	
DDT	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													ROW SUMS	CHEM. IDENTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			
DECALDEHYDE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	
1-DECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	
N-DECYL ALCOHOL	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08	
DEXTRROSE SOLUTION	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
DIACETONE ALCOHOL	1	0	0	0	0	0	2	0	0	0	1	0	0	3	.06	
DIBENZOYL PEROXIDE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	REACTIVE WITH SUSPENDED SOLIDS
DIBUTYL PHTHALATE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
O-DICHLOROBENZENE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
P-DICHLOROBENZENE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
DICHLORODIFLUOROMETHANE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP*-29.8 C
DICHLOROMETHANE	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
2,4-DICHLOROPHENOL	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
DICHLOROPROPANE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
DICHLOROPROPENE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
DICYCLOPENTADIENE	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08	
DIETANOLAMINE	3	0	0	0	0	0	2	1	0	0	0	0	0	3	.06	
DIETHYLAMINE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*55.5 C
DIETHYLBENZENE	2	2	0	0	0	0	2	2	0	0	0	0	0	6	.12	
DIETHYLCARBONATE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*126.0 C
DIETHYLENE GLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
DIETHYLENE GLYCOL DIMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
DIETHYLENE GLYCOL MONOMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
DIETHYLENE GLYCOL DIMONOMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
DIETHYLENETRIAMINE	1	1	0	0	0	0	2	1	0	0	1	0	0	5	.10	
DIISOBUTYLCARBINOL	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	
DIISOBUTYLENE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*101.5 C
DIISOPROPANOLAMINE	1	0	0	0	0	0	1	1	0	0	0	0	0	2	.04	
DIETHYLAMINE	1	0	0	0	0	0	2	1	0	0	0	0	0	3	.06	BP*6.9 C

TABLE 4.4. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP		REMOTE OR IN-SITU INSTRUMENTATION							IN-SITU INSTRUMENTATION				CHEM. IDENTIFIABILITY	COMMENTS	
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS			SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE IDENTIFIABILITY)
DIMETHYLFORMAMIDE	1	2	0	0	0	0	2	1	0	0	2	0	0	7	.14	
1,1-DIMETHYLHYDRAZINE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
DIMETHYL SULFATE	3	0	0	0	0	0	1	1	0	0	0	0	0	2	.04	
DIMETHYL SULFOXIDE	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
2,4-DINITROANILINE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
2,4-DINITROPHENOL	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
DIOCTYL ADIPATE	2	1	0	0	0	0	4	0	0	0	0	0	0	5	.10	
DIOCTYL PHTHALATE	2	1	0	0	0	1	2	0	0	0	0	0	0	4	.08	
1,4-DIOXANE	3	0	0	0	0	1	2	0	0	0	0	0	0	3	.06	
DIPHENYLMETHANE-DIISOCYANATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
DIPROPYLENE GLYCOL	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
DISTILLATES* FLASHED FEED STOCKS	2	1	0	0	0	1	2	0	0	0	0	0	0	4	.08	BP*14-135 C
DISTILLATES STRAIGHT RUN	2	1	0	0	0	1	2	0	0	0	0	0	0	4	.08	BP*14-135 C
DODECANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	
DODECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	
1-DODECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	
DOWTHERM	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	
EPICHLOROHYDRIN	3	0	0	0	0	0	1	1	0	0	0	0	0	2	.04	BP*115.2 C
EPOXIDIZED VEGETABLE OILS	2	2	0	0	0	1	2	0	0	0	0	0	0	5	.10	
ETHANE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*-88.6 C
ETHOXYLATED DODECANOL	1	1	0	0	0	0	1	0	0	0	1	0	0	3	.06	
ETHOXYLATED PENTADECANOL	1	1	0	0	0	0	1	0	0	0	1	0	0	3	.06	
ETHOXYLATED TETRADECANOL	1	1	0	0	0	0	1	0	0	0	1	0	0	3	.06	
ETHOXYLATED TRIDECANOL	1	1	0	0	0	0	1	0	0	0	1	0	0	3	.06	
ETHOXY TRIGLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	
ETHYL ACETATE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP*77 C
ETHYL ACRYLATE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP*88.6 C
ETHYL ALCOHOL	1	0	0	0	0	0	1	0	0	5	0	0	0	1	.02	

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. IDENTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE IDENTIFIABILITY)		
ETHYLBENZENE	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	BP=136.2 C	
ETHYL BUTANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=146 C	
ETHYL CHLORIDE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=12.2 C	
ETHYLENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=-109.7 C	
ETHYLENE CYANOHYDRIN	3	0	0	0	0	0	1	0	0	0	1	0	0	2	.04		
ETHYLENEDIAMINE	1	0	0	0	0	0	2	1	0	0	0	0	0	3	.06		
ETHYLENEDIAMINE TETRACETIC ACID	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08		
ETHYLENE DIBROMIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
ETHYLENE DICHLORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
ETHYLENE GLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
ETHYLENE GLYCOL DIMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP=65.2 C	
ETHYLENE GLYCOL MONOBUTYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
ETHYLENE GLYCOL MONOETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
ETHYLENE GLYCOL MONOETHYL ETHER ACETATE	1	1	0	0	0	0	1	0	0	0	0	0	0	2	.04		
ETHYLENE GLYCOL MONOMETHYL ETHER	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
ETHYLENEIMINE	1	0	0	0	0	0	2	2	0	0	0	0	0	4	.08		
ETHYLENE OXIDE	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP=10.6 C	
ETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP=34.6 C	
2-ETHYL HEXANOL	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08		
ETHYL HEXYL TALLATE	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08		
2-ETHYL-3-PROPYLACROLEIN	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08		
FEROUS SULFATE	3	0	0	0	0	0	1	1	0	0	1	0	0	3	.06		
FLUORINE	1	1	0	0	0	0	1	2	0	0	0	0	0	4	.08	BP=-108 C REACTS	
FORMALDEHYDE SOLUTION	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
FORMIC ACID	3	0	0	0	0	0	2	2	0	0	0	0	0	4	.08		
FURFURAL	3	1	0	0	0	0	2	0	0	0	2	0	0	5	.10		
GAS OIL- CRACKED	2	2	0	0	0	1	2	0	0	0	0	0	0	5	.10		
GASOLINES AUTOMOTIVE (<4.250 LEAD/GAL)	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=60-100 C	

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													IN-SITU INSTRUMENTATION	CHEM. IDENTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PROPR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE IDENTIFIABILITY)		
GASOLINES* AVIATION (<4.860 LEAD/GAL)	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*71-171 C	
GASOLINES* CASINGHEAD	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINES* POLYMER	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINES* STRAIGHT RUN	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINE BLENDING STOCKS* REFORMATES	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINE BLENDING STOCKS* ALKYLATES	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*14-135 C	
GLYCERINE	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
GLYCIDYL METHACRYLATE	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08		
HEPTANE	2	1	0	0	0	0	4	0	0	0	0	0	0	5	.10	BP*98.4 C	
HEPTANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
1-HEPTENE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*93.6 C	
HEXAMETHYLENEDIAMINE	1	0	0	0	0	0	2	1	0	0	0	0	0	3	.06		
HEXAMETHYLEMETETRAMINE	3	0	0	0	0	0	2	1	0	0	1	0	0	4	.08		
HEXANE	2	1	0	0	0	0	4	0	0	0	0	0	0	5	.10	BP*68.7 C	
HEXANOL	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08		
1-HEXENE	2	1	0	0	0	0	4	0	0	0	0	0	0	5	.10	BP*63.5 C	
HEXYLENE GLYCOL	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
HYDRAZINE	3	0	0	0	0	0	1	1	0	0	0	0	0	2	.04		
HYDROCHLORIC ACID	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04		
HYDROFLUORIC ACID	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04		
HYDROGEN CHLORIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	BP*-85 C REACTS	
HYDROGEN CYANIDE	1	1	0	0	0	0	1	1	0	0	1	0	0	4	.08	BP*25.7 C MODERATE REACTION	
HYDROGEN FLUORIDE	1	0	0	0	0	0	1	2	0	0	0	0	0	3	.06	BP*19.5 C	
HYDROGEN PEROXIDE	3	0	0	0	0	0	0	1	0	0	0	0	0	1	.02		
HYDROGEN SULFIDE	2	0	0	0	0	0	2	0	0	0	0	0	0	2	.04	BP*-68.4 C	
ISOAMYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
ISOBUTANE	2	1	0	0	0	0	4	0	0	0	0	0	0	5	.10	BP*-11.0 C	
ISOBUTYL ACETATE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*117.9 C	

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION											IN-SITU INSTRUMENTATION				CHEM. IDENTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PRDPR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	POV SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE IDENTIFIABILITY)		
ISOBUTYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	2	.04			
ISOBUTYLENE	2	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP+6.9 C		
ISODECYL ALCOHOL	2	2	0	0	0	0	2	0	0	0	0	0	4	.08			
ISODECALDEHYDE	2	1	0	0	0	0	2	0	0	0	0	0	3	.06			
ISOHEXANE	2	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP+68.3 C		
ISOCTYL ALCOHOL	2	0	0	0	0	0	2	0	0	0	0	0	2	.04			
ISOCTALDEHYDE	2	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP+153-178 C		
ISOPENTANE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP+27.9 C		
ISOPRENE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP+34.1 C		
ISOPROPYL ACETATE	1	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP+88.5 C		
ISOPROPYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	2	.04			
JET FUELS+JP-1(KEROSENE)	2	2	0	0	0	1	2	0	0	0	0	0	5	.10			
JET FUELS+JP-3	2	2	0	0	0	1	2	0	0	0	0	0	5	.10			
JET FUELS+JP-4	2	2	0	0	0	1	2	0	0	0	0	0	5	.10			
JET FUELS+JP-5 (KEROSENE HEAVY)	2	2	0	0	0	1	2	0	0	0	0	0	5	.10			
KEROSENE	2	2	0	0	0	1	2	0	0	0	0	0	5	.10			
LATEX LIQUID SYNTHETIC	3	1	0	0	0	0	1	0	0	0	2	0	4	.08			
LAURYL MERCAPTAN	2	2	0	0	0	0	2	0	0	0	0	0	4	.08			
LEAD ARSENATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00			
LINEAR ALCOHOLS (12-15 CARBONS)	2	2	0	0	0	0	4	0	0	0	0	0	6	.12			
LIQUEFIED NATURAL GAS	2	1	0	0	0	0	4	0	0	0	0	0	5	.10	BP+-161 C		
LIQUIFIED PETROLEUM GAS	2	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP+-60 C		
LITHIUM ALUMINUM HYDRIDE	1	0	0	0	0	0	0	2	0	0	0	0	2	.04	REACTS VIOLENTLY WITH WATER		
MALATHION	4	0	0	0	0	1	0	0	0	0	0	0	1	.02			
MALEIC ANHYDRIDE	3	0	0	0	0	0	2	0	0	0	0	0	2	.04			
MERCURY	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00			
METHANE	2	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP+-161.5 C		
METHANEARSONIC ACID, SODIUM SALTS	1	1	0	0	0	0	1	1	0	0	1	0	4	.08			

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEM. IDENTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RFDRR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND		
METHYL ACRYLATE	1	0	0	0	0	0	2	0	0	0	0	0	2	.04	BP=88.6 C
METHYL ALCOHOL	1	0	0	0	0	0	2	0	0	0	0	0	2	.04	
METHYL AMYL ACETATE	2	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP=146.2 C
METHYL AMYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP=131.8 C
METHYL BROMIDE	4	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP=3.6 C
METHYL CHLORIDE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP=-24.2 C
METHYL ETHYL KETONE	1	0	0	0	0	0	2	0	0	0	0	0	2	.04	
METHYLETHYLPYRIDINE	1	0	0	0	0	0	1	1	0	0	0	0	2	.04	
METHYL ISOBUTYL CARBINOL	1	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP=131.8 C
METHYL ISOBUTYL KETONE	1	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP=116.2 C
METHYL METHACRYLATE	1	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP=101 C
METHYL PARATHION	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
MINERAL SPIRITS	2	1	0	0	0	1	2	0	0	0	0	0	4	.08	
MONOCHLORO-DIFLUOROMETHANE	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP=-40.5 C
MONOETHANOLAMINE	3	0	0	0	0	0	1	2	0	0	0	0	3	.06	
MONISOPROPANOLAMINE	1	0	0	0	0	0	1	2	0	0	0	0	3	.06	
MORPHOLINE	1	1	0	0	0	1	1	2	0	0	0	0	5	.10	
MOTOR FUEL ANTI-KNOCK COMPOUNDS-LEAD ALKYL	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
NAPHTHA- COAL TAR	2	1	0	0	0	2	2	0	0	0	0	0	5	.10	BP=93-260 C
NAPHTHA- SOLVENT	2	1	0	0	0	1	2	0	0	0	0	0	4	.08	BP=138-155 C
NAPHTHA- STOODARD SOLVENT	2	1	0	0	0	1	2	0	0	0	0	0	4	.08	BP=168-198 C
NAPHTHA- VM&P (75% NAPHTHA)	2	1	0	0	0	1	2	0	0	0	0	0	4	.08	BP=93-149 C
NAPHTHALENE- MOLTEN	4	0	0	0	0	1	0	0	0	0	0	0	1	.02	
NICKEL SULFATE	3	0	0	0	0	0	2	1	0	0	1	0	4	.08	
NITRIC ACID	3	0	0	0	0	0	2	2	0	0	2	0	6	.12	
NITROBENZENE	4	0	0	0	0	0	1	0	0	0	0	0	1	.02	
NITROGEN TETROXIDE	3	0	0	0	0	0	1	2	0	0	1	0	4	.08	REACTS WITH WATER
NITROMETHANE	3	0	0	0	0	0	1	1	0	0	1	0	3	.06	

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION					CHEM. IDENTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RF/MW	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	POW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE IDENTIFIABILITY)		
NITROSYL CHLORIDE	1	2	0	0	0	0	1	2	0	0	2	0	0	7	.14	BP*-5.8 C REACTS	
NONANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
NONENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*135-140 C	
1-NONENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*147 C	
NONYLPHENOL	2	2	0	0	0	1	2	0	0	0	0	0	0	5	.10		
OCTANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
1-OCTENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*121.3 C	
OILS, CLARIFIED	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, CRAUDE	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, DIESEL	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, EDIBLE, CASTOR	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
OILS, EDIBLE, COTTONSEED	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
OILS, EDIBLE, FISH	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
OILS, EDIBLE, OLIVE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
OILS, EDIBLE, PEANUT	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
OILS, EDIBLE, SOYA BEAN	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
OILS, EDIBLE, VEGETABLE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
OILS, FUEL, NO. 1 (KEROSENE)	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, FUEL, NO. 1-D	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS FUEL, NO. 2	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, FUEL, NO. 2-D	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, FUEL, NO. 4	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, FUEL, NO. 5	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, FUEL, NO. 6	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, ABSORPTION	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, COAL TAR	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	BP*106-167 C	
OILS, MISCELLANEOUS, LUBRICATING	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, MINERAL	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12		

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION			CHEM. IDENTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIVIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE IDENTIFIABILITY)	
OILS, MISCELLANEOUS, MINERAL SEAL	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, MOTOR	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, MEATSFOOT	2	2	0	0	0	0	4	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, PENETRATING	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, RANGE	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, RESIN	2	2	0	0	0	1	2	0	0	0	0	0	5	.10		
OILS, MISCELLANEOUS, ROAD	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, ROSIN	2	2	0	0	0	1	2	0	0	0	0	0	5	.10		
OILS, MISCELLANEOUS, SPEARM	2	2	0	0	0	0	4	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, SPINDLE	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, SPRAY	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, TALL	2	2	0	0	0	1	2	0	0	0	0	0	5	.10		
OILS, MISCELLANEOUS, TANNER'S	2	2	0	0	0	0	4	0	0	0	0	0	6	.12		
OILS, MISCELLANEOUS, TRANSFORMER	2	2	0	0	0	2	2	0	0	0	0	0	6	.12		
OLEUM	3	0	0	0	0	0	2	2	0	0	0	0	4	.08	HIGHLY EXOTHERMIC DISSOLUTION	
OXALIC ACID	3	0	0	0	0	0	2	2	0	0	1	0	5	.10		
PARAFORMALDEHYDE	4	0	0	0	0	0	1	0	0	0	0	0	1	.02		
PENTACHLOROPHENOL	4	0	0	0	0	0	1	0	0	0	0	0	1	.02		
PENTADECANOL	2	2	0	0	0	0	4	0	0	0	0	0	6	.12		
PENTANE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP=36.1 C	
1-PENTENE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP=29.9 C	
PETROLATUM	2	2	0	0	0	0	4	0	0	0	0	0	6	.12		
PETROLEUM NAPHTHA	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP=97.2 C	
PHENOL	3	0	0	0	0	2	1	0	0	0	2	0	5	.10		
PHOSGENE	3	0	0	0	0	0	0	2	0	0	0	0	2	.04	BP=8.2 C REACTS	
PHOSPHORIC ACID	3	0	0	0	0	0	2	1	0	0	0	0	3	.06	BP>136 C	
PHOSPHORUS, RED	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
PHOSPHORUS, WHITE	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00		

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION											IN-SITU INSTRUMENTATION			CHEM. IDENTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	RDW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE IDENTIFIABILITY)		
SODIUM ALKYL SULFATES	1	1	0	0	0	0	2	2	0	0	1	0	0	6	.12		
SODIUM AMIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	REACTS VIOLENTLY WITH WATER	
SODIUM BISULFITE	3	0	0	0	0	0	2	2	0	0	0	0	0	4	.08		
SODIUM BOROHYDRIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	REACTS	
SODIUM CHLORATE	3	0	0	0	0	0	2	2	0	0	1	0	0	5	.10		
SODIUM CYANIDE	3	0	0	0	0	0	1	2	0	0	1	0	0	4	.08	MILD REACTION	
SODIUM DICHROMATE	3	1	0	0	0	0	2	1	0	0	2	0	0	6	.12		
SODIUM FERROCYANIDE	3	1	0	0	0	0	1	1	0	0	2	0	0	5	.10		
SODIUM FLUORIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04		
SODIUM HYDRIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	VIGOROUS REACTION	
SODIUM HYDROXIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	VIGOROUS REACTION	
SODIUM HYPOCHLORITE	3	1	0	0	0	0	0	2	0	0	2	0	0	5	.10		
SODIUM SILICATE	3	0	0	0	0	0	1	2	0	0	0	0	0	3	.06		
SODIUM SULFIDE	3	1	0	0	0	0	0	2	0	0	2	0	0	5	.10		
SODIUM SILFITE	3	1	0	0	0	0	1	1	0	0	2	0	0	5	.10		
SORBITOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
STYRENE	2	2	0	0	0	0	2	2	0	0	0	0	0	6	.12	BP=145.2 C	
SULFOLANE	3	0	0	0	0	0	2	0	0	0	0	0	0	2	.04		
SULFUR (LIQUID)	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
SULFUR DIOXIDE	3	0	0	0	0	0	2	2	0	0	0	0	0	4	.08	BP=-10 C REACTS	
SULFUR MONOCHLORIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2	.04	REACTS VIOLENTLY WITH WATER	
SULFURIC ACID	3	0	0	0	0	0	2	2	0	0	0	0	0	4	.08	REACTS	
SULFURIC ACID, SPENT	3	0	0	0	0	0	2	2	0	0	1	0	0	5	.10		
SULFURYL CHLORIDE	3	0	0	0	0	0	2	2	0	0	0	0	0	4	.08	VIGOROUS REACTION	
TALLOW	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
TETRACHLOROETHYLENE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TETRADECANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	FP=37.6 C	
1-TETRADECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		

TABLE 4.4. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													IN-SITU INSTRUMENTATION													CHEM. IDENTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE	RELATIVE IDENTIFIABILITY													
TETRAETHYL LEAD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00					
TETRAHYDROFURAN	1	0	0	0	0	0	2	0	0	0	0	0	0	2											.04				
TETRAHYDRONAPHTHALENE	2	2	0	0	0	2	2	0	0	0	0	0	0	6											.12				
TETRAMETHYL LEAD	4	0	0	0	0	0	0	0	0	0	0	0	0	0											0.00				
TITANIUM TETRACHLORIDE	3	0	0	0	0	0	0	2	0	0	0	0	0	2											.04	REACTS			
TOLUENE	2	2	0	0	0	2	2	0	0	0	0	0	0	6											.12	BP=110.6 C			
TOLUENE 2,4-DIISOCYANATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0											0.00				
TOXAPHENE	4	0	0	0	0	0	1	0	0	0	0	0	0	1											.02	FP=60-95 C			
TRICHLOROETHANE	4	0	0	0	0	0	1	0	0	0	0	0	0	1											.02				
TRICHLOROETHYLENE	4	0	0	0	0	0	1	0	0	0	0	0	0	1											.02				
TRICHLOROFUOROMETHANE	4	0	0	0	0	0	1	0	0	0	0	0	0	1											.02	BP=23.0 C			
TRICHLOROPHENOL	4	0	0	0	0	0	1	0	0	0	0	0	0	1											.02				
TRICRESYL PHOSPHATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0											0.00				
TRIDECANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6											.12				
1-TRIDECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6											.12				
TRIETHANOLAMINE	3	0	0	0	0	0	2	0	0	0	0	0	0	2											.04				
TRIETHYLAMINE	1	0	0	0	0	0	0	0	0	0	0	0	0	0											0.00				
TRIETHYLBENZENE	2	2	0	0	0	2	2	0	0	0	0	0	0	6											.12				
TRIETHYLENE GLYCOL	3	0	0	0	0	0	2	0	0	0	0	0	0	2											.04				
TRIETHYLENETETRAMINE	1	2	0	0	0	0	2	1	0	0	2	0	0	7											.14				
TRIMETHYLAMINE	1	0	0	0	0	0	2	0	0	0	0	0	0	2											.04	BP=2.9 C			
TURPENTINE	2	2	0	0	0	1	2	0	0	0	0	0	0	5											.10	BP=150-160 C			
UNDECANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6											.12	FP=15.9 C			
1-UNDECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6											.12				
UREA	3	0	0	0	0	0	2	0	0	0	0	0	0	2											.04				
VALERALDEHYDE	1	2	0	0	0	0	2	0	0	0	0	0	0	4											.08	BP=143 C			
VINYL ACETATE	1	2	0	0	0	0	2	0	0	0	0	0	0	4											.08	BP=72.9 C			
VINYL CHLORIDE	2	2	0	0	0	0	4	0	0	0	0	0	0	6											.12	BP=13.6 C			

TABLE 4.4. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP													ROW SUMS	CHEM. IDENTIFIABILITY	COMMENTS	
	OPTICAL REFLECTANCE						REMOTE OR IN-SITU INSTRUMENTATION						IN-SITU INSTRUMENTATION				
	THERMAL INFRARED	PASSIVE INFRARED	PROPR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND						
VINYLDIENE CHLORIDE, INHIBITED	4	0	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
VINYLTOLUENE	2	2	0	0	0	2	2	0	0	0	0	0	0	0	6	.12	BP=167.7 C
WAXES* CARNAUBA	2	2	0	0	0	1	2	0	0	0	0	0	0	0	5	.10	
WAXES* PARAFFIN	2	2	0	0	0	1	2	0	0	0	0	0	0	0	5	.10	
M-XYLENE	2	2	0	0	0	2	2	0	0	0	0	0	0	0	6	.12	BP=191.9 C
O-XYLENE	2	2	0	0	0	2	2	0	0	0	0	0	0	0	6	.12	BP=144 C
P-XYLENE	2	2	0	0	0	2	2	0	0	0	0	0	0	0	6	.12	BP=136.3 C
ZINC CHLORIDE	3	0	0	0	0	0	1	1	0	0	0	0	0	0	2	.04	
COLUMN SUMS	332	0	0	0	124	718	147	0	0	91	0	0					
SUMS/MAXIMUM POSSIBLE VALUE	.20	0.0	0.0	0.0	.07	.44	.09	0.0	0.0	.05	0.0	0.0					
SUMS/MAXIMUM VALUE	.46	0.0	0.0	0.0	.17	1.0	.20	0.0	0.0	.12	0.0	0.0					RELATIVE SYSTEM EFFECTIVENESS
NUMBER OF CHEMICALS PROBABLY IDENTIFIABLE	0	0	0	0	0	69	0	0	0	0	0	0					

techniques which have non-zero values of Relative System Effectiveness are considered to be capable only of "possible" identification or identification under special circumstances. In many cases, these systems will provide a coarse identification capability or they may be capable of identifying a specific chemical in a small list of known possibilities.

4.4 QUANTIFIABILITY

The term "quantifiability" has two meanings in this analysis. The first is the determination of the volume of the chemical in the spill or the thickness of a slick. This meaning would apply, for example, in cases where a remote sensing system such as a fluorosensor or a microwave radiometer is used to quantify a chemical which floats on, or at least remains concentrated near, the water surface. The second meaning is the determination of the concentration of a dissolved chemical at a given location. This kind of a measurement is important in monitoring the dispersion of spill and its toxicity. It could apply, for example, to a Raman scattering measurement or to a measurement by an in situ technique.

Quantification of a spilled chemical, like identification, requires that the chemical be detectable. But a sensing device need not be capable of identifying a chemical in order to be able to quantify it. For this reason, the detectability values given in the Chemical Detectability Chart are again used as the basis for estimating chemical quantifiability. A quantifiability factor, Q, was defined as follows:

- 2 = probably effective for chemical quantification;
- 1 = possibly effective for chemical quantification; and
- 0 = probably ineffective for chemical quantification.

For a given sensing system, the value of Q depends on the accessibility group of the chemical to be identified. The assigned values of Q for all system/accessibility group combinations are given in Table 4.5.

TABLE 4.5. Quantification Factors

ACCESSIBILITY GROUP	REMOTE OR IN SITU INSTRUMENTATION						IN SITU INSTRUMENTATION					
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTRO-CONDUCTIVITY	REDUCTION-OXIDATION POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND
1	1	0	0	0	1	1	2	1	1	2	0	0
2	1	0	1	0	2	2	0	0	0	0	0	0
3	1	0	0	0	1	1	2	1	1	2	0	0
4	0	0	0	0	1	1	0	0	0	0	0	0

The following Chemical Quantifiability Chart, Table 4.6, presents, in the form of a numerical matrix, estimates of the relative potential effectiveness of each of the twelve sensing techniques for quantifying each of the CHRIS chemicals. Each matrix element is the product of the corresponding element in the Detectability Chart and the appropriate value of Q. In addition, each of the products has been divided by 2 in order to make the range of the possible values (0,1,2,4) equal to the range of values in the Detectability Chart. A 4 indicates that quantification is probable; a 1 or a 2 indicates that quantification may be possible under certain circumstances; and a 0 indicates that quantification is unlikely.

The matrix elements are summed across the rows. In the column labeled SUMS/MAXIMUM POSSIBLE VALUE, the row sums are divided by 48 to provide a numerical ranking of the relative potential quantifiability of the chemicals on a scale from 0 to 1.

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OCT 76 G A SANDNESS, J F WASHBURN, S B AILES DOT-CG-54323-A
USCG-D-114-76

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The column sums and the normalized values listed at the bottom of the last page of the chart provide a ranking of the relative effectiveness of each of the sensing techniques for the complete range of CHRIS chemicals. The maximum possible column sum is 1600, corresponding to a sensing system which can potentially quantify all 400 of the chemicals listed. Values for the row labeled NUMBER OF CHEMICALS PROBABLY QUANTIFIABLE were derived by counting the 4's in each of the system columns.

An apparent peculiarity of these results is that although Raman Scattering has high Column Sums and Relative System Effectiveness values, it is judged capable of "probably" quantifying only 69 of the 400 CHRIS chemicals. Similarly, Optical Reflectance is considered to be incapable of "probably" quantifying any of the CHRIS chemicals. The high relative effectiveness rankings for these and other sensing methods are a result of their capability for "possibly" quantifying many of the CHRIS chemicals.

System	Column Sum	Relative System Effectiveness	Number of Chemicals Probably Quantifiable
Optical Reflectance	1600	1.00	0
Raman Scattering	1500	0.94	69
Thermal Spectrometry	1400	0.88	100
Mass Spectrometry	1300	0.81	150
Gas Chromatography	1200	0.75	200
Ultraviolet Spectrometry	1100	0.69	250
Infrared Spectrometry	1000	0.63	300
Visible Spectrometry	900	0.56	350
Acoustic Spectrometry	800	0.50	400
Electromagnetic Interference	700	0.44	400
Thermal Imaging	600	0.38	400
Thermal Spectrometry	500	0.31	400
Thermal Spectrometry	400	0.25	400
Thermal Spectrometry	300	0.19	400
Thermal Spectrometry	200	0.13	400
Thermal Spectrometry	100	0.06	400
Thermal Spectrometry	0	0.00	400

TABLE 4.6. Chemical Quantifiability Chart

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. QUANTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PMOPR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS MAXIMUM POSSIBLE VALUE	RELATIVE QUANTIFIABILITY	
ACETALDEHYDE	3	0	0	0	0	0	1	1	1	0	2	0	0	5	.10		
ACETIC ACID	3	0	0	0	0	0	1	1	1	0	4	0	0	7	.14		
ACETIC ANHYDRIDE	3	0	0	0	0	0	1	1	1	1	4	0	0	8	.16		
ACETONE	1	1	0	0	0	0	1	0	0	0	4	0	0	6	.12		
ACETONE CYANOHYDRIN	1	0	0	0	0	0	0	2	1	0	0	0	0	3	.06		
ACETONITRILE	1	1	0	0	0	0	1	0	0	0	2	0	0	4	.08		
ACETOPHENONE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02		
ACETYLENE	2	0	0	0	0	0	4	0	0	0	0	0	0	4	.08	BP=84.C	
ACRYLIC ACID	3	0	0	0	0	0	1	1	1	0	2	0	0	5	.10		
ACRYLONITRILE	1	1	0	0	0	0	0	0	0	0	2	0	0	3	.06		
ADIPONITRILE	2	2	0	1	0	0	2	0	0	0	0	0	0	5	.10		
ALDRIN	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
ALLYL ALCOHOL	1	0	0	0	0	0	1	2	1	0	0	0	0	4	.08		
ALLYL CHLORIDE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP=45 C	
ALUMINUM CHLORIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	VIOLENT REACTION WITH WATER	
ALUMINUM FLUORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
AMINOETHYLETHANOLAMINE	3	0	0	0	0	0	1	1	1	0	0	0	0	3	.06		
AMMONIA, ANHYDROUS	1	0	0	0	0	0	0	4	2	1	0	0	0	7	.14	BP=-33.4 C	
AMMONIUM HYDROXIDE (<26% AQUEOUS AMMONIA)	1	0	0	0	0	0	0	4	2	1	0	0	0	7	.14		
AMMONIUM NITRATE	3	0	0	0	0	0	0	1	1	0	2	0	0	4	.08		
AMMONIUM PERCHLORATE	3	1	0	0	0	0	0	1	1	0	4	0	0	7	.14		
AMMONIUM SULFATE	3	1	0	0	0	0	0	1	1	0	4	0	0	7	.14		
AMYL ACETATE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=146 C	
N-AMYL ALCOHOL	1	0	0	0	0	0	1	0	1	0	0	0	0	2	.04		
ANILINE	3	0	0	0	0	2	0	1	1	0	2	0	0	6	.12		
ANTIMONY TRIFLUORIDE	3	1	0	0	0	0	0	1	1	1	4	0	0	8	.16		
ASPHALT	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02		
ASPHALT BLENDING STOCKS+ ROOFERS FLUX	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02		

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION											IN-SITU INSTRUMENTATION			CHEM. QUANTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE INFRARED	PASIR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROY SUMS	SUMS/MAXIMUM POSSIBLE VALUE	RELATIVE QUANTIFIABILITY	
ASPHALT BLENDING STOCKS* STRAIGHT RUN RESIDUE	4	0	0	0	0	1	0	0	0	0	0	0	1	.02			
BARIUM CARBONATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00			
BENZALDEHYDE	2	2	0	1	0	2	2	0	0	0	0	0	7	.14			
BENZENE	2	2	0	0	0	4	2	0	0	0	0	0	8	.16	BP*66.1 C		
BENZENE HEXACHLORIDE	4	0	0	0	0	1	0	0	0	0	0	0	1	.02			
BENZOIC ACID	4	0	0	0	0	1	1	0	0	0	0	0	2	.04			
BENZOYL CHLORIDE	4	0	0	0	0	1	1	0	0	0	0	0	2	.04	REACTS SLOWLY		
BISPHENOL A	4	0	0	0	0	1	1	0	0	0	0	0	2	.04			
BROMINE	3	1	0	0	0	0	0	1	1	2	4	0	9	.18			
BUTADIENE, INHIBITED	2	2	0	2	0	0	2	0	0	0	0	0	6	.12	BP*-4.4 C		
BUTANE	2	2	0	2	0	0	4	0	0	0	0	0	8	.16	BP*-0.48 C		
1,4-BUTANEDIOL	3	0	0	0	0	0	1	0	0	0	0	0	1	.02			
1,4-BUTENEDIOL	3	0	0	0	0	0	1	0	0	0	2	0	3	.06			
N-BUTYL ACETATE	1	1	0	0	0	0	1	0	1	0	0	0	3	.06			
SEC-BUTYL ACETATE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*112 C		
N-BUTYL ACRYLATE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*146.8 C		
ISO-BUTYL ACRYLATE	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*137.9 C		
N-BUTYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP*117 C		
SEC-BUTYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP*98.5 C		
TEAT-BUTYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP*82.6 C		
BUTYLENE	2	2	0	2	0	0	4	0	0	0	0	0	8	.16	BP*-6.3 C		
TEAT-BUTYL HYDROPEROXIDE	1	0	0	0	0	0	1	0	1	2	2	0	6	.12	DECOMPOSES		
1,4-BUTYNEEDIOL	3	1	0	0	0	0	1	0	0	0	4	0	6	.12			
N-BUTYRALDEHYDE	1	0	0	0	0	0	1	0	1	1	0	0	3	.06	BP*74.8 C		
ISO-BUTYRALDEHYDE	1	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP*64.1 C		
CADMIUM CHLORIDE	3	0	0	0	0	0	0	1	1	1	0	0	3	.06			
CALCIUM CARBIDE	3	0	0	0	0	0	1	0	0	0	0	0	1	.02	REACTIVE, FORMS GAS AND WHITE PPT		
CALCIUM FLUORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0.00			

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION					CHEM. QUANTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	MOON	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ION SULFS	SUM OF ALL IN-SITU POSSIBLE VALUES		
CALCIUM HYDROXIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
CALCIUM HYPOCHLORITE	3	0	0	0	0	0	1	1	1	0	0	0	3		.06		
CALCIUM OXIDE	3	0	0	0	0	0	2	2	1	0	0	0	5		.10		REACTS VIOLENTLY WITH WATER
CAMPHOR OIL	2	2	0	1	0	2	2	0	0	0	0	0	7		.14		
CARBARYL	4	0	0	0	0	1	0	0	0	0	0	0	1		.02		
CARBOLIC OIL	3	0	0	0	0	2	0	0	0	0	2	0	4		.06		
CARBON BISULFIDE	4	0	0	0	0	0	1	0	0	0	0	0	1		.02		
CARBON TETRACHLORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0		0.00		
CAUSTIC POTASH SOLUTION	3	0	0	0	0	0	2	2	2	0	0	0	6		.12		
CAUSTIC SODA SOLUTION	3	0	0	0	0	0	2	2	2	0	0	0	6		.12		
CHLORINE	3	1	0	0	0	0	0	1	1	1	4	0	8		.16		BP=34.1 C
CHLOROBENZENE	4	0	0	0	0	1	0	0	0	0	0	0	1		.02		
CHLOROFORM	4	0	0	0	0	0	0	0	0	0	0	0	0		0.00		
CHLOROHYDRINS (CRUDE)	3	0	0	0	0	1	0	0	0	0	2	0	3		.06		
CHLOROSULFONIC ACID	3	0	0	0	0	0	2	2	2	0	0	0	6		.12		REACTS VIOLENTLY WITH WATER
CHROMIC ANHYDRIDE	3	1	0	0	0	0	0	2	2	2	4	0	11		.22		
COPPER SULFATE	3	1	0	0	0	0	0	1	1	0	4	0	7		.14		
CORN SYRUP	3	0	0	0	0	1	0	0	0	0	0	0	1		.02		
CRESOLS	3	1	0	0	0	2	0	0	0	0	4	0	7		.14		
CROTONALDEHYDE	1	2	0	0	0	0	1	0	0	0	4	0	7		.14		BP=102.2 C
CUMENE	2	2	0	0	0	4	2	0	0	0	0	0	8		.16		BP=152.4 C
CYANOGEN BROMIDE	3	0	0	0	0	0	0	1	1	1	0	0	3		.06		
CYANOGEN CHLORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0		0.00		BP=13.1 C
CYCLOHEXANE	2	2	0	0	0	0	4	0	0	0	0	0	6		.12		BP=80.7 C
CYCLOHEXANOL	1	2	0	0	0	0	1	0	0	0	2	0	5		.10		
CYCLOHEXANONE	1	0	0	0	0	0	1	0	0	0	0	0	1		.02		
CYCLOHEXYLAMINE	1	0	0	0	0	0	1	4	2	1	0	0	8		.16		
DDT	4	0	0	0	0	0	0	0	0	0	0	0	0		0.00		

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. QUANTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS		
DECALDEHYDE	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	
1-DECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	
N-DECYL ALCOHOL	2	2	0	1	0	0	2	0	0	0	0	0	0	5	.10	
DEXTRASE SOLUTION	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
DIACETONE ALCOHOL	1	0	0	0	0	0	1	0	0	0	2	0	0	3	.06	
DIBENZOYL PEROXIDE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	REACTIVE WITH SUSPENDED SOLIDS
DIBUTYL PHTHALATE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
O-DICHLOROBENZENE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
P-DICHLOROBENZENE	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
DICHLORODIFLUOROMETHANE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP*-29.4 C
DICHLOROMETHANE	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
2,4-DICHLOROPHENOL	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
DICHLOROPROPANE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
DICHLOROPROPENE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
DICYCLOPENTADIENE	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.06	
DIETANOLAMINE	3	0	0	0	0	0	1	1	1	0	0	0	0	3	.06	
DIETHYLAMINE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*53.5 C
DIETHYLBENZENE	2	2	0	0	0	0	4	2	0	0	0	0	0	8	.16	
DIETHYLCARBONATE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP*126.6 C
DIETHYLENE GLYCOL	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
DIETHYLENE GLYCOL DIMETHYL ETHER	1	0	0	0	0	0	6	1	0	0	0	0	0	1	.02	
DIETHYLENE GLYCOL MONOETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
DIETHYLENE GLYCOL MONOMETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
1,8-DIETHYLENETRIAMINE	1	1	0	0	0	0	1	2	1	0	2	0	0	7	.14	
DIISOBUTYLCARBONOL	2	1	0	1	0	0	2	0	0	0	0	0	0	4	.06	
DIISOBUTYLENE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*161.5 C
DIISOPROPANOLAMINE	1	0	0	0	0	0	0	2	1	0	0	0	0	3	.06	
DIMETHYLAMINE	1	0	0	0	0	0	1	2	1	0	0	0	0	4	.06	BP*6.9 C

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. QUANTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP		OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RFID/RF	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE	
DIMETHYLFORMAMIDE	1	2	0	0	0	0	1	2	1	0	4	0	0	10	.20		
1,1-DIMETHYLHYDRAZINE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
DIMETHYL SULFATE	3	0	0	0	0	0	0	1	1	0	0	0	0	2	.04		
DIMETHYL SULFOXIDE	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
2,4-DINITROANILINE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
2,4-DINITROPHENOL	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
DIOCTYL ADIPATE	2	1	0	1	0	0	4	0	0	0	0	0	0	6	.12		
DIOCTYL PHTHALATE	2	1	0	1	0	2	2	0	0	0	0	0	0	6	.12		
1,4-DIOXANE	3	0	0	0	0	1	1	0	0	0	0	0	0	2	.04		
DIPHENYL METHANE-DIISOCYANATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
DIPROPYLENE GLYCOL	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
DISTILLATES-FLASHED FEED STOCKS	2	1	0	0	0	2	2	0	0	0	0	0	0	5	.10	BP=14-135 C	
DISTILLATES STRAIGHT RUN	2	1	0	0	0	2	2	0	0	0	0	0	0	5	.10	BP=14-135 C	
DODECANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
DODECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
1-DODECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
DOWTHAM	2	2	0	0	0	0	4	2	0	0	0	0	0	6	.16		
EPICHLOROHYDRIN	3	0	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP=115.2 C	
EPOXIDIZED VEGETABLE OILS	2	2	0	2	0	2	2	0	0	0	0	0	0	6	.16		
ETHANE	2	1	0	2	0	0	2	0	0	0	0	0	0	5	.10	BP=-88.6 C	
ETHOXYLATED DODECANOL	1	1	0	0	0	0	0	0	0	2	0	0	0	3	.06		
ETHOXYLATED PENTADECANOL	1	1	0	0	0	0	0	0	0	2	0	0	0	3	.06		
ETHOXYLATED TETRADECANOL	1	1	0	0	0	0	0	0	0	2	0	0	0	3	.06		
ETHOXYLATED TRIDECANOL	1	1	0	0	0	0	0	0	0	2	0	0	0	3	.06		
ETHOXY TRIGLYCOL	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
ETHYL ACETATE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP=77 C	
ETHYL ACRYLATE	1	0	0	0	0	0	0	1	0	0	0	0	0	1	.02	BP=85.6 C	
ETHYL ALCOHOL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEM. QUANTIFIABILITY	COMMENTS	
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RF/MW	FLUORESCENCE	RF/MW SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			RF/MW SENSITIVE VALUE
ETHYLBENZENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	BP=136.2 C
ETHYL BUTANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=146 C
ETHYL CHLORIDE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	BP=12.2 C
ETHYLENE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	BP=-183.7 C
ETHYLENE CYANOHYDRIN	3	0	0	0	0	0	0	0	0	2	0	0	2	.04		
ETHYLENEDIAMINE	1	0	0	0	0	0	1	2	1	1	0	0	0	5	.10	
ETHYLENEDIAMINE TETRAACETIC ACID	2	2	0	1	0	0	2	0	0	0	0	0	0	5	.10	
ETHYLENE DIBROMIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
ETHYLENE DICHLORIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
ETHYLENE GLYCOL	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
ETHYLENE GLYCOL DIMETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP=85.2 C
ETHYLENE GLYCOL MONOBUTYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
ETHYLENE GLYCOL MONOETHYL ETHER	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
ETHYLENE GLYCOL MONOETHYL ETHER ACETATE	1	1	0	0	0	0	0	0	0	0	0	0	0	1	.02	
ETHYLENE GLYCOL MONOMETHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
ETHYLENEIMINE	1	0	0	0	0	0	1	4	2	2	0	0	0	9	.18	
ETHYLENE OXIDE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP=18.6 C
ETHYL ETHER	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP=34.6 C
2-ETHYL HEXANOL	2	2	0	1	0	0	2	0	0	0	0	0	0	5	.10	
ETHYL HEXYL TALLATE	2	2	0	1	0	0	2	0	0	0	0	0	0	5	.10	
2-ETHYL-3-PROPYLACROLEIN	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08	
FERROUS SULFATE	3	0	0	0	0	0	0	1	1	1	2	0	0	5	.10	
FLUORINE	1	1	0	0	0	0	0	4	2	2	0	0	0	9	.18	BP=-188 C REACTS
FORMALDEHYDE SOLUTION	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
FORMIC ACID	3	0	0	0	0	0	1	2	2	1	0	0	0	6	.12	
FURFURAL	3	1	0	0	0	0	1	0	0	0	4	0	0	6	.12	
GAS OIL - CRACKED	2	2	0	0	0	0	2	2	0	0	0	0	0	6	.12	
GASOLINES AUTOMOTIVE (<4.280 LEAD/GAL)	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=68-188 C

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. QUANTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PROPR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	POW SUMS		
GASOLINES* AVIATION (<4.860 LEAD/GAL)	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*71-171 C	
GASOLINES* CASINGHEAD	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINES* POLYMER	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINES* STRAIGHT RUN	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINE BLENDING STOCKS* REFORMATES	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*14-135 C	
GASOLINE BLENDING STOCKS* ALKYLATES	2	2	0	0	0	0	4	0	0	0	0	0	6	.12	BP*14-135 C	
GLYCERINE	3	0	0	0	0	0	1	0	0	0	0	0	1	.02		
GLYCIDYL METHACRYLATE	2	2	0	1	0	0	2	0	0	0	0	0	5	.10		
HEPTANE	2	1	0	0	0	0	4	0	0	0	0	0	5	.10	BP*90.4 C	
HEPTANOL	2	2	0	1	0	0	4	0	0	0	0	0	7	.14		
1-HEPTENE	2	1	0	1	0	0	2	0	0	0	0	0	4	.08	BP*83.6 C	
HEXAMETHYLENEDIAMINE	1	0	0	0	0	0	1	2	1	0	0	0	4	.08		
HEXAMETHYLENETETRAMINE	3	0	0	0	0	0	1	1	1	0	2	0	5	.10		
HEXANE	2	1	0	0	0	0	4	0	0	0	0	0	5	.10	BP*68.7 C	
HEXANOL	2	2	0	0	0	0	2	0	0	0	0	0	4	.08		
1-HEXENE	2	1	0	0	0	0	4	0	0	0	0	0	5	.10	BP*69.5 C	
HEXYLENE GLYCOL	1	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
HYDRAZINE	3	0	0	0	0	0	1	1	1	0	0	0	3	.06		
HYDROCHLORIC ACID	3	0	0	0	0	0	0	2	2	2	0	0	6	.12		
HYDROFLUORIC ACID	3	0	0	0	0	0	0	2	2	2	0	0	6	.12		
HYDROGEN CHLORIDE	3	0	0	0	0	0	0	2	1	2	0	0	5	.10	BP*-85 C REACTS	
HYDROGEN CYANIDE	1	1	0	0	0	0	0	2	1	1	2	0	7	.14	BP*25.7 C MODERATE REACTION	
HYDROGEN FLUORIDE	1	0	0	0	0	0	0	4	1	2	0	0	7	.14	BP*19.5 C	
HYDROGEN PEROXIDE	3	0	0	0	0	0	0	1	1	1	0	0	3	.06		
HYDROGEN SULFIDE	2	0	0	2	0	0	2	0	0	0	0	0	4	.08	BP*-88.4 C	
ISOPHYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	1	.02		
ISOBUTANE	2	1	0	2	0	0	4	0	0	0	0	0	7	.14	BP*-11.0 C	
ISOBUTYL ACETATE	2	1	0	0	0	0	2	0	0	0	0	0	3	.06	BP*117.3 C	

TABLE 4.6. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP													ROW SUMS	CHEM. QUANTIFIABILITY	COMMENTS
	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE QUANTIFIABILITY)			
ISOBUTYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
ISOBUTYLENE	2	1	0	2	0	0	2	0	0	0	0	0	0	5	.10	BP*-6.9 C
ISODECYL ALCOHOL	2	2	0	1	0	0	2	0	0	0	0	0	0	5	.10	
ISODECALDEHYDE	2	1	0	1	0	0	2	0	0	0	0	0	0	4	.08	
ISOMEXANE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*60.3 C
ISOOCTYL ALCOHOL	2	0	0	1	0	0	2	0	0	0	0	0	0	3	.06	
ISOOCTALDEHYDE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP*153-176 C
ISOPENTANE	2	2	0	2	0	0	4	0	0	0	0	0	0	6	.16	BP*27.9 C
ISOPRENE	2	2	0	2	0	0	4	0	0	0	0	0	0	6	.16	BP*34.1 C
ISOPROPYL ACETATE	1	1	0	0	0	0	1	0	1	0	0	0	0	3	.06	BP*86.5 C
ISOPROPYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
JET FUELS* JP-1 (KEROSENE)	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	
JET FUELS* JP-3	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	
JET FUELS* JP-4	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	
JET FUELS* JP-5 (KEROSENE HEAVY)	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	
KEROSENE	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	
LATEX LIQUID SYNTHETIC	3	1	0	0	0	0	0	0	0	4	0	0	0	5	.10	
LAURYL MERCAPTAN	2	2	0	0	0	0	2	0	0	0	0	0	0	4	.08	
LEAD ARSENATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
LINEAR ALCOHOLS (12-15 CARBONS)	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	
LIQUEFIED NATURAL GAS	2	1	0	2	0	0	4	0	0	0	0	0	0	7	.14	BP*-161 C
LIQUEFIED PETROLEUM GAS	2	1	0	2	0	0	2	0	0	0	0	0	0	5	.10	BP*-48 C
LITHIUM ALUMINUM HYDRIDE	1	0	0	0	0	0	0	4	2	2	0	0	0	8	.16	REACTS VIOLENTLY WITH WATER
MALATHION	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02	
MALEIC ANHYDRIDE	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
MERCURY	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
METHANE	2	1	0	2	0	0	2	0	0	0	0	0	0	5	.10	BP*-161.5 C
METHANESULFONIC ACID, SODIUM SALTS	1	1	0	0	0	0	0	2	1	0	2	0	0	6	.12	

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. QUANTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE QUANTIFIABILITY)		
METHYL ACRYLATE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP=88.6 C	
METHYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
METHYL AMYL ACETATE	2	1	0	0	0	0	2	0	0	0	0	0	0	3	.06	BP=146.2 C	
METHYL AMYL ALCOHOL	1	0	0	0	0	0	0	0	1	0	0	0	0	1	.02	BP=131.8 C	
METHYL BROMIDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP=3.6 C	
METHYL CHLORIDE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	BP=-24.2 C	
METHYL ETHYL KETONE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
METHYLETHYLPIRIDINE	1	0	0	0	0	0	0	2	1	0	0	0	0	3	.06		
METHYL ISOBUTYL CARBINOL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP=131.8 C	
METHYL ISOBUTYL KETONE	1	1	0	0	0	0	1	0	0	0	0	0	0	2	.04	BP=116.2 C	
METHYL METHACRYLATE	1	1	0	0	0	0	1	0	0	0	0	0	0	2	.04	BP =101 C	
METHYL PARATHION	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
MINERAL SPIRITS	2	1	0	1	0	2	2	0	0	0	0	0	0	6	.12		
MONOCHLORODIFLUOROMETHANE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	BP=-40.5 C	
MONOETHANOLAMINE	3	0	0	0	0	0	0	2	2	1	0	0	0	5	.10		
MONOISOPROPANOLAMINE	1	0	0	0	0	0	0	4	2	1	0	0	0	7	.14		
MORPHOLINE	1	1	0	0	0	1	0	4	2	1	0	0	0	9	.18		
MOTOR FUEL ANTI-KNOCK COMPOUNDS-LEAD ALKYLs	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
NAPHTHA- COAL TAR	2	1	0	1	0	4	2	0	0	0	0	0	0	8	.16	BP=83-260 C	
NAPHTHA- SOLVENT	2	1	0	1	0	2	2	0	0	0	0	0	0	6	.12	BP=130-135 C	
NAPHTHA- STOODARD SOLVENT	2	1	0	1	0	2	2	0	0	0	0	0	0	6	.12	BP=160-189 C	
NAPHTHA- VMAP (75% NAPHTHA)	2	1	0	1	0	2	2	0	0	0	0	0	0	6	.12	BP=85-140 C	
NAPHTHALENE, MOLTEN	4	0	0	0	0	1	0	0	0	0	0	0	0	1	.02		
NICKEL SULFATE	3	0	0	0	0	0	1	1	1	1	2	0	0	6	.12		
NITRIC ACID	3	0	0	0	0	0	1	2	2	2	4	0	0	11	.22		
NITROBENZENE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
NITROGEN TETROXIDE	3	0	0	0	0	0	0	2	2	2	2	0	0	8	.16	REACTS WITH WATER	
NITROMETHANE	3	0	0	0	0	0	0	1	1	0	2	0	0	4	.08		

TABLE 4.6. (Continued)

CHEMICAL NAME	ACCESSIBILITY GROUP		REMOTE OR IN-SITU INSTRUMENTATION							IN-SITU INSTRUMENTATION					CHEM. QUANTIFIABILITY		COMMENTS
	OPTICAL	REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RADAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	RON SUMS	SUMS MAXIMUM POSSIBLE VALUE	RELATIVE QUANTIFIABILITY	
NITROSYL CHLORIDE	1	2	0	0	0	0	0	4	2	1	4	0	0	13	.27	BP=-5.8 C REACTS	
NONANOL	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14		
NONENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=135-140 C	
1-NONENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=147 C	
NONYLPHENOL	2	2	0	2	0	2	2	0	0	0	0	0	0	8	.16		
OCTANOL	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14		
1-OCTENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	BP=121.9 C	
OILS, CLARIFIED	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18		
OILS, CRAUDE	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18		
OILS, DIESEL	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18		
OILS, EDIBLE, CASTOR	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
OILS, EDIBLE, COTTONSEED	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
OILS, EDIBLE, FISH	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
OILS, EDIBLE, OLIVE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
OILS, EDIBLE, PEANUT	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
OILS, EDIBLE, SOYA BEAN	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
OILS, EDIBLE, VEGETABLE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
OILS, FUEL, NO. 1 (KEROSENE)	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16		
OILS, FUEL, NO. 1-D	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16		
OILS, FUEL, NO. 2	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16		
OILS, FUEL, NO. 2-D	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16		
OILS, FUEL, NO. 4	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18		
OILS, FUEL, NO. 5	2	2	0	2	0	4	2	0	0	0	0	0	0	10	.20		
OILS, FUEL, NO. 6	2	2	0	2	0	4	2	0	0	0	0	0	0	10	.20		
OILS, MISCELLANEOUS, ABSORPTION	2	2	0	2	0	4	2	0	0	0	0	0	0	10	.20		
OILS, MISCELLANEOUS, CUVET TEST	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18	BP=166-167 C	
OILS, MISCELLANEOUS, LUBRICATING	2	2	0	2	0	4	2	0	0	0	0	0	0	10	.20		
OILS, MISCELLANEOUS, MINERAL	2	2	0	2	0	4	2	0	0	0	0	0	0	10	.20		

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEM. QUANTIFIABILITY	COMMENTS	
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RFID/R	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			ROV SUNS
OILS, MISCELLANEOUS* MINERAL SEAL	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18	
OILS, MISCELLANEOUS* MOTOR	2	2	0	2	0	4	2	0	0	0	0	0	0	10	.20	
OILS, MISCELLANEOUS* NEATSFOOT	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	
OILS, MISCELLANEOUS* PENETRATING	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18	
OILS, MISCELLANEOUS* RANGE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	
OILS, MISCELLANEOUS* RESIN	2	2	0	2	0	2	2	0	0	0	0	0	0	8	.16	
OILS, MISCELLANEOUS* ROAD	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18	
OILS, MISCELLANEOUS* ROSIN	2	2	0	2	0	2	2	0	0	0	0	0	0	8	.16	
OILS, MISCELLANEOUS* SPERM	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	
OILS, MISCELLANEOUS* SPINDLE	2	2	0	1	0	4	2	0	0	0	0	0	0	9	.18	
OILS, MISCELLANEOUS* SPRAY	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	
OILS, MISCELLANEOUS* TALL	2	2	0	2	0	2	2	0	0	0	0	0	0	8	.16	
OILS, MISCELLANEOUS* TANNER'S	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	
OILS, MISCELLANEOUS* TRANSFORMER	2	2	0	2	0	4	2	0	0	0	0	0	0	10	.20	
OLEUM	3	0	0	0	0	0	1	2	2	2	0	0	0	7	.14	HIGHLY EXOTHERMIC DISSOLUTION
OXALIC ACID	3	0	0	0	0	0	1	2	2	2	2	0	0	9	.18	
PARAFORMALDEHYDE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
PENTACHLOROPHENOL	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
PENTAOECANOL	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12	
PENTANE	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	BP*36.1 C
1-PENTENE	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	BP*29.9 C
PETROLATUM	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	
PETROLEUM NAPHTHA	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	BP*97.2 C
PHENOL	3	0	0	0	0	2	0	0	0	0	4	0	0	6	.12	
PHOSGENE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	BP*8.2 C REACTS
PHOSPHORIC ACID	3	0	0	0	0	0	1	1	1	1	0	0	0	4	.08	BP>130 C
PHOSPHORUS, RED	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
PHOSPHORUS, WHITE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION													CHEM. QUANTIFIABILITY	COMMENTS	
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	PRDAR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND			ROW SUMS
PHOSPHORUS OXYCHLORIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	REACTS WITH WATER
PHOSPHORUS PENTASULFIDE	3	0	0	0	0	0	0	1	1	1	0	0	0	3	.06	REACTS WITH WATER
PHOSPHORUS TRICHLORIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	REACTS VIOLENTLY WITH WATER
PHTHALIC ANHYDRIDE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	
POLYBUTENE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	
POLYCHLORINATED BIPHENYL	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
POLYPHOSPHORIC ACID	3	0	0	0	0	0	1	1	1	0	0	0	0	3	.06	REACTS WITH WATER
POLYPROPYLENE GLYCOL METHYL ETHER	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
POTASSIUM CYANIDE	3	0	0	0	0	0	0	2	2	2	2	0	0	8	.16	REACTS WITH WATER
POTASSIUM DICHROMATE	3	1	0	0	0	0	1	1	1	2	4	0	0	10	.20	
POTASSIUM HYDROXIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	EXOTHERMIC
POTASSIUM IODIDE	3	0	0	0	0	0	0	1	1	1	2	0	0	5	.10	
POTASSIUM PERNANGANATE	3	1	0	0	0	0	1	1	1	1	4	0	0	9	.18	
PROPANE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	BP*-42.1 C
PROPIONALDEHYDE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
PROPIONIC ACID	1	1	0	0	0	0	1	0	0	1	2	0	0	5	.10	
N-PROPYL ACETATE	1	1	0	0	0	0	1	0	0	0	0	0	0	2	.04	BP*101.6 C
N-PROPYL ALCOHOL	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
PROPYLENE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	BP*-47.7 C
PROPYLENE BUTYLENE POLYMER	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	
PROPYLENE GLYCOL	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
PROPYLENE GLYCOL METHYL ETHER	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	
PROPYLENE OXIDE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP*36.8 C
PROPYLENE TETRAMER	2	2	0	1	0	0	4	0	0	0	0	0	0	7	.14	
PYRIDINE	1	2	0	0	0	0	1	0	0	0	4	0	0	7	.14	
SILVER NITRATE	3	0	0	0	0	0	1	0	0	1	2	0	0	4	.08	
SODIUM	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	REACTS VIOLENTLY WITH WATER
SODIUM ALKYL-BENZENESULFONATES	1	1	0	0	0	1	0	4	2	2	2	0	0	12	.25	

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. QUANTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RAMAN	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE QUANTIFIABILITY)		
SODIUM ALKYL SULFATES	1	1	0	0	0	0	1	4	2	2	2	0	0	12	.25		
SODIUM AMIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	REACTS VIOLENTLY WITH WATER	
SODIUM BISULFITE	3	0	0	0	0	0	1	2	2	1	0	0	0	6	.12		
SODIUM BOROHYDRIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	REACTS	
SODIUM CHLORATE	3	0	0	0	0	0	1	2	2	2	2	0	0	9	.18		
SODIUM CYANIDE	3	0	0	0	0	0	0	2	2	2	2	0	0	8	.16	MILD REACTION	
SODIUM DICHROMATE	3	1	0	0	0	0	1	1	1	1	4	0	0	9	.18		
SODIUM FERROCYANIDE	3	1	0	0	0	0	0	1	1	0	4	0	0	7	.14		
SODIUM FLUORIDE	3	0	0	0	0	0	0	2	2	0	0	0	0	4	.08		
SODIUM HYDRIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	VIGOROUS REACTION	
SODIUM HYDROXIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	VIGOROUS REACTION	
SODIUM HYPOCHLORITE	3	1	0	0	0	0	0	2	2	2	4	0	0	11	.22		
SODIUM SILICATE	3	0	0	0	0	0	0	2	2	0	0	0	0	4	.08		
SODIUM SULFIDE	3	1	0	0	0	0	0	2	2	0	4	0	0	9	.18		
SODIUM SILFITE	3	1	0	0	0	0	0	1	1	0	4	0	0	7	.14		
SORBITOL	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
STYRENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	BP=145.2 C	
SULFOLANE	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
SULFUR (LIQUID)	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
SULFUR DIOXIDE	3	0	0	0	0	0	1	2	2	2	0	0	0	7	.14	BP=-10 C REACTS	
SULFUR MONOCHLORIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	REACTS VIOLENTLY WITH WATER	
SULFURIC ACID	3	0	0	0	0	0	1	2	2	2	0	0	0	7	.14	REACTS	
SULFURIC ACID, SPENT	3	0	0	0	0	0	1	2	2	2	2	0	0	9	.18		
SULFURYL CHLORIDE	3	0	0	0	0	0	1	2	2	2	0	0	0	7	.14	VIGOROUS REACTION	
TALLOW	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
TETRACHLOROETHYLENE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TETRADECANOL	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	FP=57.8 C	
1-TETRADECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION					CHEM. QUANTIFIABILITY	COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	PASSIVE MICROWAVE	RFDR	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	RON SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE QUANTIFIABILITY)		
TETRAETHYL LEAD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TETRAHYDROFURAN	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
TETRAHYDRONAPHTHALENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16		
TETRAMETHYL LEAD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TITANIUM TETRACHLORIDE	3	0	0	0	0	0	0	2	2	2	0	0	0	6	.12	REACTS	
TOLUENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	BP*110.6 C	
TOLUENE 2,4-DIISOCYANATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TOXAPHENE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	FP*60-95 C	
TRICHLOROETHANE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
TRICHLOROETHYLENE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
TRICHLOROFLUOROMETHANE	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP*23.8 C	
TRICHLOROPHENOL	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
TRICRESYL PHOSPHATE	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TRIDECANOL	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16		
1-TRIDECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
TRIETHANOLAMINE	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
TRIETHYLAMINE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00		
TRIETHYLBENZENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16		
TRIETHYLENE GLYCOL	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
TRIEthyLENETETRAMINE	1	2	0	0	0	0	1	2	1	0	4	0	0	10	.20		
TRIMETHYLAMINE	1	0	0	0	0	0	1	0	0	0	0	0	0	1	.02	BP*2.9 C	
TURPENTINE	2	2	0	0	0	2	2	0	0	0	0	0	0	6	.12	BP*150-160 C	
UNDECANOL	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	FP*15.9 C	
1-UNDECENE	2	2	0	0	0	0	4	0	0	0	0	0	0	6	.12		
UREA	3	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
VALERALDEHYDE	1	2	0	0	0	0	1	0	0	0	0	0	0	3	.06	BP*103 C	
VINYL ACETATE	1	2	0	0	0	0	1	0	0	0	0	0	0	3	.06	BP*72.9 C	
VINYL CHLORIDE	2	2	0	2	0	0	4	0	0	0	0	0	0	8	.16	BP*-13.8 C	

TABLE 4.6. (Continued)

CHEMICAL NAME	REMOTE OR IN-SITU INSTRUMENTATION										IN-SITU INSTRUMENTATION				CHEM. QUANTIFIABILITY		COMMENTS
	ACCESSIBILITY GROUP	OPTICAL REFLECTANCE	THERMAL INFRARED	POSITIVE MICROWAVE	RFID/R	FLUORESCENCE	RAMAN SCATTERING	ION-SELECTIVE ELECTRODES	ELECTROCONDUCTIVITY	REDOX POTENTIAL	OPTICAL ABSORPTIOMETRY	DISSOLVED OXYGEN	TOTAL OXYGEN DEMAND	ROW SUMS	SUMS/MAXIMUM POSSIBLE VALUE (RELATIVE QUANTIFIABILITY)		
VINYLDIENE CHLORIDE, INHIBITED	4	0	0	0	0	0	1	0	0	0	0	0	0	1	.02		
VINYLTOLUENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	BP*167.7 C	
WAXES* CARNAUBA	2	2	0	2	0	2	2	0	0	0	0	0	0	8	.16		
WAXES* PARAFFIN	2	2	0	2	0	2	2	0	0	0	0	0	0	8	.16		
M-XYLENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	BP*131.9 C	
O-XYLENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	BP*144 C	
P-XYLENE	2	2	0	0	0	4	2	0	0	0	0	0	0	8	.16	BP*136.9 C	
ZINC CHLORIDE	3	0	0	0	0	0	0	1	1	1	0	0	0	3	.06		
COLUMN SUMS	332	0	133	0	219	561	183	151	112	182	0	0					
SUMS/MAXIMUM POSSIBLE VALUE	.20	0.0	.00	0.0	.13	.35	.11	.09	.07	.11	0.0	0.0					
SUMS/MAXIMUM VALUE	.59	0.0	.23	0.0	.39	1.0	.32	.26	.19	.32	0.0	0.0				RELATIVE SYSTEM EFFECTIVENESS	
NUMBER OF CHEMICALS PROBABLY QUANTIFIABLE	0	0	0	0	36	69	12	0	0	26	0	0					

SECTION 5 CURRENT CAPABILITIES

5.1 DISCUSSION

The purpose of this section is to estimate the detection, identification, and quantification capabilities of currently available, or operational, water pollution sensing devices. The preceding analysis (Section 4) yielded estimates of the potential, relative detectability, identifiability, and quantifiability of the CHRIS chemicals. It also yielded estimates of the relative potential effectiveness of the twelve generalized sensing techniques. Precise quantitative determinations of chemical detectability, identifiability, and quantifiability and sensor capabilities require additional data, including instrument specifications, environmental conditions, and the results of laboratory and field research and testing programs. Most of this data is unavailable or beyond the scope of this study.

Each of the twelve generalized sensing techniques under consideration can encompass a wide variety of specific sensing devices, each operating in a different way and for a different purpose. Fluorescence sensors are a good example. They can be:

- for remote or in situ applications;
- active or passive;
- imaging, profiling, or fixed;
- airborne, ship-mounted, buoy mounted, shore mounted, or submerged (fixed or towed);
- single channel, ratioing, or multispectral.

Nevertheless, some of the generalized techniques for pollution sensing are inherently more sensitive than others. Estimated ranges of minimum detectable chemical concentrations or film thickness are given in Table 5.1 for the twelve sensing techniques. The values shown in the table apply mainly to the CHRIS chemicals that are listed as probably detectable in Table 4.2. They are not intended to be universally applicable.

TABLE 5.1. Detection Limits for Twelve Sensing Techniques

<u>Sensing Technique</u>	<u>Chemical Concentration or Film Thickness</u>
Optical Reflectance	10-1000 ppm, <1 μ m (oil)
Thermal IR	10 μ m (oil)
Passive Microwave	1000 ppm (fresh water), 1-100 μ m (oil)
Radar	>1 μ m (oil)
Fluorescence	.01-1 ppm (remote), <.1 ppb (in situ)
Raman Scattering	100-1000 ppm*
Ion-Selective Electrodes	pH 10^{-14} m, other ISE's 1 ppm
Electroconductivity	10-100 ppm
Redox Potential	10-100 ppm
Optical Absorptivity	.1-100 ppm
Dissolved Oxygen	1 ppm oxygen
Total Oxygen Demand	100 ppm

*Current experimental Raman techniques appear to have a detection limit of about 1-10 ppm, but require long integration times. The concentration range given in Table 5.1 is consistent with the measurement speeds of the other systems and with the practical requirements of pollution monitoring.

The criteria used to construct Tables 4.2, 4.4, and 4.6 are based on the published results of research programs to develop pollution sensing techniques and instrumentation. Therefore, the chemicals that are listed in those tables as "probably" potentially detectable, identifiable, or quantifiable should ultimately be detectable, identifiable or quantifiable by a set of well developed, operational sensors. In most cases, available sensors are not yet well developed; in other cases, sensors are not yet available.

In this section, the chemicals that are ranked in Table 4.2 as "probably" potentially detectable are tabulated for each of the twelve sensing techniques. Even though they are redundant, these tabulations are presented

in the following pages because they are instructive and because they will relieve the reader of the need to search through Table 4.2 to pick out the detectable chemicals. The listed chemicals are evaluated with respect to the known characteristics of available instrumentation to assess their current detectability, identifiability, and quantifiability. Chemicals that are not detectable by available instrumentation are identified in the listings by appropriate notation.

It turns out that for most of the sensing techniques, either all or none of the potentially detectable chemicals are judged to be currently detectable. This result is partially due to the limited number of probability levels permitted by the present analysis, but it is also due to the fact that chemical detectability, unlike identifiability and quantifiability, is largely determined by rather gross optical, physical, and chemical characteristics. For example, chemical detection by thermal IR methods depends primarily on density, solubility, and viscosity. If a sensor can detect one chemical, it can usually detect other, similar chemicals. In general, current capabilities, even for detection, are seriously limited in terms of areal coverage, chemical range, and range of operating conditions. Major efforts are needed to design and develop operational sensing systems that are more sensitive, more accurate, more reliable, more rugged, and more versatile than existing instruments. The identification and quantification capabilities of existing sensors are minimal.

It should be pointed out again that the environmental factors and other variables discussed at the beginning of Section 4 will largely determine the effectiveness of a sensor. The conclusions that are presented in this section are therefore estimates based on available data and on the assumption of reasonably favorable operating conditions for the instrumentation.

5.2 CHEMICAL LISTINGS AND AVAILABLE INSTRUMENTATION

The tables on the following pages are listings of the "probably potentially detectable" CHRIS chemicals as determined in Table 4.2. Chemicals that are not judged to be probably or usually detectable by

currently available instrumentation are denoted by an asterisk in front of the chemical name. Each chemical listing is preceded by a discussion or listing of appropriate, currently available sensing devices. Manufacturers are referenced by number in the instrumentation listings, and a list of manufacturers is included in the Appendix.

Estimated current identification and quantification capabilities will be discussed in the text. For simplicity, I and Q will refer to identifiability and quantifiability, respectively, and the following numerical scale will be used:

- 2 = Probable, or will provide a good estimate of concentration, thickness, or volume.
- 1 = Possible under some circumstances, or will reduce a list of known possibilities, or will provide some information on concentration, thickness or volume.
- 0 = Unlikely.

5.2.1 OPTICAL REFLECTANCE

In general, operational instruments for detecting pollutants by their surface or volume optical reflectance characteristics are more readily available than are instruments for most other sensing methods. At least five types of instrumentation are available:

- 1) Cameras and multiband camera systems.
Manufacturers: 1-4
Spectral Range: 290-1200 nm
Operating Mode: Remote sensing, passive, imaging.
- 2) Line scanners.
Manufacturers: 5-8
Spectral Range: 380-1100 nm
Operating mode: Remote sensing, passive, imaging.
- 3) Spectrophotometers.
Manufacturers: 8-10
Spectral Range: 200-1200 nm
Operating Mode: Remote or in situ, passive, non-imaging.

- 4) Television.
Numerous manufacturers and models.
Spectral Range: 200-1100 nm.
Operating Mode: Remote sensing, passive, imaging.
- 5) Oil Sensor.
Manufacturer: II
Spectral Range: 3.4-3.8 microns
Operating Mode: Remote sensing, active, non-imaging.

A large percentage of the chemicals in the following table are considered to be detectable by means of IR reflectivity measurements (RAMCO Oil Sensor). This capability has not yet been demonstrated for chemicals other than oils, but it is based in each case on the presence of an absorption peak at the stretching frequency of the C-H bond.

Current identification and quantification capabilities are I=Q=1 for chemicals with absorption peaks that are detectable in the UV or visible range. The notation UVV is used to refer to the UV and/or visible spectral region; IR means infrared.

TABLE 5.2. Chemicals Detectable by Optical Reflectance Methods

<u>CHEMICAL NAME</u>	<u>SPECTRAL RANGE</u>
ADIPONITRILE	UVV, IR
AMYL ACETATE	UVV, IR
BENZALDEHYDE	UVV, IR
BENZENE	UVV, IR
BUTADIENE, INHIBITED	UVV, IR
BUTANE	IR
SEC-BUTYL ACETATE	UVV, IR
N-BUTYL ACRYLATE	UVV, IR
ISO-BUTYL ACRYLATE	UVV, IR
BUTYLENE	IR
CAMPHOR OIL	UVV, IR
CROTONALDEHYDE	UVV
CUMENE	UVV, IR
CYCLOHEXANE	IR
CYCLOHEXANOL	UVV, IR
DECALDEHYDE	UVV, IR
1-DECENE	UVV, IR
N-DECYL ALCOHOL	UVV, IR
DICYCLOPENTADIENE	IR
DIETHYLAMINE	IR

TABLE 5.2. (Continued)

CHEMICAL NAME	SPECTRAL RANGE
DIETHYLBENZENE	UVV, IR
DIETHYLCARBONATE	IR
DIMETHYLFORMAMIDE	UVV, IR
DODECANOL	IR
DODECENE	IR
1-DODECENE	IR
DOWTHERM	UVV, IR
EPOXIDIZED VEGETABLE OILS	UVV, IR
ETHYLBENZENE	UVV, IR
ETHYL BUTANOL	IR
ETHYL CHLORIDE	IR
ETHYLENE	IR
ETHYLENEDIAMINE TETRACETIC ACID	UVV, IR
2-ETHYL HEXANOL	IR
ETHYL HEXYL TALLATE	UVV, IR
2-ETHYL-3-PROPYLACROLEIN	UVV, IR
GAS OIL: CRACKED	UVV, IR
GASOLINES: AUTOMOTIVE (<4.230 LEAD/GAL)	UVV, IR
GASOLINES: AVIATION (<4.860 LEAD/GAL)	UVV, IR
GASOLINES: CASINGHEAD	IR
GASOLINES: POLYMER	IR
GASOLINES: STRAIGHT RUN	IR
GASOLINE BLENDING STOCKS: ALKYLATES	IR
GASOLINE BLENDING STOCKS: REFORMATES	IR
GLYCIDYL METHACRYLATE	IR
HEPTANOL	IR
HEXANOL	IR
ISODECYL ALCOHOL	IR
ISOPENTANE	IR
ISOPRENE	IR
JET FUELS: JP-1(KEROSENE)	UVV, IR
JET FUELS: JP-3	UVV, IR
JET FUELS: JP-4	UVV, IR
JET FUELS: JP-5(KEROSENE HEAVY)	UVV, IR
KEROSENE	UVV, IR
LAURYL MERCAPTAN	IR
LINEAR ALCOHOLS (12-15 CARBONS)	IR
METHYL CHLORIDE	IR
NITROSYL CHLORIDE	UVV
NONANOL	IR
NONENE	IR
1-NONENE	IR
NONYLPHENOL	UVV, IR
OCTANOL	IR
1-OCTENE	IR

TABLE 5.2. (Continued)

CHEMICAL NAME	SPECTRAL RANGE
OILS: CLARIFIED	UVV, IR
OILS: CRUDE	UVV, IR
OILS: DIESEL	UVV, IR
OILS, EDIBLE: CASTOR	UVV, IR
OILS, EDIBLE: COTTONSEED	UVV, IR
OILS, EDIBLE: FISH	UVV, IR
OILS, EDIBLE: OLIVE	UVV, IR
OILS, EDIBLE: PEANUT	UVV, IR
OILS, EDIBLE: SOYA BEAN	UVV, IR
OILS, EDIBLE: VEGETABLE	UVV, IR
OILS, FUEL: NO.1 (KEROSENE)	UVV, IR
OILS, FUEL: NO.1-D	UVV, IR
OILS, FUEL: NO.2	UVV, IR
OILS, FUEL: NO.2-D	UVV, IR
OILS, FUEL: NO.4	UVV, IR
OILS, FUEL: NO.5	UVV, IR
OILS, FUEL: NO.6	UVV, IR
OILS, MISCELLANEOUS: ABSORPTION	UVV, IR
OILS, MISCELLANEOUS: COAL TAR	UVV, IR
OILS, MISCELLANEOUS: LUBRICATING	UVV, IR
OILS, MISCELLANEOUS: MINERAL	UVV, IR
OILS, MISCELLANEOUS: MINERAL SEAL	UVV, IR
OILS, MISCELLANEOUS: MOTOR	UVV, IR
OILS, MISCELLANEOUS: NEATSFOOT	UVV, IR
OILS, MISCELLANEOUS: PENETRATING	UVV, IR
OILS, MISCELLANEOUS: RANGE	UVV, IR
OILS, MISCELLANEOUS: RESIN	UVV, IR
OILS, MISCELLANEOUS: ROAD	UVV, IR
OILS, MISCELLANEOUS: ROSIN	UVV, IR
OILS, MISCELLANEOUS: SPERM	UVV, IR
OILS, MISCELLANEOUS: SPINDLE	UVV, IR
OILS, MISCELLANEOUS: SPRAY	UVV, IR
OILS, MISCELLANEOUS: TALL	UVV, IR
OILS, MISCELLANEOUS: TANNER'S	UVV, IR
OILS, MISCELLANEOUS: TRANSFORMER	UVV, IR
PENTADECANOL	IR
PENTANE	IR
1-PENTENE	IR
PETROLATUM	UVV, IR
PETROLEUM NAPHTHA	IR
POLYBUTENE	IR
PROPANE	IR
PROPYLENE	IR
PROPYLENE BUTYLENE POLYMER	IR
PROPYLENE TETRAMER	IR
PYRIDINE	UVV, IR

TABLE 5.2. (Continued)

CHEMICAL NAME	SPECTRAL RANGE
STYRENE	UVV, IR
TALLOW	UVV, IR
TETRADECANOL	IR
1-TETRADECENE	IR
TETRAHYDRONAPHTHALENE	UVV, IR
TOLUENE	UVV, IR
TRIDECANOL	IR
1-TRIDECENE	IR
TRIETHYLBENZENE	UVV, IR
TRIETHYLENETETRAMINE	UVV
TURPENTINE	IR
UNDECANOL	IR
1-UNDECENE	UVV, IR
VALERALDEHYDE	UVV, IR
VINYL ACETATE	UVV, IR
VINYL CHLORIDE	IR
VINYLTOLUENE	UVV, IR
WAXES: CARNAUBA	UVV, IR
WAXES: PARAFFIN	UVV, IR
M-XYLENE	UVV, IR
O-XYLENE	UVV, IR
P-XYLENE	UVV, IR

5.2.2 THERMAL INFRARED

Aerial thermal IR scanners have been used in environmental studies for many years. Several systems are commercially available. Other thermal IR sensors are also available.

- 1) Line Scanners.
 Manufacturers: 5-8, 12-15.
 Spectral Range: 3-16 microns.
 Operating Mode: Remote sensing, passive, imaging.
- 2) Radiometers.
 Manufacturers: 8,10,14-16.
 Spectral Range: 3-14 microns.
 Operating Mode: Remote sensing, passive, non-imaging.
- 3) Imaging or Spatial Radiometers
 Manufacturers: 7,15,17.
 Spectral Range: 4-15 microns.
 Operating Mode: Remote sensing, passive, imaging.

Thermal IR sensors do not provide the types of information needed for chemical identification and quantification. For this technique, $I=Q=0$.

TABLE 5.3. Chemicals Detectable by Thermal Infrared Methods

<u>CHEMICAL NAME</u>
BUTADIENE, INHIBITED
BUTANE
BUTYLENE
DIETHYLAMINE
EPOXIDIZED VEGETABLE OILS
ETHANE
ETHYL CHLORIDE
ETHYLENE
ETHYLENEDIAMINE TETRACETIC ACID
1-HEPTENE
HYDROGEN SULFIDE
ISOBUTANE
ISOBUTYLENE
ISOPENTANE
ISOPRENE
LIQUEFIED NATURAL GAS
LIQUIFIED PETROLEUM GAS
METHANE
METHYL CHLORIDE
NONYLPHENOL
OILS, EDIBLE: CASTOR
OILS, EDIBLE: COTTONSEED
OILS, EDIBLE: FISH
OILS, EDIBLE: OLIVE
OILS, EDIBLE: PEANUT
OILS, EDIBLE: SOYA BEAN
OILS, EDIBLE: VEGETABLE
OILS, FUEL: NO.4
OILS, FUEL: NO.5
OILS, FUEL: NO.6
OILS, MISCELLANEOUS: ABSORPTION
OILS, MISCELLANEOUS: LUBRICATING
OILS, MISCELLANEOUS: MINERAL
OILS, MISCELLANEOUS: MOTOR
OILS, MISCELLANEOUS: NEATSFOOT
OILS, MISCELLANEOUS: RESIN
OILS, MISCELLANEOUS: ROSIN
OILS, MISCELLANEOUS: SPERM
OILS, MISCELLANEOUS: SPINDLE
OILS, MISCELLANEOUS: TALL
OILS, MISCELLANEOUS: TRANSFORMER

TABLE 5.3. (Continued)

<u>CHEMICAL NAME</u>
PENTANE
1-PENTENE
PETROLATUM
POLYBUTENE
PROPANE
PROPYLENE
PROPYLENE BUTYLENE POLYMER
PROPYLENE TETRAMER
TALLOW
TETRADECANOL
TRIDECANOL
UNDECANOL
VINYL CHLORIDE
WAXES: CARNAUBA
WAXES: PARAFFIN

5.2.3 PASSIVE MICROWAVE

Numerous passive microwave imagers and radiometers, operating in the wavelength range .3-30 cm, have been developed and tested by the Coast Guard (AOSS), NASA, Naval Research Laboratory, and others. The operating mode of these instruments is passive, slow-scan imaging, or profiling. Available systems appear to be limited in spatial resolution and signal-to-noise ratio, but under favorable conditions can probably detect most of the chemicals in the following list.

Passive microwave systems have no chemical identification capability; I=0. Surface film thickness measurements are possible by multifrequency microwave radiometers; Q=1.

Many of the chemicals in the following table have very low boiling points and will be short-lived as spills on water.

TABLE 5.4. Chemicals Detectable by Passive Microwave Methods

<u>CHEMICAL NAME</u>
*AMMONIUM HYDROXIDE (<28% AQUEOUS AMMONIA)
BUTADIENE, INHIBITED

*Probably not currently detectable

TABLE 5.4. (Continued)

CHEMICAL NAME
BUTANE
BUTYLENE
EPOXIDIZED VEGETABLE OILS
ETHANE
ETHYL CHLORIDE
ETHYLENE
*ETHYLENEIMINE
HYDROGEN SULFIDE
ISOBUTANE
ISOBUTYLENE
ISOPENTANE
ISOPRENE
LIQUIFIED NATURAL GAS
LIQUIFIED PETROLEUM GAS
METHANE
METHYL CHLORIDE
NONYLPHENOL
OILS, EDIBLE: CASTOR
OILS, EDIBLE: COTTONSEED
OILS, EDIBLE: FISH
OILS, EDIBLE: OLIVE
OILS, EDIBLE: PEANUT
OILS, EDIBLE: SOYA BEAN
OILS, EDIBLE: VEGETABLE
OILS, FUEL: NO. 5
OILS, FUEL: NO. 6
*OILS, MISCELLANEOUS: ABSORPTION
OILS, MISCELLANEOUS: LUBRICATING
*OILS, MISCELLANEOUS: MINERAL
OILS, MISCELLANEOUS: MOTOR
OILS, MISCELLANEOUS: NEATSFOOT
*OILS, MISCELLANEOUS: RESIN
*OILS, MISCELLANEOUS: ROSIN
OILS, MISCELLANEOUS: TALL
OILS, MISCELLANEOUS: TRANSFORMER
PETROLATUM
POLYBUTENE
PROPANE
PROPYLENE
TALLOW

*Probably not currently detectable

TABLE 5.4. (Continued)

<u>CHEMICAL NAME</u>
TETRADECANOL
TRIDECANOL
*UNDECANOL
*VINYL CHLORIDE
WAXES: CARNAUBA
WAXES: PARAFFIN

*Probably not currently detectable

5.2.4 RADAR

Many airborne side scanning radar systems have been built in recent years for military and civilian remote sensing applications. Appropriate systems for pollution detection have wavelengths in the 1-30 centimeter range and are capable of real-time image processing and display. The real aperture, X-band radar currently used in the Coast Guard's AOSS system should be capable of detecting the chemicals listed in Table 5.5.

Radar systems do not have significant chemical identification or quantification capabilities, except for areal mapping; $I=Q=0$.

TABLE 5.5. Chemicals Detectable by Radar

<u>CHEMICAL NAME</u>
BUTADIENE, INHIBITED
BUTANE
BUTYLENE
CAMPHOR OIL
DECALDEHYDE
DIISOBUTYL CARBINOL
DIISOBUTYLENE
DIOCTYL ADIPATE
DIOCTYL PHTHALATE
EPOXIDIZED VEGETABLE OILS
ETHANE
ETHYLENE

TABLE 5.5. (Continued)

CHEMICAL NAME
2-ETHYL HEXANOL
ETHYL HEXYL TALLATE
GLYCIDYL METHACRYLATE
HEPTANOL
HYDROGEN SULFIDE
ISOBUTANE
ISOBUTYLENE
ISODECYL ALCOHOL
ISODECALDEHYDE
ISOOCYL ALCOHOL
LINEAR ALCOHOLS (12-15 CARBONS)
LIQUIFIED NATURAL GAS
LIQUIFIED PETROLEUM GAS
METHANE
METHYL CHLORIDE
MINERAL SPIRITS
NAPHTHA: COAL TAR
NAPHTHA: SOLVENT
NAPHTHA: STODDARD SOLVENT
NAPHTHA: VM&P (75% NAPHTHA)
NONANOL
NONYLPHENOL
OCTANOL
OILS: CLARIFIED
OILS: CRUDE
OILS: DIESEL
OILS, EDIBLE: CASTOR
OILS, EDIBLE: COTTONSEED
OILS, EDIBLE: FISH
OILS, EDIBLE: OLIVE
OILS, EDIBLE: PEANUT
OILS, EDIBLE: SOYA BEAN
OILS, EDIBLE: VEGETABLE
OILS, FUEL: NO.4
OILS, FUEL: NO.5
OILS, FUEL: NO.6
OILS, MISCELLANEOUS: ABSORPTION
OILS, MISCELLANEOUS: COAL TAR
OILS, MISCELLANEOUS: LUBRICATING
OILS, MISCELLANEOUS: MINERAL
OILS, MISCELLANEOUS: MINERAL SEAL
OILS, MISCELLANEOUS: MOTOR
OILS, MISCELLANEOUS: NEATSFOOT
OILS, MISCELLANEOUS: PENETRATING
OILS, MISCELLANEOUS: RESIN
OILS, MISCELLANEOUS: ROAD

TABLE 5.5. (Continued)

CHEMICAL NAME	
OILS, MISCELLANEOUS:	RO SIN
OILS, MISCELLANEOUS:	SPERM
OILS, MISCELLANEOUS:	SPINDLE
OILS, MISCELLANEOUS:	SPRAY
OILS, MISCELLANEOUS:	TALL
OILS, MISCELLANEOUS:	TANNER'S
OILS, MISCELLANEOUS:	TRANSFORMER
PETROLATUM	
PETROLEUM NAPHTHA	
POLYBUTENE	
PROPANE	
PROPYLENE	
PROPYLENE BUTYLENE POLYMER	
PROPYLENE TETRAMER	
TALLOW	
TETRADECANOL	
TRIDECANOL	
UNDECANOL	
VINYL CHLORIDE	
WAXES:	CARNAUBA
WAXES:	PARAFFIN

5.2.5 FLUORESCENCE

Most instruments for remote fluorescence detection of pollutants in water appear to be either experimental, proposed, or under development at this time. Instruments in this category include the Coast Guard's laser fluorosensor,⁴² the Fraunhofer Line Discriminator (FLD),⁴⁶ NASA's Airborne Oceanographic Lidar (AOL),⁵⁹ and Battelle's active scanner. Except for the FLD, these are all active systems. With the exception of Battelle's scanner, they are all intended to operate in a profiling or stationary mode. Active fluorosensors which utilize a pulsed or chopped output beam, are capable of daylight as well as nighttime operation. However, some of the fluorescent materials in the following listing can probably also be detected in daylight by passive, multispectral, imaging scanners of standard design. Available in situ systems have only one or two channels. Detection of many chemicals is possible, provided that the filters used correspond to the fluorescent spectra of the chemicals. Two available systems are:

- 1) Fluorometer.
 Manufacturer: 18
 Spectral Range: 350-1100 nm. Single channel, choice of filters.
 Operating Mode: In situ, active, fixed or towed.
- 2) Oil Detection System.
 Manufacturer: 19
 Spectral Range: 350-1100 (est)
 Operating Mode: In situ, active, fixed.

Table 5.6 lists the fluorescent chemicals that are probably detectable by one or the other of the in situ sensors listed above. However, current capabilities must be qualified by the spatial and spectral limitations of the instruments. Chemical identification is not possible, or it is at least uncertain, except under special circumstances; therefore I=1. Given a knowledge of chemical species and calibration data, chemical concentration or film thickness can be measured. In that sense, Q=2.

TABLE 5.6. Chemicals Detectable by Fluorescence Methods

<u>CHEMICAL NAME</u>
ANILINE
BENZENE
CARBOLIC OIL
CRESOLS
CUMENE
DIETHYLBENZENE
DOWTHERM
ETHYLBENZENE
NAPHTHA: COAL TAR
OILS: CLARIFIED
OILS: CRUDE
OILS: DIESEL
OILS, FUEL: NO.1 (KEROSENE)
OILS, FUEL: NO.1-D
OILS, FUEL: NO.2
OILS, FUEL: NO.2-D
OILS, FUEL: NO.4
OILS, FUEL: NO.5
OILS, FUEL: NO.6
OILS, MISCELLANEOUS: ABSORPTION
OILS, MISCELLANEOUS: COAL TAR
OILS, MISCELLANEOUS: LUBRICATING
OILS, MISCELLANEOUS: MINERAL

TABLE 5.6. (Continued)

<u>CHEMICAL NAME</u>
OILS, MISCELLANEOUS: MINERAL SEAL
OILS, MISCELLANEOUS: MOTOR
OILS, MISCELLANEOUS: PENETRATING
OILS, MISCELLANEOUS: RANGE
OILS, MISCELLANEOUS: ROAD
OILS, MISCELLANEOUS: SPINDLE
OILS, MISCELLANEOUS: SPRAY
OILS, MISCELLANEOUS: TRANSFORMER
PHENOL
STYRENE
TETRAHYDRONAPHTHALENE
TOLUENE
TRIETHYLBENZENE
VINYLTOLUENE
M-XYLENE
O-XYLENE
P-XYLENE

5.2.6 RAMAN SCATTERING

Field instrumentation for detection of water pollutants is currently in a state of experimentation and development. No operational systems for field use are known to be currently available.

The following table lists the CHRIS chemicals that will probably be detectable by operational Raman sensors.

TABLE 5.7. Chemicals Detectable by Raman Scattering Methods

<u>CHEMICAL NAME</u>
*ACETYLENE
*AMYL ACETATE
*BUTANE
*SEC-BUTYL ACETATE
*N-BUTYL ACRYLATE
*ISO-BUTYL ACRYLATE
*BUTYLENE
*CYCLOHEXANE
*DECALDEHYDE

*Not currently detectable

TABLE 5.7. (Continued)

CHEMICAL NAME
*1-DECENE
*DIETHYLAMINE
*DIETHYLCARBONATE
*DIOCTYL ADIPATE
*DODECANOL
*DODECENE
*1-DODECENE
*ETHYL BUTANOL
*ETHYL CHLORIDE
*ETHYLENE
*GASOLINES: AUTOMOTIVE (<4.230 LEAD/GAL)
*GASOLINES: AVIATION (<4.860 LEAD/GAL)
*GASOLINES: CASINGHEAD
*GASOLINES: POLYMER
*GASOLINES: STRAIGHT RUN
*GASOLINE BLENDING STOCKS: REFORMATES
*GASOLINE BLENDING STOCKS: ALKYLATES
*HEPTANE
*HEPTANOL
*HEXANE
*1-HEXENE
*ISOBUTANE
*ISOPENTANE
*ISOPRENE
*LINEAR ALCOHOLS (12-15 CARBONS)
*LIQUEFIED NATURAL GAS
*METHYL CHLORIDE
*NONANOL
*NONENE
*1-NONENE
*OCTANOL
*1-OCTENE
*OILS, EDIBLE: CASTOR
*OILS, EDIBLE: COTTONSEED
*OILS, EDIBLE: FISH
*OILS, EDIBLE: OLIVE
*OILS, EDIBLE: PEANUT
*OILS, EDIBLE: SOYA BEAN
*OILS, EDIBLE: VEGETABLE
*OILS, MISCELLANEOUS: NEATSFOOT
*OILS, MISCELLANEOUS: SPERM
*OILS, MISCELLANEOUS: TANNER'S
*PENTADECANOL
*PENTANE

*Not currently detectable

TABLE 5.7. (Continued)

CHEMICAL NAME
*1-PENTENE
*PETROLATUM
*PETROLEUM NAPHTHA
*POLYBUTENE
*PROPANE
*PROPYLENE
*PROPYLENE BUTYLENE POLYMER
*PROPYLENE TETRAMER
*TALLOW
*TETRADECANOL
*1-TETRADECENE
*TRIDECANOL
*1-TRIDECENE
*UNDECANOL
*1-UNDECENE
*VINYL CHLORIDE

*Not currently detectable

5.2.7 ION-SELECTIVE ELECTRODES

Environmentally useful electrodes include:

- | | |
|-------------------------------|--------------------------------------|
| 1. BROMIDE (Br^-) | 6. NITRATE (NO_3^-) |
| 2. CHLORIDE (Cl^-) | 7. POTASSIUM (K^+) |
| 3. CYANIDE (CN^-) | 8. SODIUM (Na^+) |
| 4. FLUORIDE (F^-) | 9. HYDROGEN ION (H^+ , pH) |
| 5. IODIDE (I^-) | |

Typical sensitivities and accuracies for ion-selective electrodes are 0.01% and $\pm 0.01\%$ of full scale, respectively. For pH electrodes, typical sensitivities and accuracies are 0.001 pH and ± 0.02 pH, respectively.

Available instrumentation includes the following:

- | | |
|-----------------------|-------|
| 1. Bromide Electrode | |
| Manufacturers: | 20,21 |
| 2. Chloride Electrode | |
| Manufacturers: | 20,21 |

3. Cyanide Electrode
Manufacturers: 20,21
4. Fluoride Electrode
Manufacturer: 20
5. Iodide Electrode
Manufacturers: 20,21
6. Nitrate Electrode
Manufacturer: 20
7. Potassium Electrode
Manufacturer: 20
8. Sodium Electrode
Manufacturer: 20
9. pH Electrode
Manufacturers: 20 - 27

Ion-selective electrodes return some useful information for identification and can quantify ion concentrations; I=1, Q=2.

TABLE 5.8. Chemicals Detectable by Ion-Selective Electrodes

CHEMICAL NAME	ELECTRODES USED	DETECTION LIMIT (ppm)
ALUMINUM CHLORIDE	pH, Cl ⁻	1, 1
AMMONIA, ANHYDROUS	pH	1
AMMONIUM HYDROXIDE (<28% AQUEOUS AMMONIA)	pH	1
CALCIUM OXIDE	pH	1
CAUSTIC POTASH SOLUTION	pH, K ⁺	1, 1
CAUSTIC SODA SOLUTION	pH, Na ⁺	1, 1
CHLOROSULFONIC ACID	pH, Cl ⁻	1, 1
CHROMIC ANHYDRIDE	pH	1
CYCLOHEXYLAMINE	pH	100
ETHYLENEIMINE	pH	10-100
FLUORINE	pH	10
FORMIC ACID	pH	>100
HYDROCHLORIC ACID	pH, Cl ⁻	1, 1
HYDROFLUORIC ACID	pH, F ⁻	1, 1
HYDROGEN CHLORIDE	pH, Cl ⁻	1, 1
HYDROGEN FLUORIDE	pH	1
LITHIUM ALUMINUM HYDRIDE	pH	1
MONOETHANOLAMINE	pH	100
MONOISOPROPANOLAMINE	pH	100

TABLE 5.8. (Continued)

CHEMICAL NAME	ELECTRODES USED	DETECTION LIMIT (ppm)
MORPHOLINE	pH	100
NITRIC ACID	pH, NO ₃ ⁻	1, 1
NITROGEN TETROXIDE	pH, NO ₃ ³⁻	1, 1
NITROSYL CHLORIDE	pH, Cl ³⁻	1, 1
OLEUM	pH	1
OXALIC ACID	pH	100
PHOSGENE	pH	1
PHOSPHOROUS OXYCHLORIDE	pH, Cl ⁻	1, 1
PHOSPHORUS TRICHLORIDE	pH	1
POTASSIUM CYANIDE	K ⁺ , pH, CN ⁻	1, 1, 1
POTASSIUM HYDROXIDE	pH, K ⁺	1, 1
SODIUM	pH, Na ⁺	1, 1
SODIUM ALKYL-BENZENESULFONATES	pH, Na ⁺	1, 1
SODIUM ALKYL SULFATES	pH, Na ⁺	1, 1
SODIUM AMIDE	pH, Na ⁺	1, 1
SODIUM BISULFITE	pH, Na ⁺	1, 1
SODIUM BOROHYDRIDE	pH, Na ⁺	1, 1
SODIUM CHLORATE	Cl ⁻ , pH, Na ⁺	1, 1, 1
SODIUM CYANIDE	CN ⁻ , pH, Na ⁺	1, 1, 1
SODIUM FLUORIDE	F ⁻ , pH, Na ⁺	1, 1, 1
SODIUM HYDRIDE	pH, Na ⁺	1, 1
SODIUM HYDROXIDE	pH, Na ⁺	1, 1
SODIUM HYPOCHLORITE	pH, Na ⁺	1, 1
SODIUM SILICATE	pH, Na ⁺	1, 1
SODIUM SULFIDE	pH, Na ⁺	1, 1
SULFUR DIOXIDE	pH	1
SULFUR MONOCHLORIDE	Cl ⁻ , pH	1, 1
SULFURIC ACID	pH	1
SULFURIC ACID, SPENT	pH	1
SULFURYL CHLORIDE	pH, Cl ⁻	1, 1
TITANIUM TETRACHLORIDE	pH, Cl ⁻	1, 1

5.2.8 ELECTROCONDUCTIVITY

Typical values of sensitivity and accuracy for electroconductivity instruments are 1% and +1% full scale, respectively. Available conductivity instruments:

1. In situ instrumentation
Manufacturers: 20,22,23,25
2. Field instruments (not for unattended use)
Manufacturers: 26,28

Electroconductivity measurements return no useful information for identification purposes; $I=0$. Quantification by electroconductivity is not straightforward, and is presently done mainly in the laboratory; $Q=1$. Detection limits of electroconductivity are probably in the range 10-100 ppm.

TABLE 5.9. Chemicals Detectable by Electroconductivity Methods

CHEMICAL NAME
ALUMINUM CHLORIDE
AMMONIA, ANHYDROUS
AMMONIUM HYDROXIDE (<28% AQUEOUS AMMONIA)
CALCIUM OXIDE
CAUSTIC POTASH SOLUTION
CAUSTIC SODA SOLUTION
CHLOROSULFONIC ACID
CHROMIC ANHYDRIDE
CYCLOHEXYLAMINE
ETHYLENEIMINE
FLUORINE
FORMIC ACID
HYDROCHLORIC ACID
HYDROFLUORIC ACID
HYDROGEN CHLORIDE
HYDROGEN FLUORIDE
LITHIUM ALUMINUM HYDRIDE
MONOETHANOLAMINE
MONOISOPROPANOLAMINE
MORPHOLINE
NITRIC ACID
NITROGEN TETROXIDE
NITROSYL CHLORIDE
OLEUM
OXALIC ACID
PHOSGENE
PHOSPHORUS OXYCHLORIDE
PHOSPHORUS TRICHLORIDE
POTASSIUM CYANIDE
POTASSIUM HYDROXIDE
SODIUM
SODIUM ALKYL-BENZENESULFONATES
SODIUM ALKYL SULFATES
SODIUM AMIDE
SODIUM BISULFITE
SODIUM BOROHYDRIDE
SODIUM CHLORATE
SODIUM CYANIDE
SODIUM FLUORIDE
SODIUM HYDRIDE

TABLE 5.9. (Continued)

CHEMICAL NAME

SODIUM HYDROXIDE
SODIUM HYPOCHLORITE
SODIUM SILICATE
SODIUM SULFIDE
SULFUR DIOXIDE
SULFUR MONOCHLORIDE
SULFURIC ACID
SULFURIC ACID, SPENT
SULFURYL CHLORIDE
TITANIUM TETRACHLORIDE

5.2.9 REDUCTION-OXIDATION POTENTIAL

Typical values of sensitivity and accuracy for reduction-oxidation potential instrumentation are 0.1% and +1% of full scale, respectively.

Available in situ instrumentation for reduction-oxidation potential:

Manufacturers: 23,24,27

Reduction-oxidation potentials do not produce chemical-specific signals; I=0. Quantification by redox measurements is presently done mainly in the laboratory and is not easily extended to environmental conditions; Q=1. Detection limits for redox measurements range from 1 ppm to 100 ppm.

TABLE 5.10. Chemicals Detectable by Reduction-Oxidation Potential Methods

CHEMICAL NAME

ALUMINUM CHLORIDE
BROMINE
TERT-BUTYL HYDROPEROXIDE
CAUSTIC POTASH SOLUTION
CAUSTIC SODA SOLUTION
CHLOROSULFONIC ACID
CHROMIC ANHYDRIDE
ETHYLENEIMINE
FLUORINE
HYDROCHLORIC ACID
HYDROFLUORIC ACID
HYDROGEN CHLORIDE
HYDROGEN FLUORIDE

TABLE 5.10. (Continued)

<u>CHEMICAL NAME</u>
LITHIUM ALUMINUM HYDRIDE
NITRIC ACID
NITROGEN TETROXIDE
OLEUM
OXALIC ACID
PHOSGENE
PHOSPHORUS OXYCHLORIDE
PHOSPHORUS TRICHLORIDE
POTASSIUM CYANIDE
POTASSIUM DICHROMATE
POTASSIUM HYDROXIDE
SODIUM
SODIUM ALKYL-BENZENESULFONATES
SODIUM ALKYL SULFATES
SODIUM AMIDE
SODIUM BOROHYDRIDE
SODIUM CHLORATE
SODIUM CYANIDE
SODIUM HYDRIDE
SODIUM HYDROXIDE
SODIUM HYPOCHLORITE
SULFUR DIOXIDE
SULFUR MONOCHLORIDE
SULFURIC ACID
SULFURIC ACID, SPENT
SULFURYL CHLORIDE
TITANIUM TETRACHLORIDE

5.2.10 OPTICAL ABSORPTIMETRY

Instruments for optical absorptimetry:

1. Transmissometer
Manufacturer: 26
2. Spectrophotometer
Manufacturer: 29

Optical absorbance spectra are somewhat distinctive in the UV-visible wavelengths; therefore, $I=1$. Once a chemical has been identified, calibration curves can be used to quantify the data; therefore, for accessible compounds, $Q=2$. Detection limits are chemical dependent, but most fall in the range 100 ppb to 100 ppm.

TABLE 5.11. Chemicals Detectable by Optical Absorbance Methods

CHEMICAL NAME
ACETIC ACID
ACETIC ANHYDRIDE
ACETONE
AMMONIUM PERCHLORATE
AMMONIUM SULFATE
ANTIMONY TRIFLUORIDE
BROMINE
1,4-BUTYNEEDIOL
CHLORINE
CHROMIC ANHYDRIDE
COPPER SULFATE
CRESOLS
CROTONALDEHYDE
DEMETHYLFORMAMIDE
FURFURAL
LATEX LIQUID, SYNTHETIC
NITRIC ACID
NITROSYL CHLORIDE
PHENOL
POTASSIUM DICHROMATE
POTASSIUM PERMANGANATE
PYRIDINE
SODIUM DICHROMATE
SODIUM FERROCYANIDE
SODIUM HYPOCHLORITE
SODIUM SULFIDE
SODIUM SULFITE
TRIETHYLENETETRAMINE

5.2.11 DISSOLVED OXYGEN

Dissolved oxygen systems typically detect DO changes as small as ± 0.1 ppm. Manufacturers of DO instrumentation: 20,22,26,27,30

Dissolved oxygen measurements are not chemical specific and are difficult to relate quantitatively to chemical concentration; $I=Q=0$.

TABLE 5.12. Chemicals Detectable by Dissolved Oxygen Methods

CHEMICAL NAME
ALUMINUM CHLORIDE
AMMONIA, ANHYDROUS

TABLE 5.12. (Continued)

CHEMICAL NAME	U.S. 12. TOTAL OXYGEN DEMAND
AMMONIUM HYDROXIDE (<28% AQUEOUS AMMONIA)	
CALCIUM OXIDE	
CAUSTIC POTASH SOLUTION	
CAUSTIC SODA SOLUTION	
CHLOROSULFONIC ACID	
CHROMIC ANHYDRIDE	
CYCLOHEXYLAMINE	
ETHYLENEDIAMINE	
ETHYLENEIMINE	
FLUORINE	
FORMIC ACID	
HYDROCHLORIC ACID	
HYDROFLUORIC ACID	
HYDROGEN CHLORIDE	
LITHIUM ALUMINUM HYDRIDE	
MORPHOLINE	
NITRIC ACID	
NITROGEN TETROXIDE	
OLEUM	
OXALIC ACID	
PHOSGENE	
PHOSPHORUS OXYCHLORIDE	
PHOSPHORUS TRICHLORIDE	
POTASSIUM CYANIDE	
POTASSIUM HYDROXIDE	
SODIUM	
SODIUM ALKYL-BENZENESULFONATES	
SODIUM ALKYL SULFATES	
SODIUM AMIDE	
SODIUM BISULFITE	
SODIUM BOROHYDRIDE	
SODIUM CHLORATE	
SODIUM CYANIDE	
SODIUM FLUORIDE	
SODIUM HYDRIDE	
SODIUM HYDROXIDE	
SODIUM HYPOCHLORITE	
SODIUM SILICATE	
SODIUM SULFIDE	
SULFUR DIOXIDE	
SULFUR MONOCHLORIDE	
SULFURIC ACID	
SULFURIC ACID, SPENT	
SULFURYL CHLORIDE	
TITANIUM TETRACHLORIDE	

5.2.12 TOTAL OXYGEN DEMAND

Accuracies for total oxygen demand monitors are typically +4% of full scale. Available instrumentation for measurement of total oxygen demand:

Manufacturer: 31

Total oxygen demand measurements are not chemical specific or directly relatable to chemical concentration; $I=Q=0$.

TABLE 5.13. Chemicals Detectable by Total Oxygen Demand

<u>CHEMICAL NAME</u>
ACETALDEHYDE
ACETIC ACID
ACETIC ANHYDRIDE
ACETONE
N-BUTYL ALCOHOL
SEC-BUTYL ALCOHOL
TERT-BUTYL HYDROPEROXIDE
CALCIUM HYPOCHLORITE
CALCIUM OXIDE
CHLOROSULFONIC ACID
DEXTROSE SOLUTION
DIMETHYL SULFATE
EPICHLOROHYDRIN
ETHYL ALCOHOL
ETHYLENEDIAMINE
ETHYLENE GLYCOL
ETHYLENE GLYCOL: MONOETHYL ETHER
FLUORINE
FORMALDEHYDE SOLUTION
FURFURAL
HEXYLENE GLYCOL
HYDRAZINE
ISOBUTYL ALCOHOL
ISOPROPYL ALCOHOL
LITHIUM ALUMINUM HYDRIDE
METHYL ALCOHOL
METHYL ETHYL KETONE
METHYL IOSBUTYL KETONE
MONOETHANOLAMINE
PHENOL
PROPIONALDEHYDE
PROPIONIC ACID
N-PROPYL ALCOHOL

TABLE 5.13. (Continued)

CHEMICAL NAME
PROPYLENE GLYCOL
PROPYLENE OXIDE
PYRIDINE
SODIUM ALKYL SULFATES

5.3 SUMMARY OF CURRENT CAPABILITIES

The estimated capabilities of currently available pollution sensing devices are summarized in the following table in terms of the number of chemicals that are detectable, identifiable, or quantifiable by currently available equipment.

TABLE 5.14. Summary of Current Capabilities

	Remote Sensing Methods				In Situ Methods	Totals
	Imaging	Non-Imaging	Night	Rain, Fog, Clouds		
Detectable	134	138	149	82	136	253
Identifiable	0	0	0	0	0	0
Quantifiable	36	0	0	0	65	65

The numbers in the "totals" column are the numbers of chemicals that are detectable, identifiable, or quantifiable. They are not the sums of the numbers in the corresponding rows since a given chemical is counted only once in each row.

SECTION 6
SCOPE OF NEEDED RESEARCH

6.1 DISCUSSION OF PURPOSE

The growing concern and need for monitoring the quality of surface waters will result in continuing technological developments. New instruments, with greater analytical capabilities and wider ranges of applicability than existing instruments, will be developed for detecting, identifying, and quantifying water pollutants. The potential exists, for example, to develop automated in situ sensors based on many of the powerful techniques of laboratory analytical chemistry. The analytical instrumentation contained in the Viking spaceprobe to investigate the Martian surface is an example of what can be done if development funds are available. However, in the short term, it is necessary to utilize those capabilities that are in hand or within reach. This study is focused on pollution sensing techniques that appear to be at least on the threshold of applicability. Even so, substantial research and development efforts are needed to fully realize their potential capabilities. It is the purpose of this section to discuss some of those research needs as well as other considerations that appear to be pertinent to the task of pollution monitoring.

6.2 RECOMMENDATIONS AND COMMENTS

6.2.1 PLANNING NEEDS

It has been stressed throughout this report that broad-spectrum pollution monitoring is a complicated matter, involving many environmental factors as well as the characteristics and limitations of available instrumentation. It is clear that it is impractical if not impossible to cope with every environmental variation, to put a sensor at every location where pollution is possible, to survey every square mile of water surface or to detect every chemical that is spilled. It is therefore recommended that studies be initiated to determine and evaluate the relative probabilities for spillage of each of the CHRIS chemicals, probable spill mechanisms and

locations, and areas of probable greatest hazard to the environment and to human health. Theoretical and experimental programs should be initiated and supported to study pollution transport and dispersal mechanisms in crucial areas such as rivers, harbors, and coastal zones. Both generalized and site-specific transport models should be developed for the purpose of predicting the spatial and temporal distributions of chemicals having a wide range of physical and chemical characteristics in water. The optimum design and deployment of pollution sensors as well as effective planning for the control and cleanup of possible chemical spills will require the completion of research programs of this kind.

The results of Section 4 support the generalization that identification and quantification of chemical spills will be more difficult and costly than the already difficult task of detection alone.

Therefore, assuming that funding for the development, deployment, and maintenance of pollution sensing equipment will not be unlimited, it will be useful to consider how much effort should be expended, in the short term, on the development of each of these desired capabilities.

There appear to be three reasons to develop remote and unattended in situ sensors that can identify spilled chemicals in water:

- 1) To quickly determine the degree of hazard to the environment or to human health, and to provide prompt and accurate warnings to the appropriate agencies.
- 2) To expedite the control and cleanup of a spill.
- 3) To determine the source of the spill and to provide information to be used in legal action against the responsible party.

Of these reasons, the third is probably least compelling since it will usually be possible to obtain a sample of the polluted water for laboratory analysis. The first two are definitely valid but their importance should be evaluated.

Under certain circumstances, mainly where fixed sensors can be employed, it will not be too difficult to achieve a limited spill identification

capability. Several methods are possible. Some, such as Raman scattering and IR reflectance measurements have already been considered. Others, such as measurements of optical scattering and absorption spectra in the vapor emitted by the chemical, gas chromatography, and multisensor approaches, can be developed. But to develop and implement a comprehensive capability, geared to the wide range of chemicals in the CHRIS list and operable under a wide range of environmental conditions and spill locations, would require a massive, costly effort. Specific and reasonable needs for identification capabilities should be defined in order to maximize the cost effectiveness of hardware development programs. For the same reasons, the need for quantification capabilities should be similarly considered.

For each of the twelve sensing techniques considered in Section 4, there are a large number of chemicals which have been ranked as "possibly" detectable. This often means that although the chemical is not detectable under a wide range of conditions, it may be readily detectable under special conditions. The number of these chemicals is large enough to warrant further study to determine whether the proper conditions for detection do occur often enough to be significant or whether those conditions correspond to circumstances or locations of particular interest.

6.2.2 RESEARCH AND DEVELOPMENT NEEDS

The pollution monitoring tasks that have been assigned by Congress to the Coast Guard and the EPA require the surveillance of large areas of oceanic, coastal, and inland waters. For this reason, aerial sensing systems, particularly real-time imaging systems, should receive careful attention and be utilized to the maximum possible extent. Data formats and on-board image display systems should be designed to derive the maximum practicable benefit from the processing power of state-of-the-art digital electronics as well as the pattern recognition sensitivity of the human eye and mind when viewing two-dimensional imagery. The design of data processing, display, and recording instrumentation will be a major factor in determining the effectiveness of aerial remote sensing systems and should not be underemphasized in development programs. A research

program specifically designed to develop principles and optimum techniques for extracting pollution information from remote sensing data may be of great value in itself if it can be logically structured.

The potential applicability and effectiveness of twelve remote and in situ sensing techniques have been estimated in this study. But those estimates are only an initial step in what should be a sustained program to evaluate and develop pollution sensing techniques and instrumentation. Field experiments and measurements involving a broad spectrum of chemicals and a wide range of environmental factors are needed together with laboratory measurements that are directly relatable to field measurements. Numerous field and laboratory experiments have been conducted to study the detectability of oil spills, yet the body of knowledge gained from those studies is by no means complete or definitive. The scope of the research needed to deal with a broad range of chemicals will be appreciated by realizing that oils are among the easiest chemicals to detect.

The following items briefly outline several additional, specific suggestions for developing and implementing pollution sensing techniques:

- Optical reflectance techniques in the UV-IR spectral range appear to be potentially effective for detecting and, to some extent, identifying and quantifying many spilled chemicals. Laboratory and field measurements of surface and volume reflectance spectra of those chemicals in water are needed.
- The potential effectiveness of active and passive sensors that are capable of high resolution scanning of a broad spectral range in the IR should be studied.
- The development of fluorescence and Raman systems should be continued and should include laboratory and field measurements of fluorescence and Raman spectra for chemicals in the water environment. It may be feasible to combine fluorescence and Raman capabilities in one instrument.

- Raman measurements promise to provide a chemical identification and quantification capability in many in situ and non-aerial remote sensing applications. Efforts should be directed to finding and implementing methods for increasing the signal levels and signal-to-noise ratios of Raman (and fluorescence) measurements. This would include the development of advanced Raman techniques which will allow the separation of a Raman scattering spectrum from a fluorescence spectrum.
- Instrumentation systems which incorporate several kinds of pollution sensors will have much greater capabilities for chemical detection, identification, and quantification than can be obtained from any single sensor. The effectiveness of combining sensors in this way has not been explicitly evaluated in this study but it should be evaluated in future work.
- Digital signal processing capabilities are vital for deriving the maximum possible information from remote and in situ sensors. Useful functions include signal averaging, signature recognition, background subtraction, data display, and control of operational modes.
- Several techniques for detecting and identifying molecules of a pollutant in the air have been described in the literature. These techniques have not been included in this study, but should be evaluated in future work.
- A significant group of chemicals are insoluble and heavier than water (Accessibility Group 4). Detection of these chemicals is difficult and unlikely except by placing sensors on the bottom of the water body at the proper locations. The importance of making the effort to detect these substances, the kinds of sensors to employ, and the definition and location of key monitoring sites should be determined by further studies.

- Interference effects are a problem for in situ sensing methods, particularly in inland and coastal waters. These effects can be caused by ambient chemical or ion concentrations, suspended solids, and natural organic matter. Filtering can reduce the problem somewhat for some in situ sensors. Built-in microprocessors may provide an additional means for reducing the problem in addition to enhancing real-time, automatic, analytical capabilities.
- Optical absorption spectra in the UV-visible spectral region are not available for most of the CHRIS chemicals. These spectra should be measured.
- Thermal IR and microwave emissivity values are not available for most of the CHRIS chemicals. These quantities should be measured if thermal IR and passive microwave sensing methods are to be implemented effectively.

SECTION 7 ACTIVE SCANNER

7.1 BACKGROUND

Battelle-Northwest has constructed and operated aerial optical-mechanical scanner systems since 1968. The principal applications of these systems have been thermal IR and tracer dye studies of power plant outfalls and multispectral geological surveys. In recent years it has been evident that there is a need for aerial remote sensing systems to detect and map oil spills and other pollutants at night. With this motivation we began the development of an active multispectral scanner. The attractive possibility of using a laser to illuminate the ground and to stimulate fluorescence was examined, but was rejected because our objective was to develop a system that could be operated in a light twin-engine aircraft. This objective is incompatible with the large power and space requirements of existing, high power, UV lasers. A mercury-xenon arc lamp was adopted as an alternative light source.

The first flight tests of the prototype active scanner system were conducted in November, 1974. In nighttime flight tests, using two detector channels, a two-gallon slick of motor oil was imaged from an altitude of 1000 feet. The estimated average thickness of the slick was 40 μm . In addition, Rhodamine B was imaged from 1000 feet at a concentration of less than 1 ppm.

In August, 1975, the scanner was used in a unique hydraulic model study conducted jointly by the University of California at Berkeley and Battelle-Northwest for the Pacific Gas and Electric Company. The purpose of this study was to examine the behavior of a thermal plume produced by the discharge of cooling water from a nuclear reactor. The active scanner was mounted on a large crane approximately 22 feet above the water surface in the test basin. As the crane traversed the basin, two-dimensional tracer dye imagery

was acquired. This imagery graphically and quantitatively displayed the dynamic behavior of the plume under the influence of waves and currents in the model sea. Rhodamine B concentrations of less than 5 ppb were readily mapped at scan angles up to $\pm 55^\circ$ and slant ranges up to 37 feet.

The objectives of the present project are to install a four-channel detector assembly in the prototype active scanner, to test the modified system, and to evaluate the potential capabilities of this kind of an imaging system. Laboratory measurements of the fluorescence spectra of fourteen oils and five other chemicals are used together with flight test data to obtain a measure of the sensitivity of the prototype scanner and to determine the sensitivity and design improvements that would be needed to construct an effective operational version of this system.

7.2 SCANNER DESIGN AND MODIFICATIONS

7.2.1 GENERAL DESCRIPTION OF THE SCANNER

The basic design of the active scanner is shown in Figure 7.1. As shown in the diagram, the scanner utilizes *two reflecting telescopes* with a common field of view which is swept across the ground by means of rotating mirrors. This field of view, which is a circular or elliptical spot, is illuminated for nighttime operation by an arc lamp placed at the focal point of the telescope shown on the left side of the scanner. Light reflected or emitted by materials on the ground or on a water surface is focused on the tip of a fiber optics bundle placed at the focal point of the second telescope. The received light is then transmitted via the fiber optics into the detector assembly where it is separated into four spectral bands and detected by photomultiplier tubes.

The scanner can be operated in three modes: 1) An active mode for nighttime imaging of fluorescent materials. In this mode, the UV lines of a mercury-xenon arc lamp are projected onto the ground. The output of the lamp is filtered so that only the UV portion of its spectrum is transmitted. The UV light is blocked in the detectors so that they respond only to the light emitted by the fluorescent material. 2) An active mode for nighttime

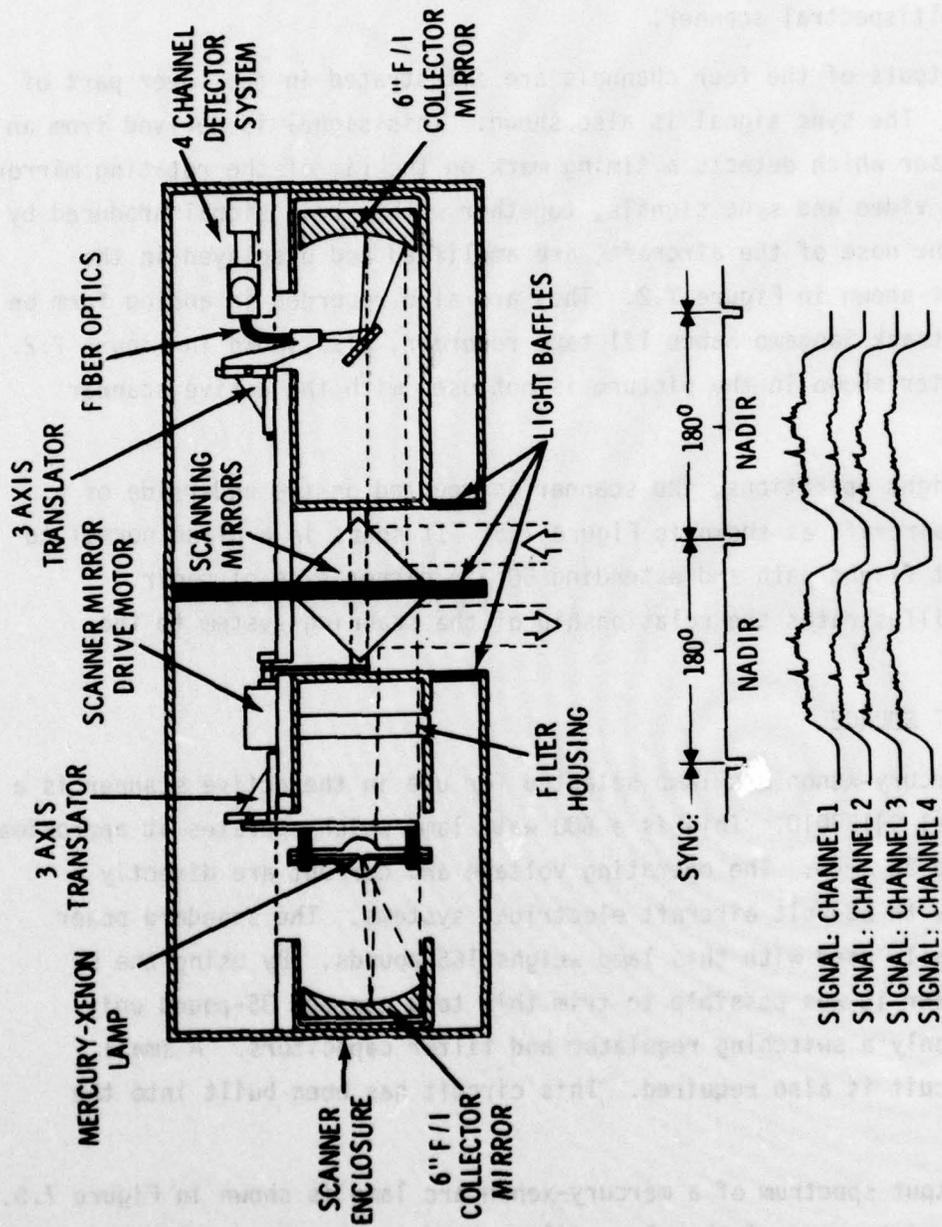


FIGURE 7.1. Schematic of Optical-Mechanical Active Scanner System and Signals Produced by the Detectors.

multispectral imaging of the ground. A xenon arc lamp is used without a source filter to illuminate the field of view. The xenon arc lamp emits a broad continuum of light in the UV to near IR spectral range. 3) The passive mode. With the arc lamp off, the scanner functions as a normal, passive, multispectral scanner.

The outputs of the four channels are illustrated in the lower part of Figure 7.1. The sync signal is also shown. This signal is derived from an optical sensor which detects a timing mark on the rim of the rotating mirror block. The video and sync signals, together with a roll signal produced by a gyro in the nose of the aircraft, are amplified and displayed in the control unit shown in Figure 7.2. They are also recorded in analog form on a fourteen-track Sangamo Sabre III tape recorder, also shown in Figure 7.2. The radiometer shown in the picture is not used with the active scanner system.

For flight operations, the scanner is mounted on the underside of a Cessna 320 aircraft as shown in Figure 7.3. It scans in a plane normal to the aircraft flight path and extending 60° to either side of nadir. Figure 7.4 illustrates the relationship of the scanning system to the ground.

7.2.2 LIGHT SOURCE

The mercury-xenon arc lamp selected for use in the active scanner is a Hanovia Model 941B0010. This is a 600 watt lamp which operates at approximately 23 volts and 26 amps. The operating voltage and current are directly compatible with 28-volt aircraft electrical systems. The standard power supply normally used with this lamp weighs 165 pounds. By using the DC aircraft power it was possible to trim this to a compact 35-pound unit containing only a switching regulator and filter capacitors. A small starter circuit is also required. This circuit has been built into the scanner.

The output spectrum of a mercury-xenon arc lamp is shown in Figure 7.5. The transmission curve of the glass filter used in the scanner is also

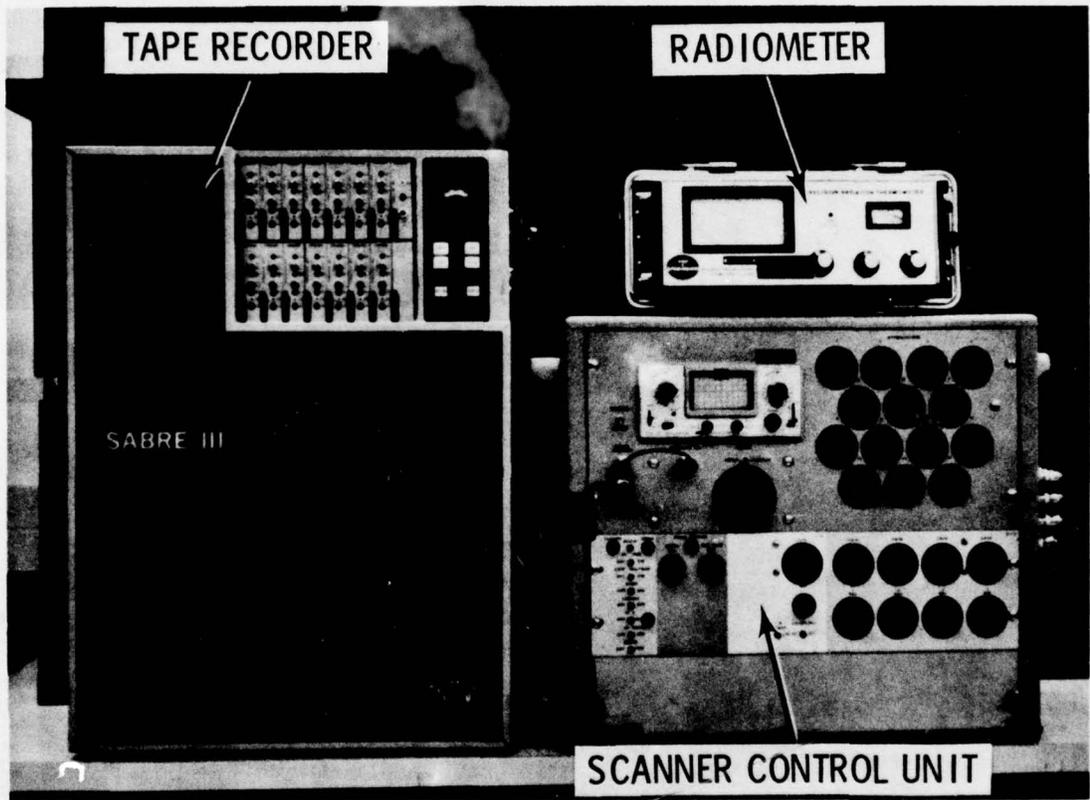


FIGURE 7.2. Recording and Control Units for the Aerial Imaging System

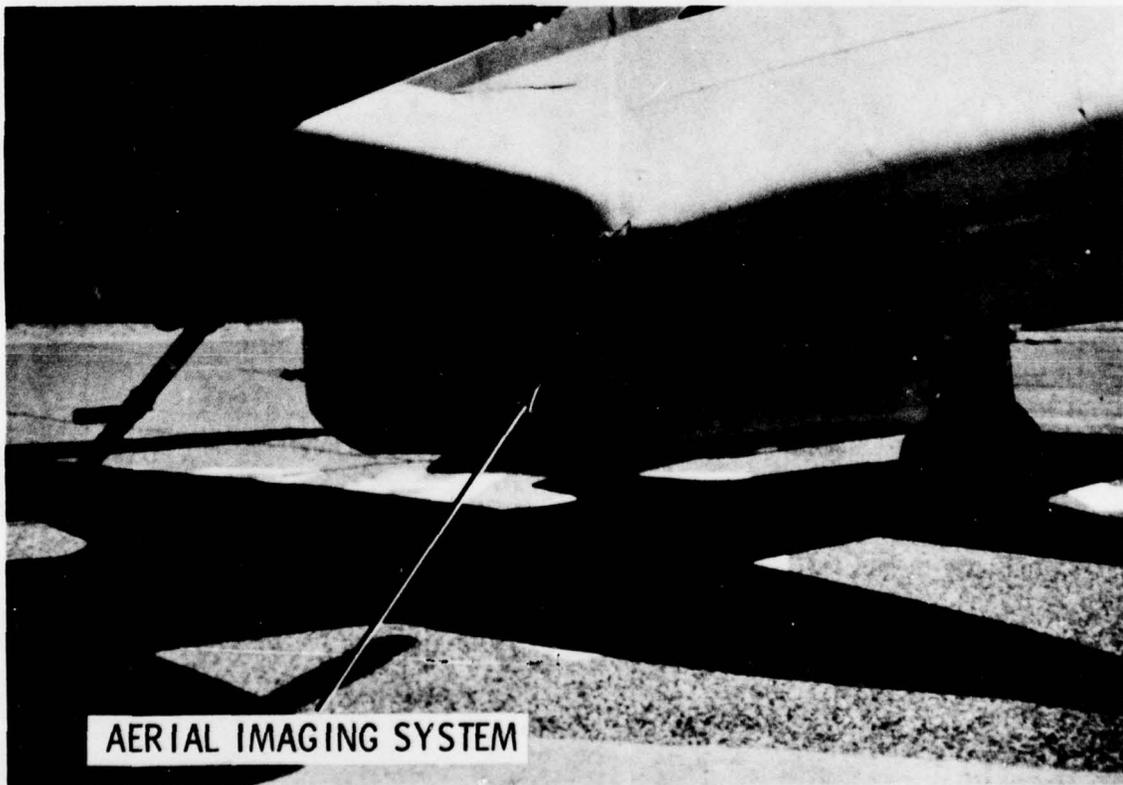
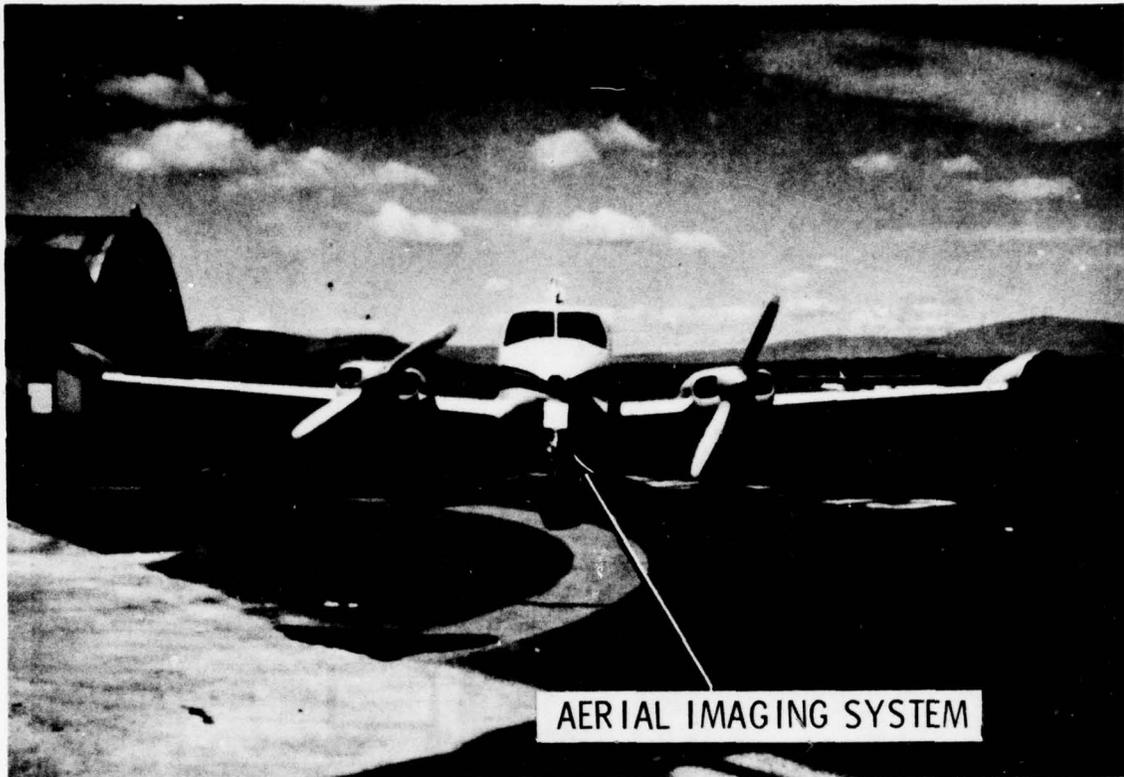


FIGURE 7.3. Aerial Imaging System Mounted on the Survey Aircraft

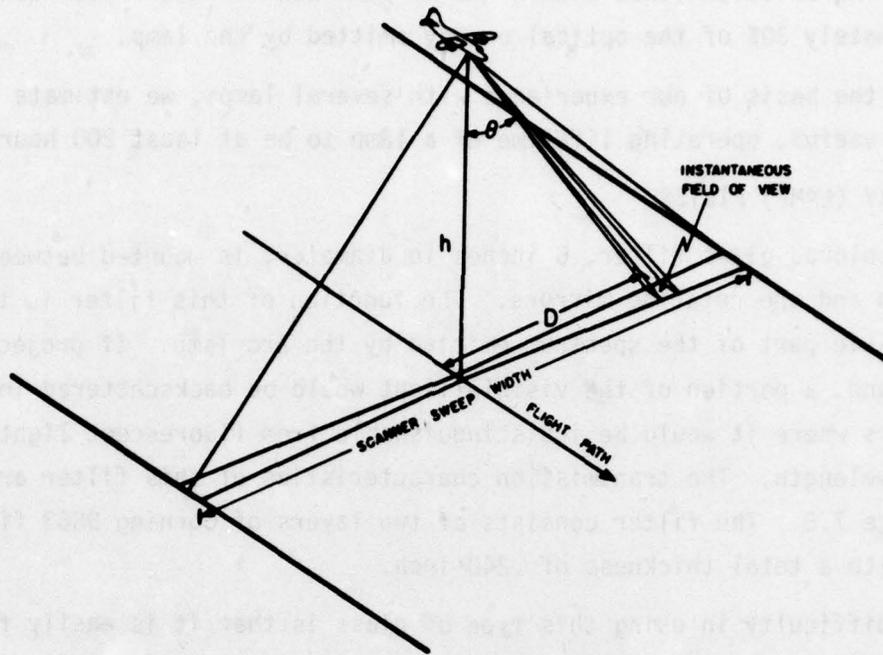


FIGURE 7.4. Imaging System Relationship to the Ground

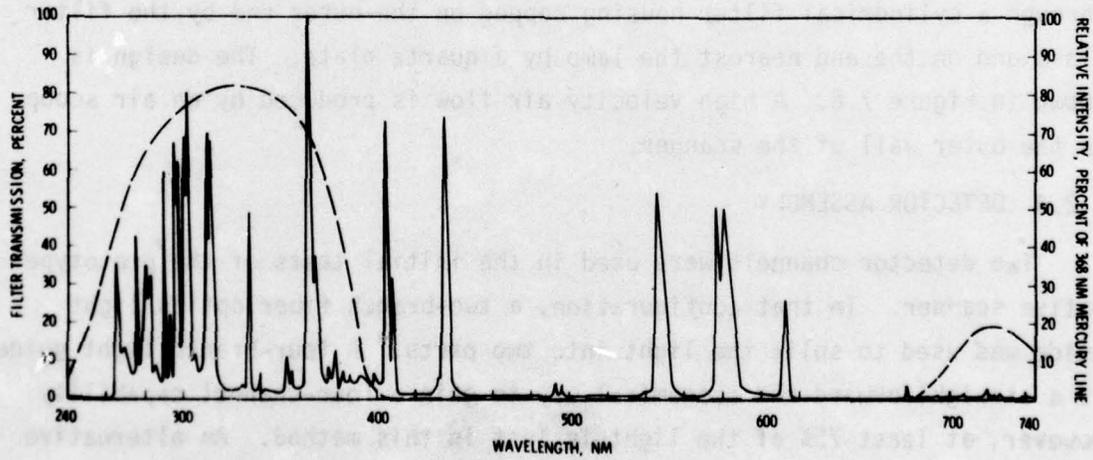


FIGURE 7.5. Mercury-Xenon Compact Arc Lamp Spectrum (Solid Line) and Corning 9863 Ultraviolet Filter Transmission (Dashed Line) Versus Wavelength

shown. The emission lines within the UV pass band of the filter contain approximately 30% of the optical energy emitted by the lamp.

On the basis of our experience with several lamps, we estimate the normal, useful, operating lifetime of a lamp to be at least 200 hours.

7.2.3 UV (LAMP) FILTER

A colored glass filter, 6 inches in diameter, is mounted between the arc lamp and the rotating mirrors. The function of this filter is to block the visible part of the spectrum emitted by the arc lamp. If projected onto the ground, a portion of the visible light would be backscattered into the detectors where it would be indistinguishable from fluorescent light of the same wavelength. The transmission characteristics of this filter are shown in Figure 7.5. The filter consists of two layers of Corning 9863 filter glass with a total thickness of .240 inch.

A difficulty in using this type of glass is that it is easily fractured by either thermal or mechanical stress. In this case, thermal stress is a severe factor because the glass absorbs much of the visible and thermal energy emitted by the arc lamp. The possibility of air cooling is complicated by the fact that the lamp, only a few inches from the filter, cannot tolerate a strong air flow. The problem was solved by ducting air through a cylindrical filter housing capped on the outer end by the filter glass and on the end nearest the lamp by a quartz plate. The design is shown in Figure 7.6. A high velocity air flow is produced by an air scoop on the outer wall of the scanner.

7.2.4 DETECTOR ASSEMBLY

Two detector channels were used in the initial tests of the prototype active scanner. In that configuration, a two-branch fiber optics light guide was used to split the light into two parts. A four-branch light guide is a straightforward and economical way to gain a four-channel capability. However, at least 75% of the light is lost in this method. An alternative method which offers a potential for better efficiency was devised and is illustrated in Figure 7.7. A bifurcated light guide is used to transmit

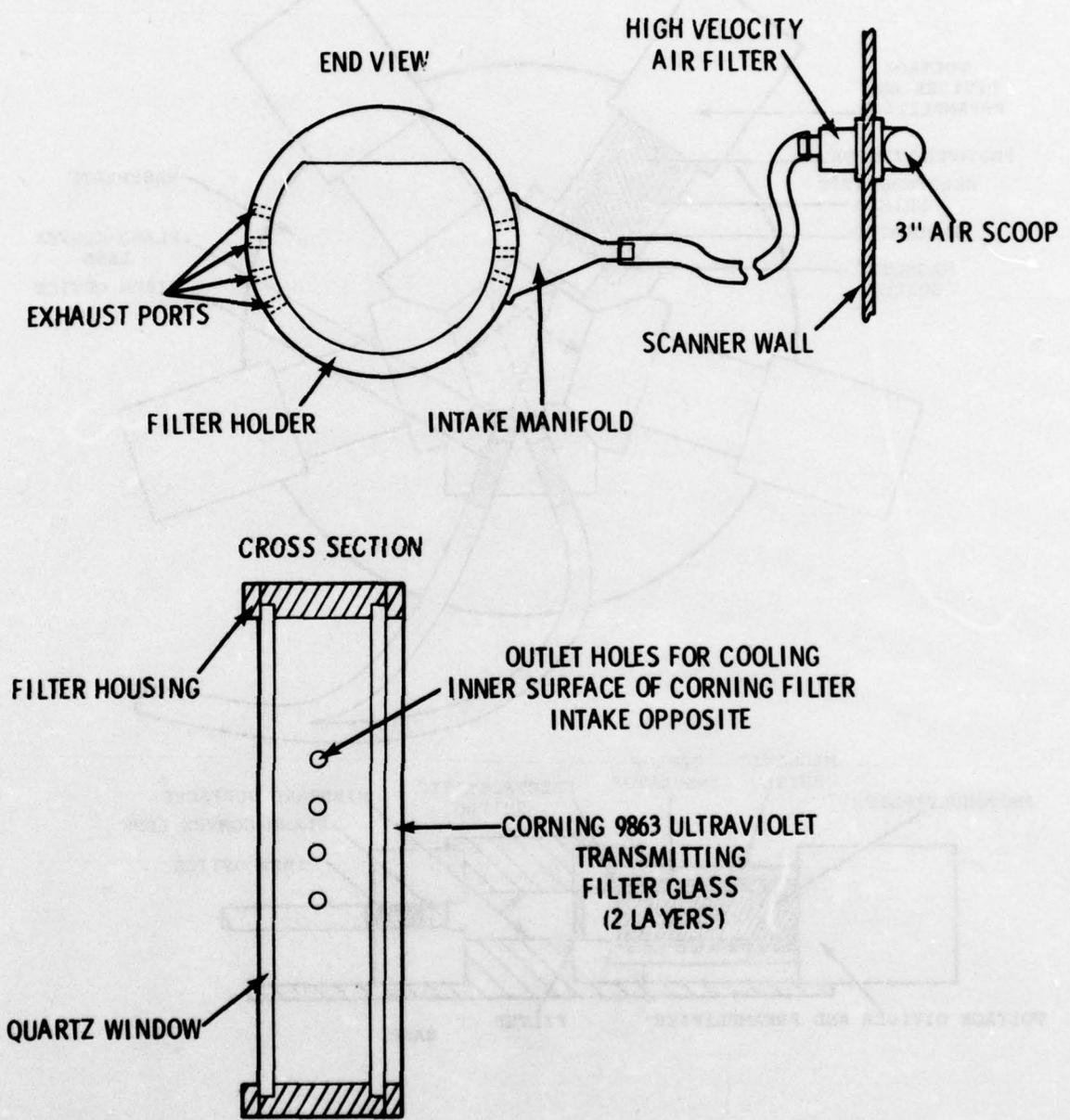


FIGURE 7.6. Assembly for Mounting and Cooling the Visible-Band Blocking Filter.

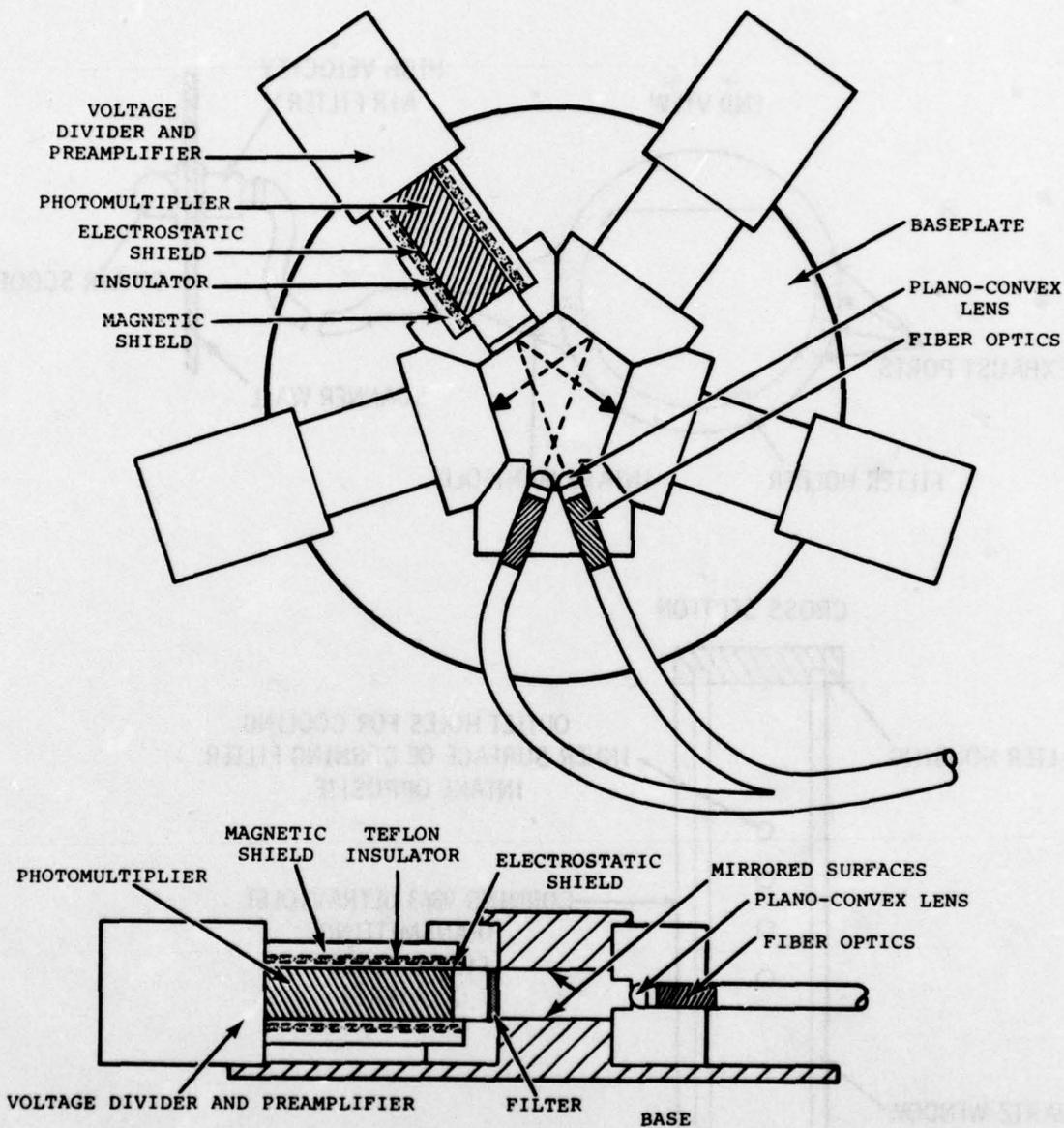


FIGURE 7.7. Four-Channel Detector Assembly. The Upper Drawing Shows the Interior of the Assembly and Details of One Detector Housing. The Lower Drawing is a Cross Section of the Assembly.

light from the receiver telescope to the interior of a pentagonal cavity. The light enters through a block on one side of the pentagon. An interference filter is mounted flush with the interior wall of each of the other four blocks. The two middle filters in the pentagon are directly illuminated by the two branches of the fiber optics light guide. Wavelengths within the passbands of these two filters are transmitted through the filters and are detected by the photomultiplier tubes mounted directly behind the filters. Wavelengths outside the passbands of the middle filters are reflected toward the other two filters where additional fractions are transmitted and detected. The reflectivity of each of the filters is in the range 80-90% at wavelengths outside its passband. Additional efficiency is derived from reflections within the cavity. Small lenses at the entry ports focus the light on the filters, and the inner surfaces of the top and bottom caps are aluminized glass mirrors. The gain in efficiency of this system in comparison with a simple four-branch light guide arrangement is approximately 50%.

The optical bandpass characteristics of the filters were selected to cover the range 400-600 nm in four approximately equal parts. The transmission curves are shown in Figure 7.8.

The photomultiplier tubes used in Channels 1-3 are RCA type C31005C. These tubes have a high sensitivity near 400 nm but the sensitivity declines rapidly above 500 nm. An RCA type C70042K which peaks at about 580 nm is therefore used in channel 4. The spectral response characteristics of these tubes are shown in Figure 7.9.

In order to minimize electrical noise due to the aircraft electrical system and mirror drive motor, the photomultiplier tubes are enclosed in both electrostatic and magnetic shields. In addition, a preamplifier is mounted directly on the back of each of the tubes. The preamps utilize COS/MOS operational amplifiers which require only a single-polarity power supply. A schematic diagram is given in Figure 7.10.

7.3 LABORATORY FLUORESCENCE MEASUREMENTS

The active scanner stimulates fluorescent emission by illuminating fluorescent materials with a broad band of UV light. The dominant components

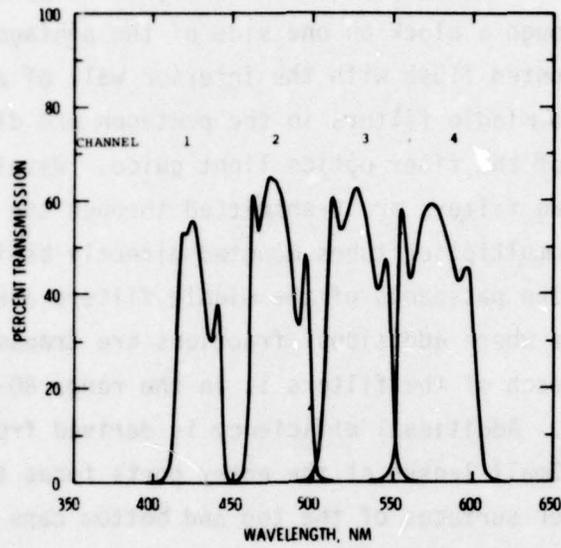


FIGURE 7.8. Detector Filter Bandpass Characteristics.

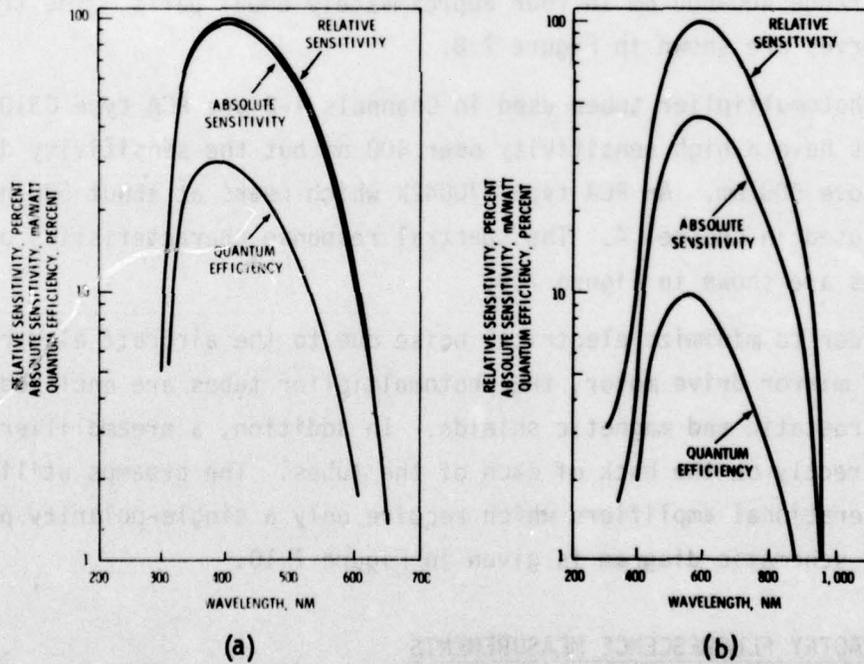


FIGURE 7.9. Photomultiplier Characteristics: (a) RCA31005C Used in Channels 1, 2, & 3; and (b) RCA70042K Used in Channel 4.

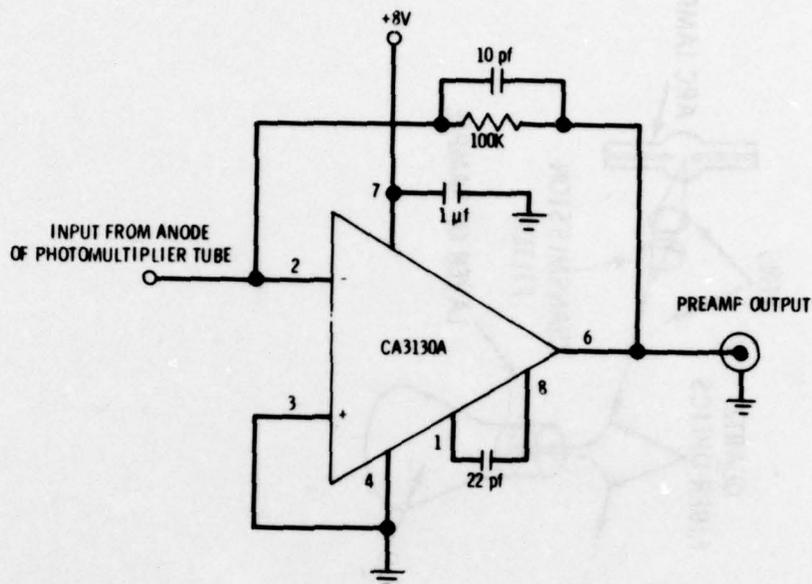


FIGURE 7.10. Circuit Diagram for Photomultiplier Preamplifier.

in this light are the mercury lines between 260 and 380 nm. This range of wavelengths is much greater than the excitation bandwidths normally used for laboratory measurements of fluorescence spectra and will produce fluorescence spectra that are different from those normally measured.

In order to test the prototype scanner and to assess its potential capabilities, it is important to determine the character of fluorescent spectra produced by the scanner's light source. For this purpose we have constructed a laboratory light source identical to the one used in the scanner, and have used it, along with a modified laboratory spectrophotometer, to measure the fluorescence spectra of fourteen oils and five other chemicals.

7.3.1 LABORATORY INSTRUMENTATION

The system that was used for the fluorescence measurements is illustrated in Figure 7.11. The assembly on the left is a Beckman DK-2A spectrophotometer

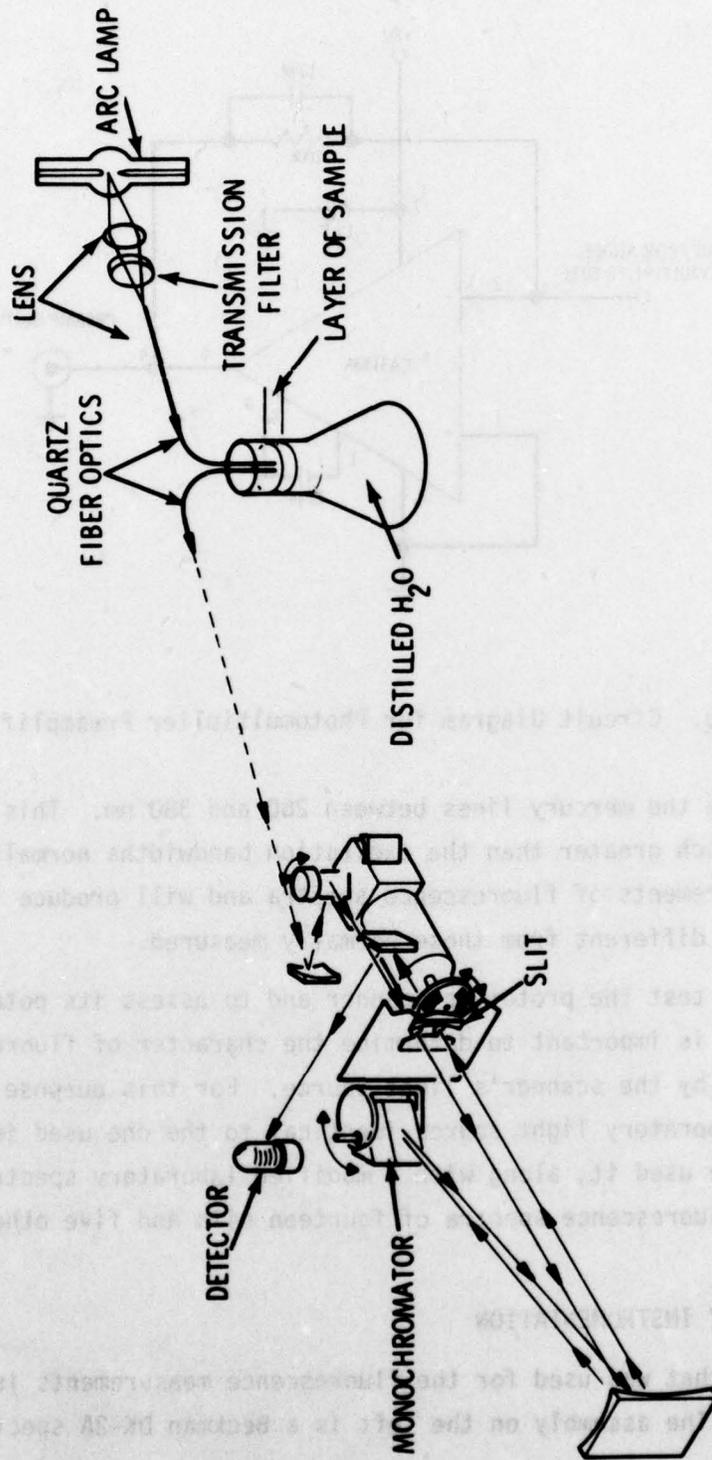


FIGURE 7.11. Optical Path Diagram of the Modified Beckman DK-2A Spectrophotometer Used for Laboratory Fluorescence Measurements. (Adapted from Beckman DK-2A Instruction Manual.)

with a modified reflectance attachment. The light emitted by a 600 watt mercury-xenon arc lamp, shown on the right, is filtered by two layers of Corning 9863 glass and is focused on one branch of a bifurcated fiber optics light guide. The light guide is constructed of special quartz fibers which have a high transmissivity in the UV as well as in the visible spectral region. The UV light emitted at the common end of the light guide is directed onto the sample which is contained in a red, actinic, glass flask. A portion of the fluorescent light emitted by the sample re-enters the light guide. The fraction that enters the fibers of the second branch of the light guide is transmitted to the spectrophotometer where it is spectrally analyzed, detected, and plotted on a paper chart.

Additional details of the construction of the light source, light guide, and sample container are shown in Figure 7.12.

Although the quartz used in the fiber optics is highly transparent in the UV, it does fluoresce slightly in the visible range. The level of this background is essentially invariant, so it can be accurately measured and subtracted from the fluorescence data. It is significant only for very weakly fluorescing samples, but at very low levels it does limit the spectral accuracy of the system.

7.3.2 MEASUREMENT PROCEDURES, CALIBRATION, AND DATA PROCESSING

In order to obtain relative fluorescence intensities of the measured spectra, each measurement was compared to the fluorescence peak of a standard, 1 ppm, 8-inch deep solution of Rhodamine B. This procedure also compensated for changes in the arc lamp power setting from day to day. Over a period of several hours, the lamp intensity was stable to within $\pm 1\%$ of the initial level.

Fluorescence spectra were measured for several film thicknesses, usually in the range .01-10. mm, although some measurements were made at thicknesses of .001 mm ($1 \mu\text{m}$) and 50 mm. Very thin films tended to be non-uniform due to surface tension effects, but in most cases, gentle stirring of the film produced a nearly uniform fluorescent intensity across

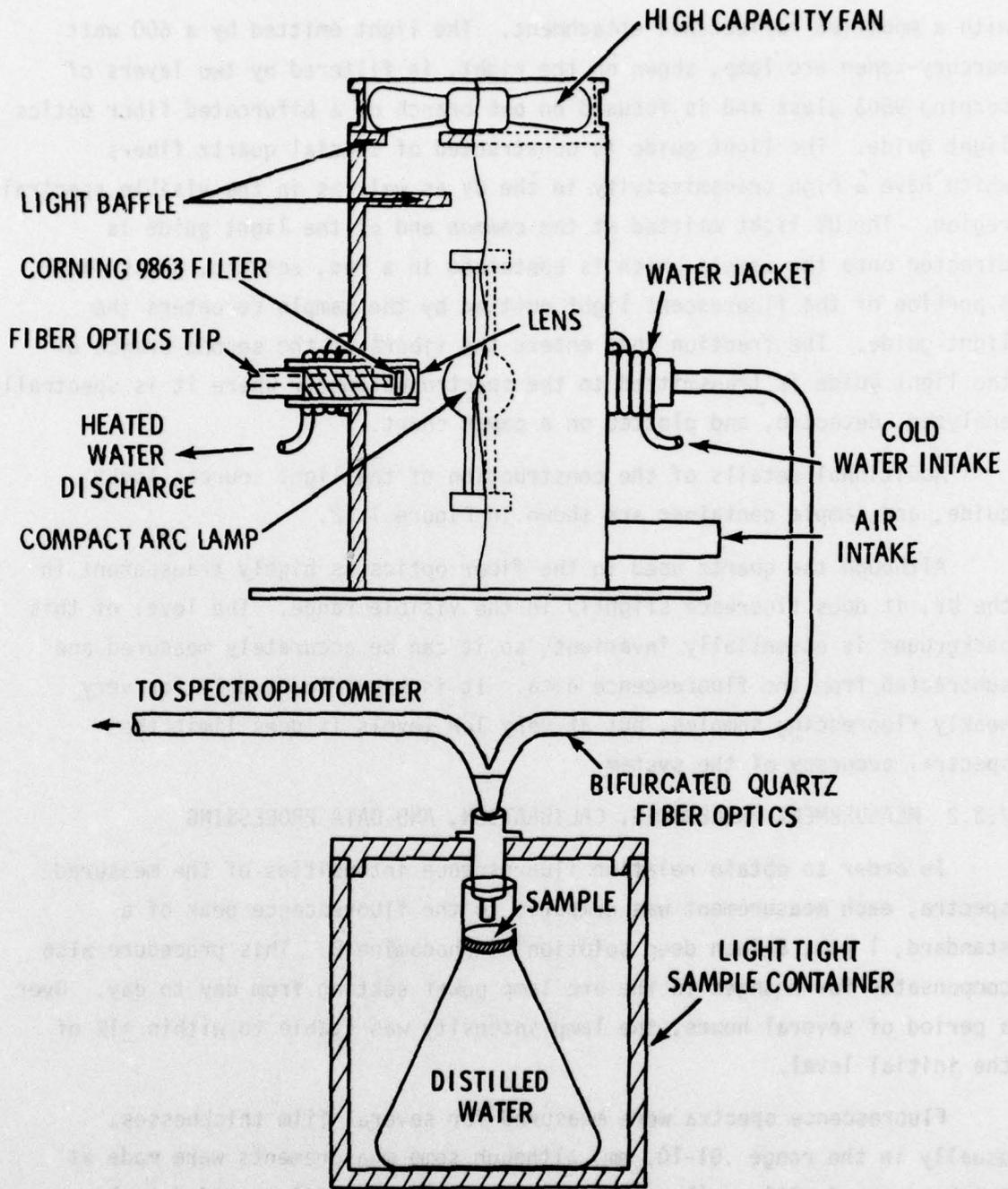


FIGURE 7.12. Diagram of Arc Lamp Housing, Sample Container, and Interconnecting Quartz Fiber Optics.

the sample. The spreading of the illuminating beam and the acceptance angle of the fiber optics yielded an average of the fluorescence intensity over a circular area approximately .5 inch in diameter. The diameter of the sample was 1.60 inches.

The fluorescence spectra were initially recorded on paper charts and subsequently digitized for computer processing and final plotting. A system response function was measured using a standard tungsten lamp at a brightness temperature of 2100 K. This function was input to the computer for automatic correction of the fluorescence spectra. The computer also subtracted the background, reduced the spectral intensities to units relative to the peak intensity of the Rhodamine standard, and output the corrected spectra to a CalComp plotter.

7.3.3 FLUORESCENCE SPECTRA

Table 7.1 lists the fourteen oils for which fluorescence measurements were made. Eight of these are crudes and six are refined oils. The sample of Santa Barbara Crude was obtained from a natural oil seep, and was provided for this study by the U.S. Coast Guard Research and Development Center, Groton, Connecticut. Eleven oils were provided by the Gulf and Chevron Oil Companies. The lubricating oils were obtained locally.

The API gravity of each of the oils and three parameters obtained from measurements of the fluorescence spectra are also listed in Table 7.1. The Relative Fluorescent Intensity is the ratio of the peak intensity of the oil fluorescence spectrum to the peak intensity of the Rhodamine spectrum. These values were measured at several oil film thicknesses. The values given in the table correspond to the peak intensities of the thickest samples. For most of the oils the fluorescence intensity of the thickest layer used in the measurements closely approaches a saturation value. Saturation occurs when the oil layer is sufficiently thick that it is opaque to incident energy in its absorption band. Thinner layers are partially transparent and the emitted fluorescence intensity is correspondingly weaker. The film thickness which yields an intensity equal to half the

TABLE 7.1. Summary of Oil Samples and Measured Data.

OIL TYPE	ABBREVIATION	API GRAVITY	RELATIVE FLUORESCENT INTENSITY	THICKNESS AT 1/2 MAX INTENSITY (MM)	PEAK WAVELENGTH (NM)
JET FUEL	JF	45.2			<400
PENNSYLVANIA CRUDE	PC	43.5	3.10	0.056	435
ARABIAN HEAVY DIESEL	AHD	40.0		1.96	<400
SOUTH LOUISIANA CRUDE	SLC	35.1	2.50	0.020	472
NUMBER 2 FUEL OIL	N2FO	34.9			<400
ARABIAN LIGHT CRUDE	ALC	31.1	0.70	0.008	535
KUWAIT CRUDE	KC	30.6	0.42	0.0012	550
CEUTA (VENEZUELA) CRUDE	CVC	29.1	0.29	0.0022	525
SAN JOAQUIN VALLEY HEAVY DIESEL	SJVHD	27.3	4.03	0.185	<400
ARABIAN HEAVY CRUDE	AHC	25.3	0.29	0.0016	575
VALVOLINE 85W140	V85W	22.9	7.75	0.136	432
SANTA BARBARA CRUDE	SBC	21.9	0.11	0.001	545
AERO NUMBER 20 MOTOR OIL	A20MO	18.4	5.60	0.13	438
SAN JOAQUIN VALLEY HEAVY CRUDE	SJVHC	17.2	0.29	0.0018	555

saturation value was arbitrarily selected as a parameter to characterize the intensity versus thickness behavior, or the transparency, of the oils.

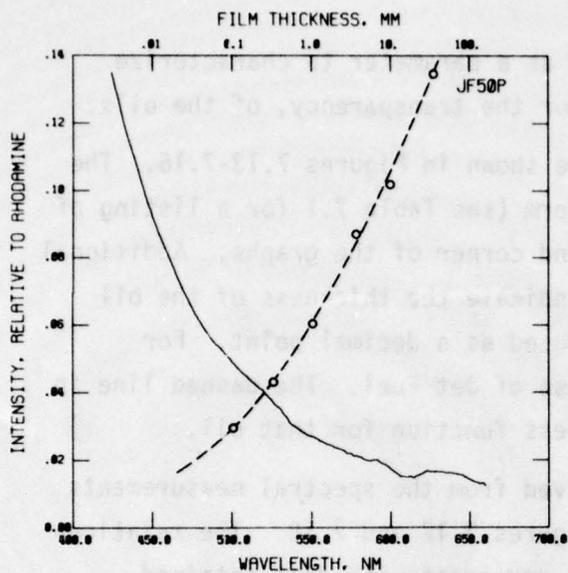
The measured fluorescence spectra are shown in Figures 7.13-7.16. The oil type is specified in an abbreviated form (see Table 7.1 for a listing of the abbreviations) in the upper right-hand corner of the graphs. Additional characters are appended to each name to indicate the thickness of the oil layer (in millimeters). The letter P is used as a decimal point. For example, JF50P refers to a 50. mm thickness of Jet Fuel. The dashed line in each group shown the intensity vs. thickness function for that oil.

The oil fluorescence parameters derived from the spectral measurements and listed in Table 7.1 are plotted in Figures 7.17 and 7.18. The relationships shown in these plots are in general agreement with data obtained previously by other investigators using different methods. In particular, the curves of intensity vs. peak wavelength and peak wavelength vs. API gravity (Figures 7.18b and 7.18c) correspond reasonably well to similar curves obtained by Fantasia and Ingra⁴².

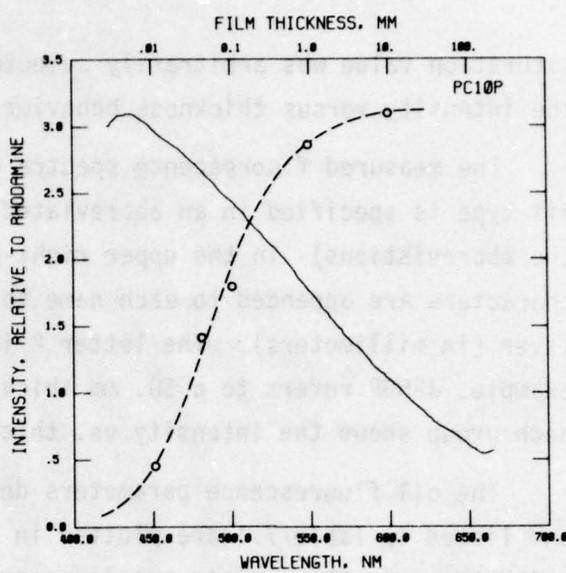
In all of these plots, there is a tendency for the crude and refined oils to form distinct groups. This tendency is particularly striking in Figure 7.17b, where the separation has been accentuated by fitting two straight lines to the data. In Figures 7.18a and 7.18c, straight lines have been fitted to the crude oil data only.

Several generalizations are suggested by these data. They can be stated as follows:

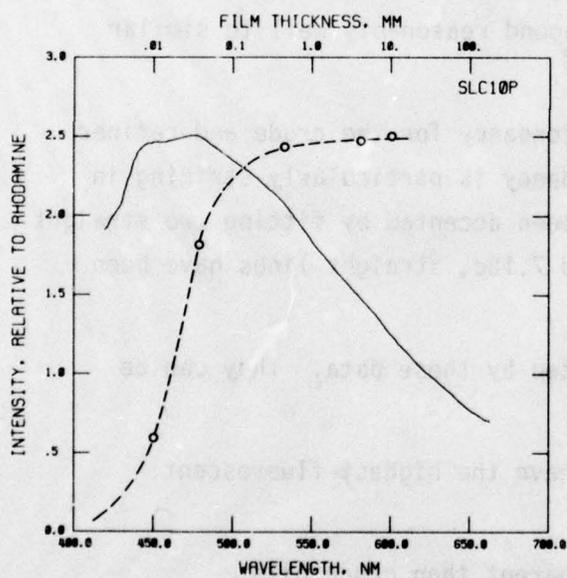
- The most transparent oils tend to have the highest fluorescent intensities.
- Refined oils tend to be more transparent than crude oils.
- Light crude oils tend to be more transparent, to have higher fluorescent intensities, and to fluoresce at shorter wavelengths than do heavy crude oils.



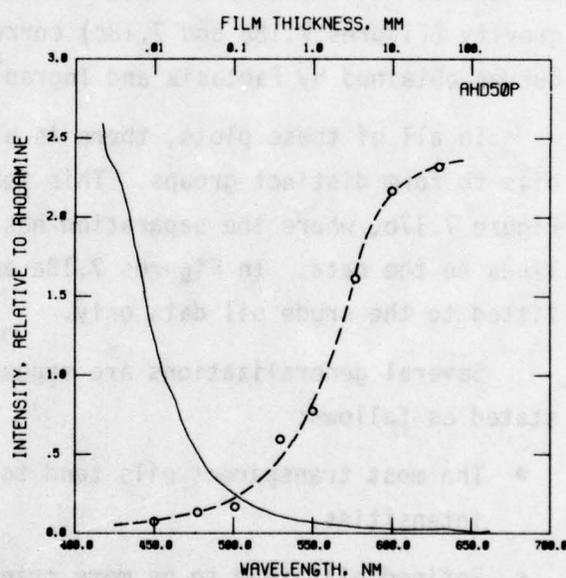
(a)



(b)

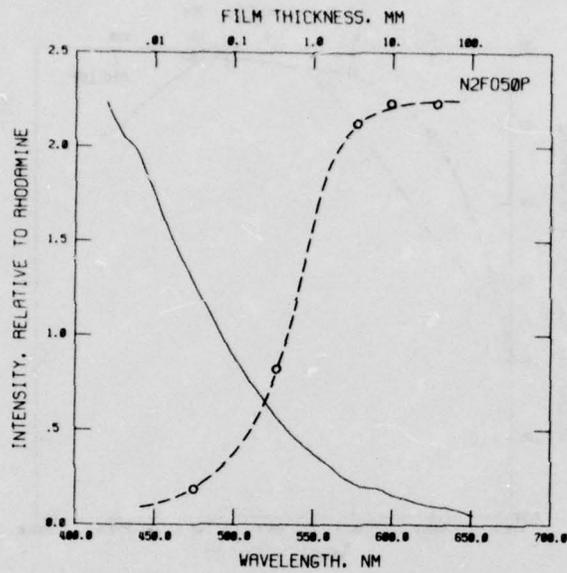


(c)

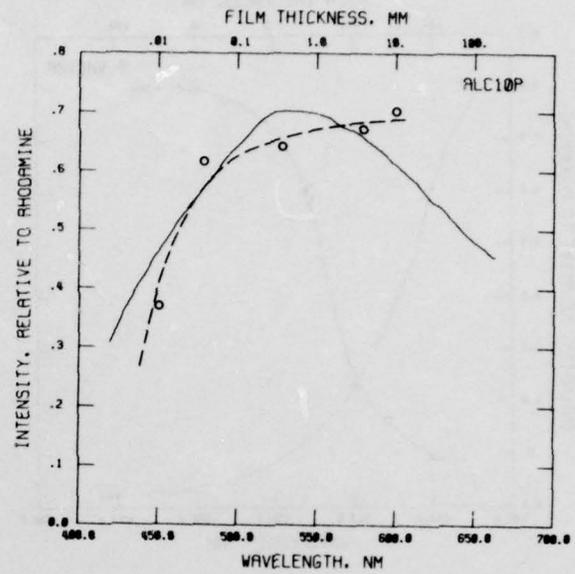


(d)

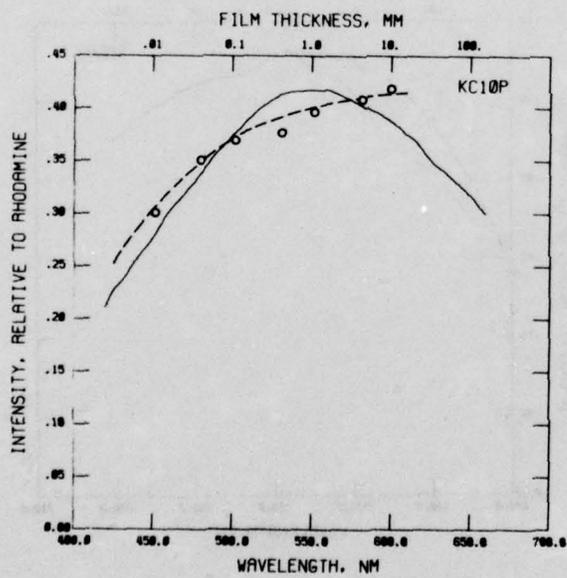
FIGURE 7.13. Fluorescence Intensity Versus Wavelength (Solid Line) and Film Thickness (Dashed Line) for: (a) Jet Fuel; (b) Pennsylvania Crude; (c) South Louisiana Crude; and (d) Arabian Heavy Diesel.



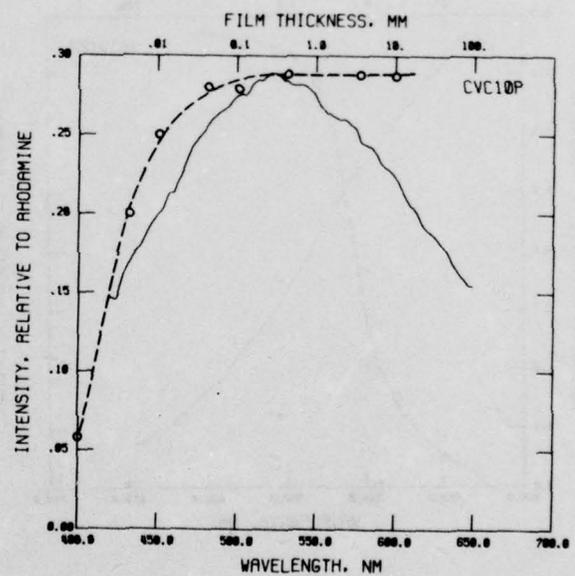
(a)



(b)

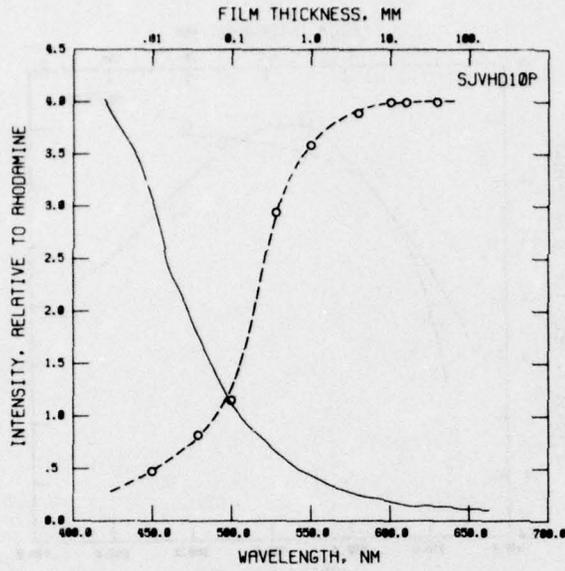


(c)

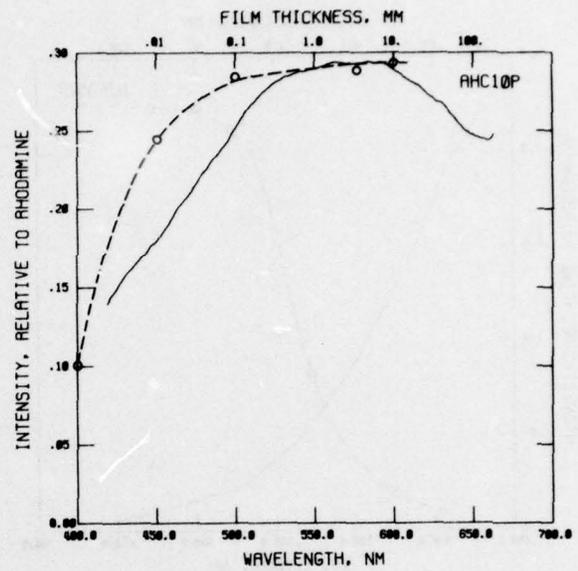


(d)

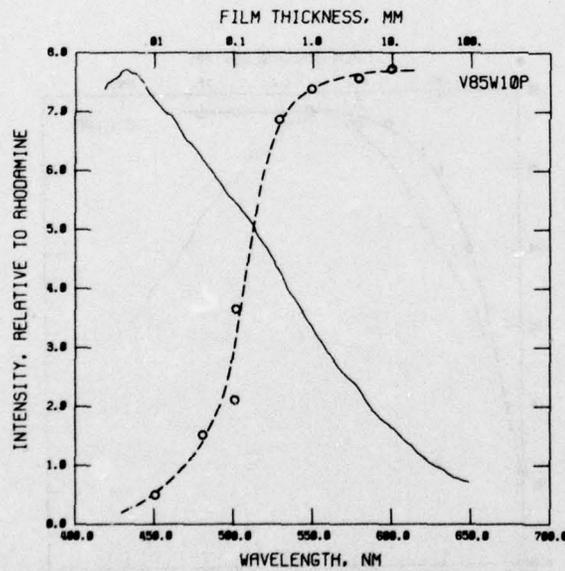
FIGURE 7.14. Fluorescence Intensity Versus Wavelength (Solid Line) and Film Thickness (Dashed Line) for: (a) No. 2 Fuel Oil; (b) Arabian Light Crude; (c) Kuwait Crude; and (d) Venezuelan Crude.



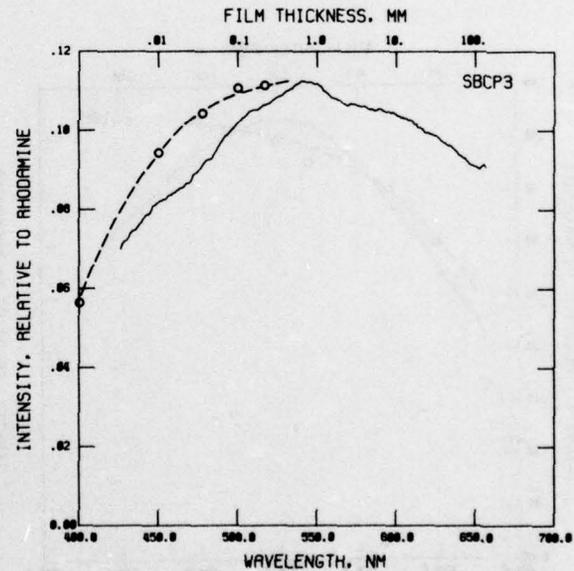
(a)



(b)

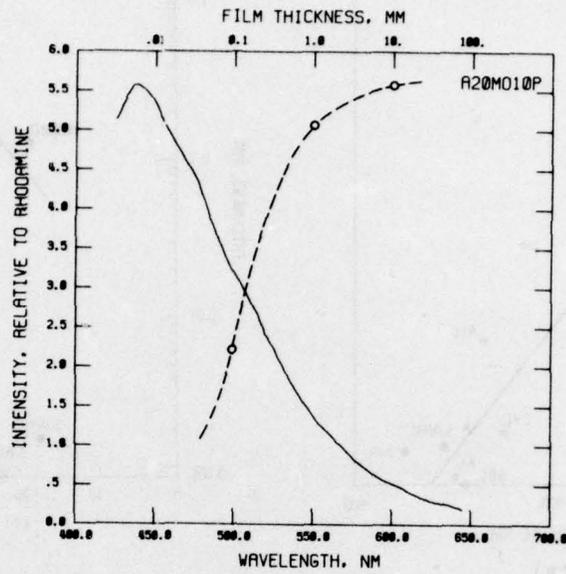


(c)

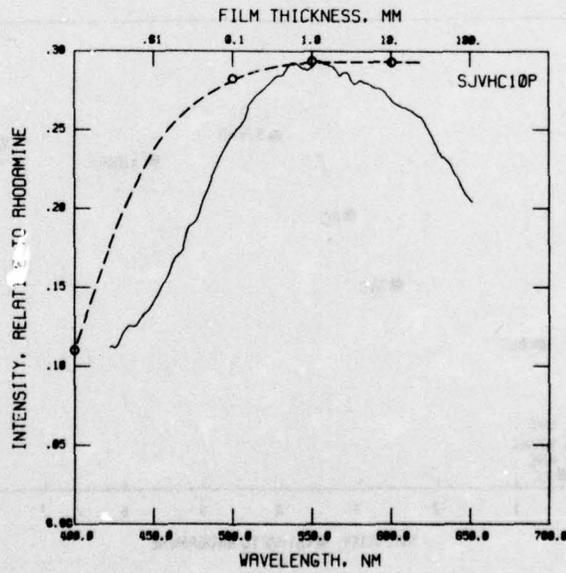


(d)

FIGURE 7.15. Fluorescence Intensity Versus Wavelength (Solid Line) and Film Thickness (Dashed Line) for: (a) San Joaquin Valley Heavy Diesel; (b) Arabian Heavy Crude; (c) Valvoline 85W140 Gear Oil, and (d) Santa Barbara Crude.

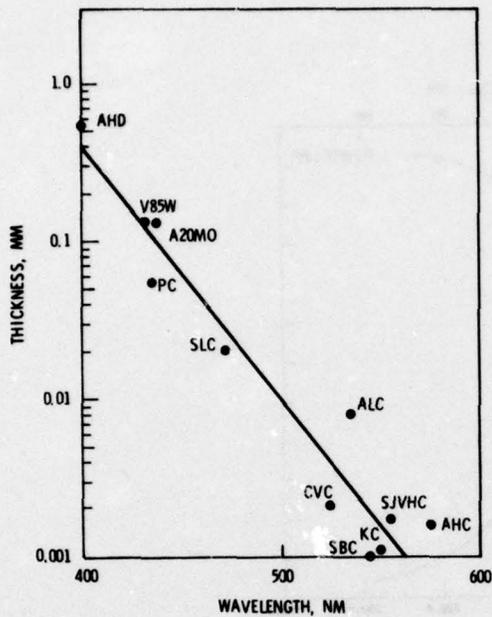


(a)

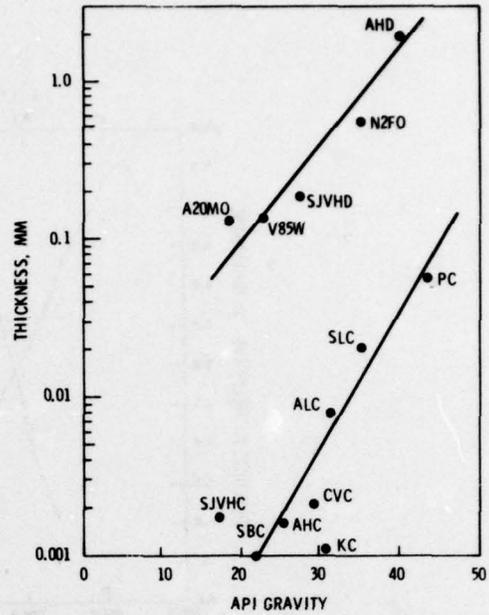


(b)

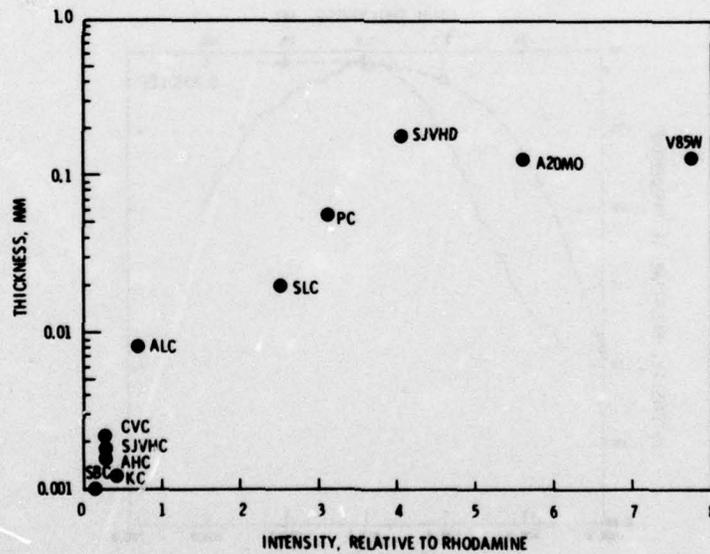
FIGURE 7.16. Fluorescence Intensity Versus Wavelength (Solid Line) and Film Thickness (Dashed Line) for: (a) Aero 20 Motor Oil; and (b) San Joaquin Valley Heavy Crude.



(a)

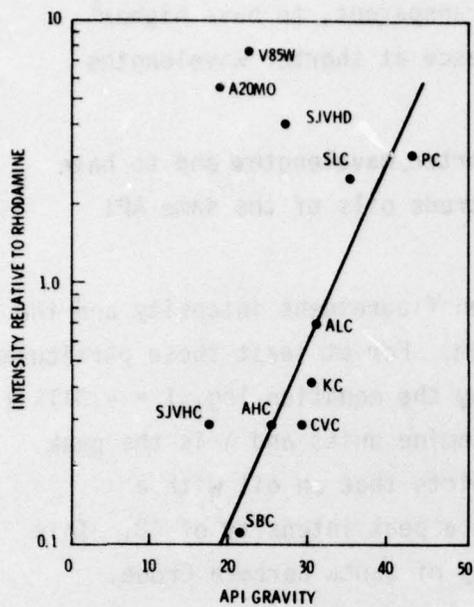


(b)

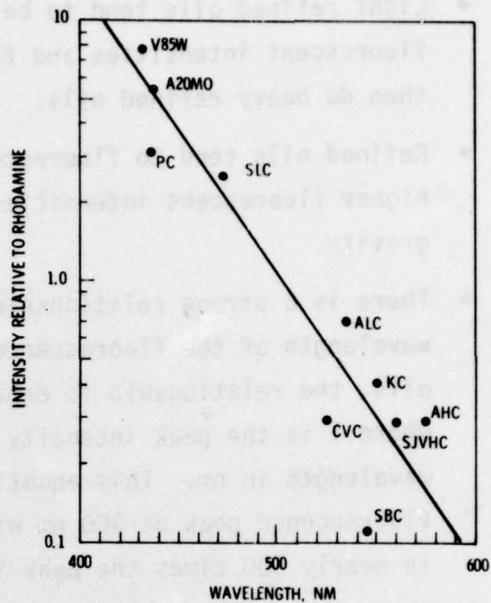


(c)

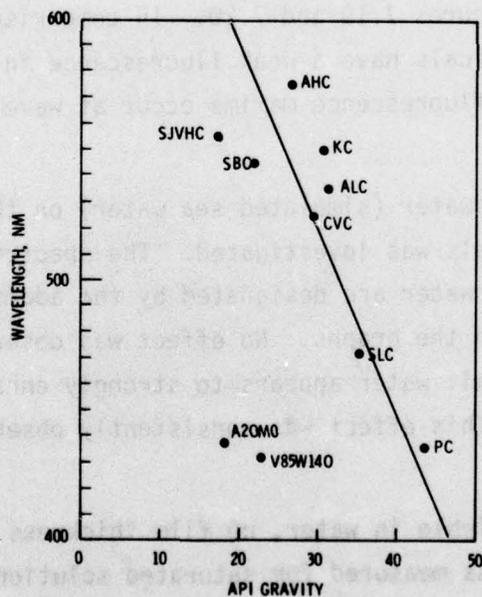
FIGURE 7.17. Oil Film Thickness at 1/2 Maximum Intensity Versus: (a) Peak Wavelength; (b) API Gravity; and (c) Fluorescence Intensity.



(a)



(b)



(c)

FIGURE 7.18. (a) Oil Fluorescence Intensity Versus API Gravity; (b) Fluorescence Intensity Versus Peak Wavelength; and (c) Peak Wavelength Versus API Gravity.

- Light refined oils tend to be more transparent, to have higher fluorescent intensities and to fluoresce at shorter wavelengths than do heavy refined oils.
- Refined oils tend to fluoresce at shorter wavelengths and to have higher fluorescent intensities than crude oils of the same API gravity.
- There is a strong relationship between fluorescent intensity and the wavelength of the fluorescence maximum. For at least these particular oils, the relationship is expressed by the equation $\log_{10} I = -.011\lambda + 5.5$, where I is the peak intensity in Rhodamine units and λ is the peak wavelength in nm. This equation predicts that an oil with a fluorescence peak at 350 nm will have a peak intensity of 48. This is nearly 500 times the peak intensity of Santa Barbara Crude.

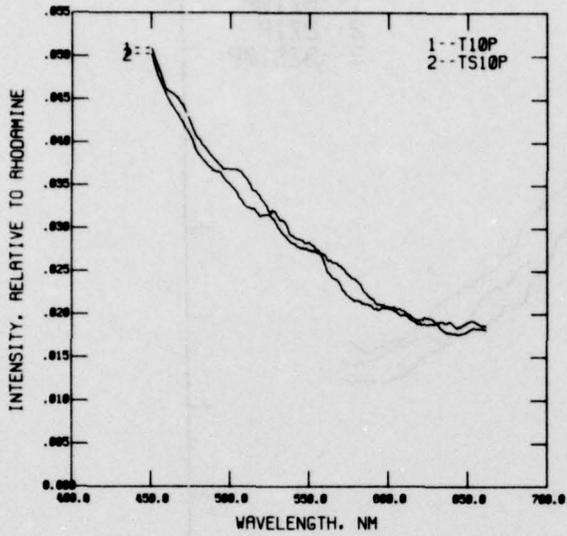
Fluorescence measurements were also made for the chemicals toluene(T), xylene(X), phenol(PHN), styrene(S), and benzene(BZ). Their fluorescence spectra are shown in Figures 7.19 and 7.20. In comparison with the oils, all of these chemicals have a weak fluorescence in the visible spectral range. Their fluorescence maxima occur at wavelengths less than 400 nm.

The effect of salt water (simulated sea water) on the fluorescence spectra of these chemicals was investigated. The spectral curves which were measured with salt water are designated by the addition of the letter S in the labels printed on the graphs. No effect was observed except in the case of styrene where salt water appears to strongly enhance the fluorescence in the visible range. This effect was consistently observed in repeated measurements.

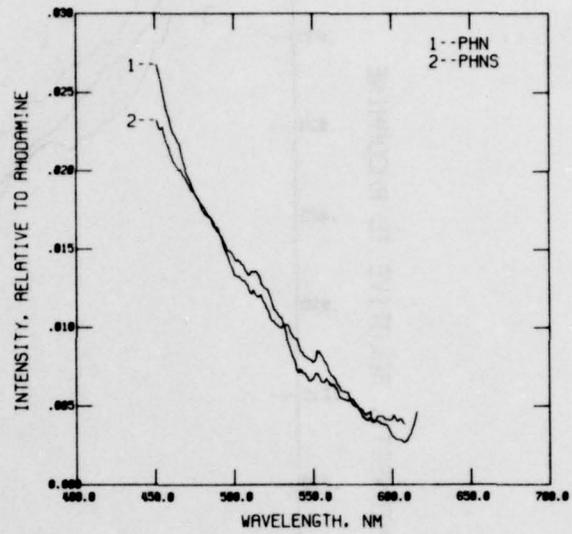
Since phenol is soluble in water, no film thickness is indicated. Its fluorescence spectrum was measured for saturated solutions in distilled water and salt water.

7.3.4 SCANNER TESTS

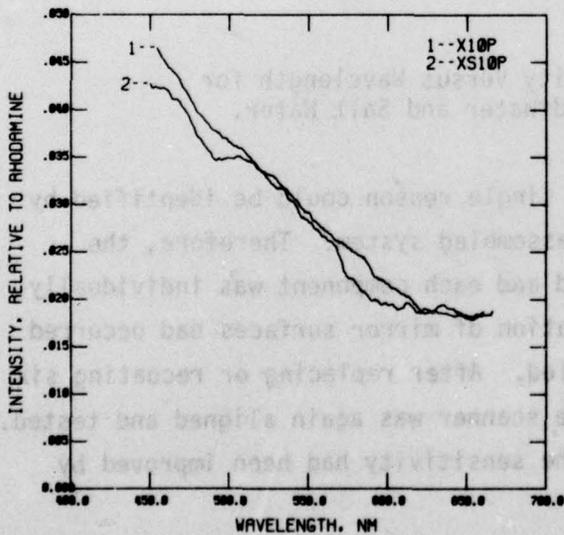
Initial laboratory tests of the modified active scanner indicated that the sensitivity was not as high as expected. Subsequent flight tests over



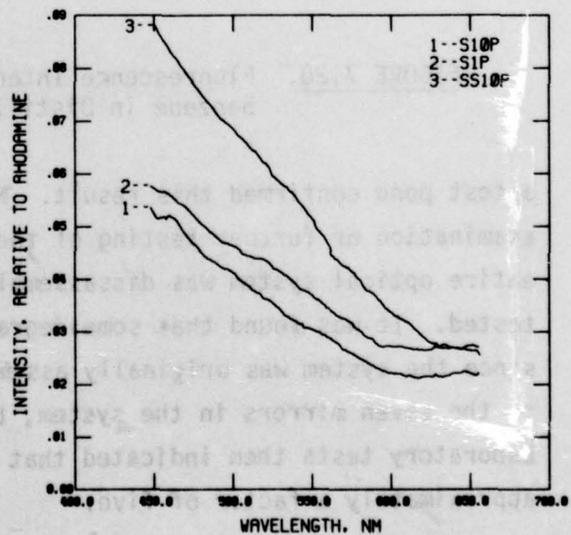
(a)



(b)



(c)



(d)

FIGURE 7.19. Fluorescence Intensity Versus Wavelength for:
 (a) Toluene; (b) Phenol; (c) Xylene; and (d) Styrene.

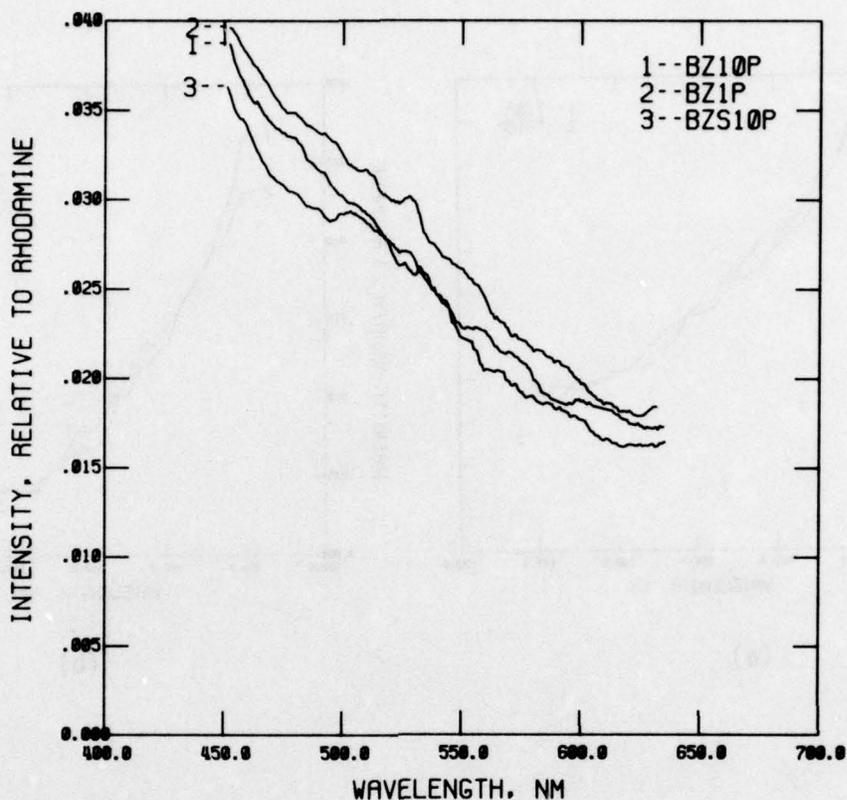


FIGURE 7.20. Fluorescence Intensity Versus Wavelength for Benzene in Distilled Water and Salt Water.

a test pond confirmed this result. No single reason could be identified by examination or further testing of the assembled system. Therefore, the entire optical system was disassembled and each component was individually tested. It was found that some degradation of mirror surfaces had occurred since the system was originally assembled. After replacing or recoating six of the seven mirrors in the system, the scanner was again aligned and tested. Laboratory tests then indicated that the sensitivity had been improved by approximately a factor of five.

The system response functions for the four signal channels are shown in Figure 7.21. These curves include, in addition to the detector and filter response functions the reflectivities of all of the mirror surfaces in the receiver section of the scanner. While these curves have the general shape of the filter transmission curves shown in Figure 7.8, they do not show the same detailed structure. The reason is that the system response measurements were made with a broader spectral bandwidth. The sensitivity of channel 4 is unexpectedly low, but in order to be able to proceed quickly with a testing program it was decided to accept this result.

As a preliminary test of the system, a piece of cardboard was painted with a thin film of AERO Number 20 motor oil and was scanned at a range of 117 feet. The oil fluorescence was easily detected in all four channels. The measured signal levels are plotted in Figure 7.22 along with the corresponding fluorescence spectrum as measured by the spectrophotometer. The measured spectrum has been normalized to a peak value of 1.0. The scanner signals were scaled to match the spectral curve at the center wavelength of channel 1.

For the purpose of conducting local flight tests of the scanner, a set of shallow, plastic-lined test ponds were constructed on a large concrete slab. Six ponds were assembled, each having the dimensions 20 ft x 10 ft x 3 inches. These were positioned on the slab in a 3 x 2 array with spacings varying from a few inches to approximately 4 feet. The ponds were filled with water to a depth of approximately 2 inches. In order to insure complete coverage of the water surface, 8 gallons of Valvoline 85W140 gear oil were distributed equally among the six ponds. The resulting film thickness was nominally about .25 mm. However, the ponds were not completely water-tight and some water and a thin film of oil spread out over part of the concrete slab.

Nighttime test flights were made over these ponds at altitudes of 1000, 560, 350, and 230 feet. The oil was detected at all of these altitudes.

Figure 7.23 is a blowup of imagery obtained from an altitude of 1000 feet. The ponds are clearly distinguished except for two ponds which appear to have merged.

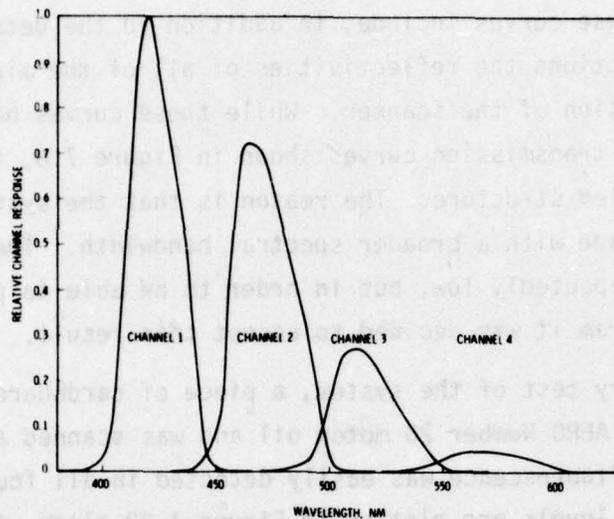


FIGURE 7.21. Relative Response Curves for the 4-Channel Detector System.

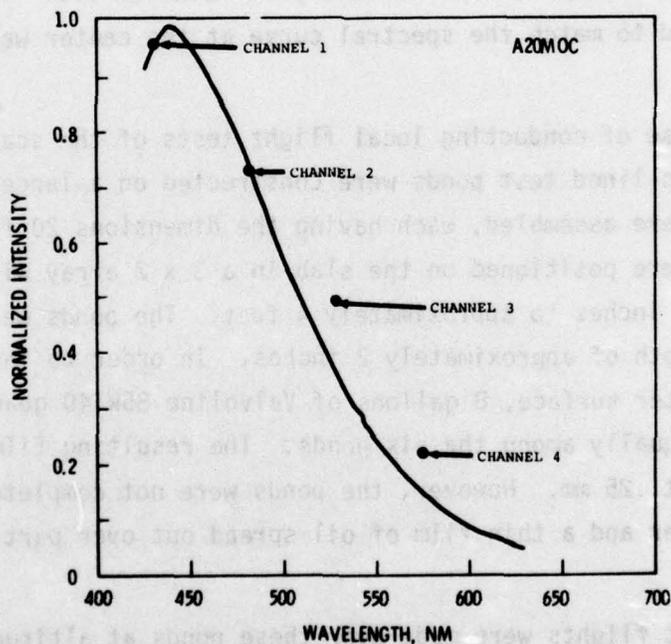


FIGURE 7.22. Oil Fluorescence Spectra Measured by the Active Scanner and the Spectrophotometer. The Dots are Normalized Signal Levels for the Four Scanner Detector Channels. The Curve is the Measured Fluorescence Spectrum for AERO 20 Motor Oil Painted on Cardboard. The Data were Measured in the Laboratory at a Range of 117 Feet.

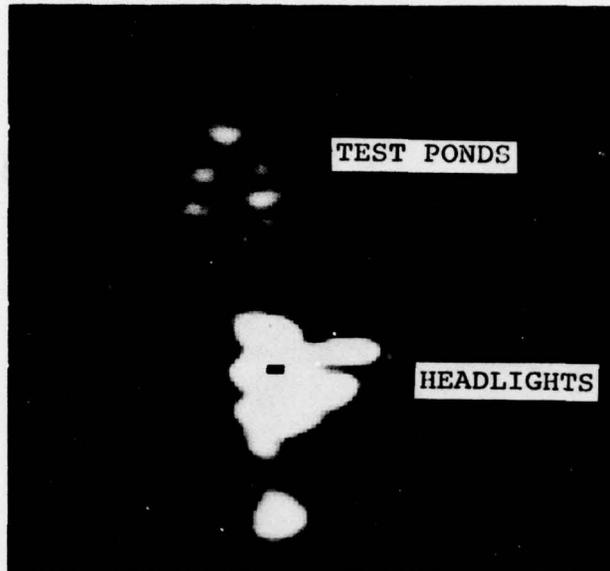


FIGURE 7.23. Active Imagery From an Altitude of 1000 Feet Showing Oil Fluorescence in the Test Ponds (Channel 2)

Figure 7.24 is a level-sliced color picture obtained from channel 2 at an altitude of 350 feet. Colors near the red end of the spectrum correspond to high signal levels, dark blue being an essentially zero signal. The red color of the pond in the upper right corner of the array shows an exceptionally strong fluorescence. This was visually observed on the ground as well, but the reason for the high intensity is not understood since the oil was uniformly distributed. The leakage mentioned above is clearly visible both above and below the ponds. A puddle is in the upper left corner of the picture.

Figure 7.25 is a three-channel color image of the same data as shown in Figure 7.24. Channels 1, 2, and 3 were used to produce the colors. The white color of the "hot" pond is the result of strong signals in all three bands.

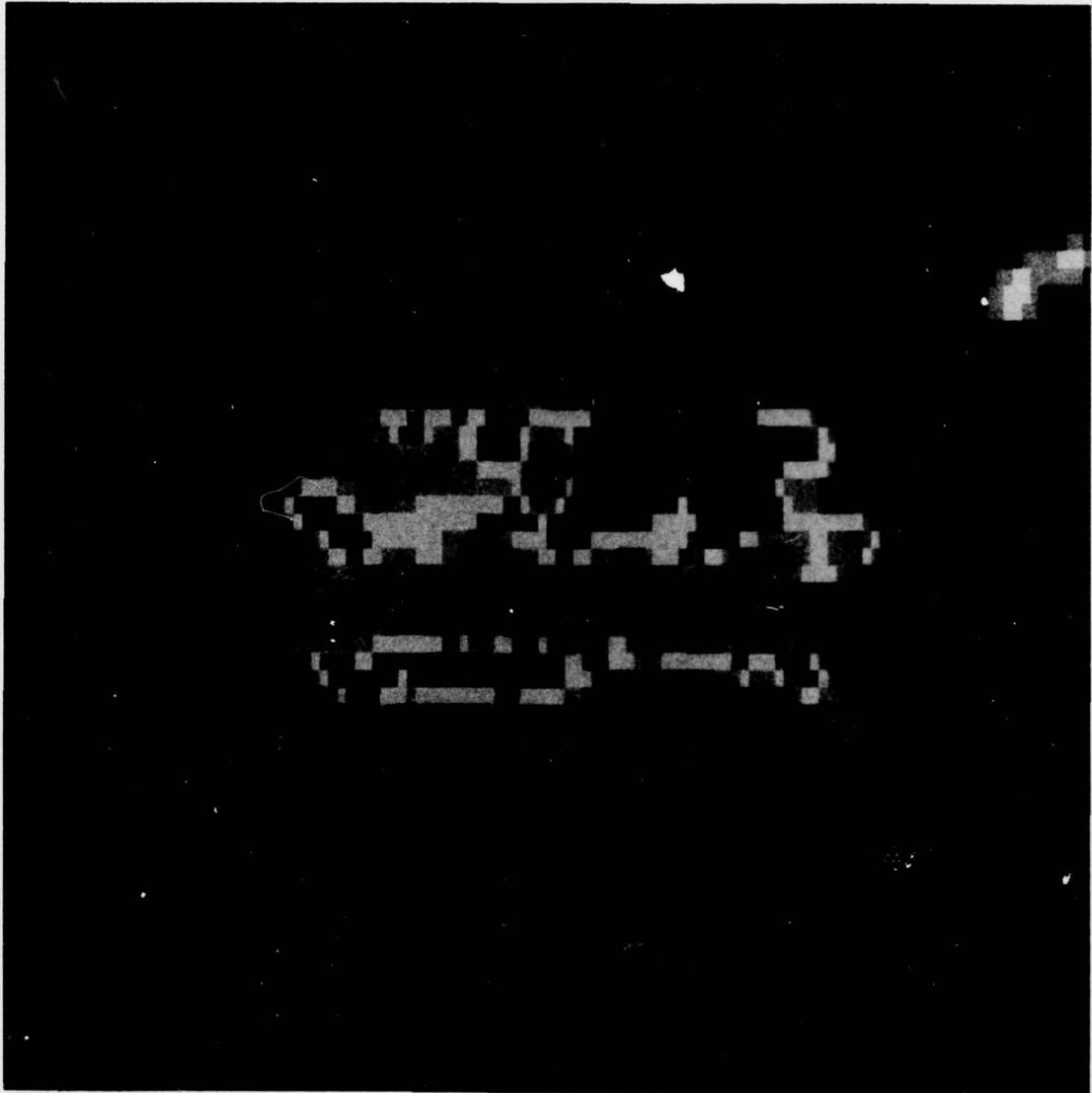


FIGURE 7.24 - Level Sliced Picture of Active Nighttime Imagery
Collected over Local Test Ponds. The Data were
Processed from Channel 2.

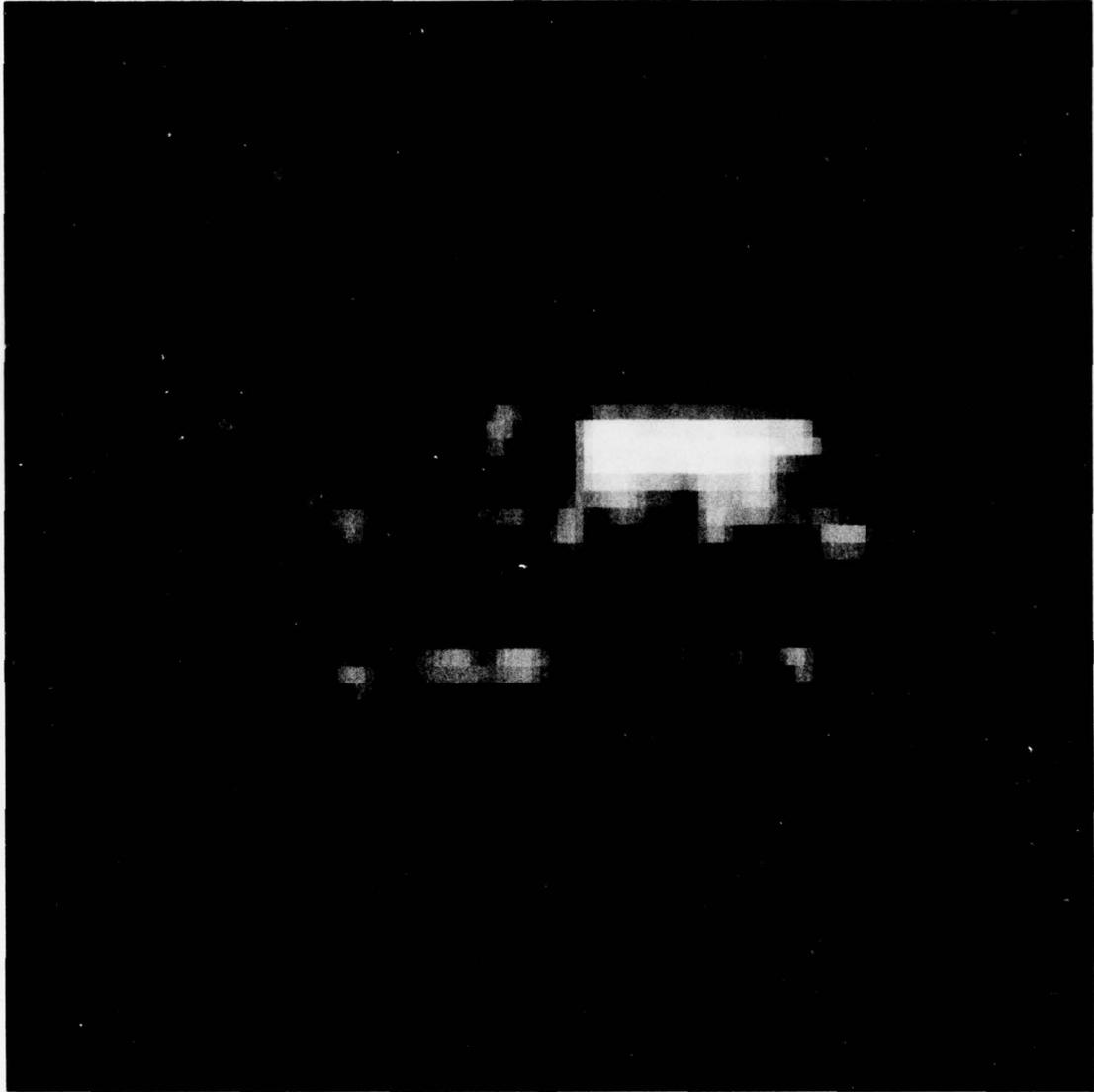


FIGURE 7.25 - Three-Channel Color Picture of Active Nighttime Imagery Collected over Local Test Ponds.

The multispectral character of the scanner signals was evaluated by using the same procedure that was described earlier for the laboratory test. In this case, the scanner signal levels were superimposed on a normalized, laboratory-measured fluorescence spectrum of Valvoline 85W140. This plot is shown in Figure 7.26. Scanner data from runs at 230 feet and 350 feet are plotted. The scatter in the data from channel 4 is due to the insensitivity of that channel.

7.3.5 SANTA BARBARA TEST

Because of its continuous natural oil seeps, the Santa Barbara Channel is an ideal site for conducting field tests of oil sensing devices. It was hoped that a field test in that area would help to evaluate the characteristics and capabilities of the active scanner under realistic field survey conditions. However, after measuring the various oil spectra in the laboratory and conducting the local flight tests, it was realized that a survey at Santa Barbara would be just about a "worst case" test for the scanner. The reason for this can be seen from the measured oil spectra in Figure 7.15. A comparison of the intensity versus thickness curves of Valvoline 85W140 and Santa Barbara Crude indicates that at expected slick thickness the fluorescent intensity of the Santa Barbara Crude is likely to be 50-100 times less than the intensity measured in the pond tests. It was therefore hoped that the scanner could be tested on a different type of oil spill, but a suitable alternative did not become available at the proper time.

Flight tests were conducted at Santa Barbara on June 4-6, 1976. To give the experiments the maximum chance for success, the local Coast Guard was consulted prior to the aerial surveys to determine seep activity. From June 3 coastal surveillance reports, the most active oil seep was in the area of the off-shore platform "Holly". Aerial photographs of this area are shown in Figure 7.27. The upper picture shows several thin oil slicks between Coal Oil Point and Holly. The bottom picture is a smaller, but thicker, slick approximately two miles east of Holly.

Aircraft overflights were conducted in the evening of June 4 to pinpoint oil seep activity, determine headings for active nighttime surveys, and

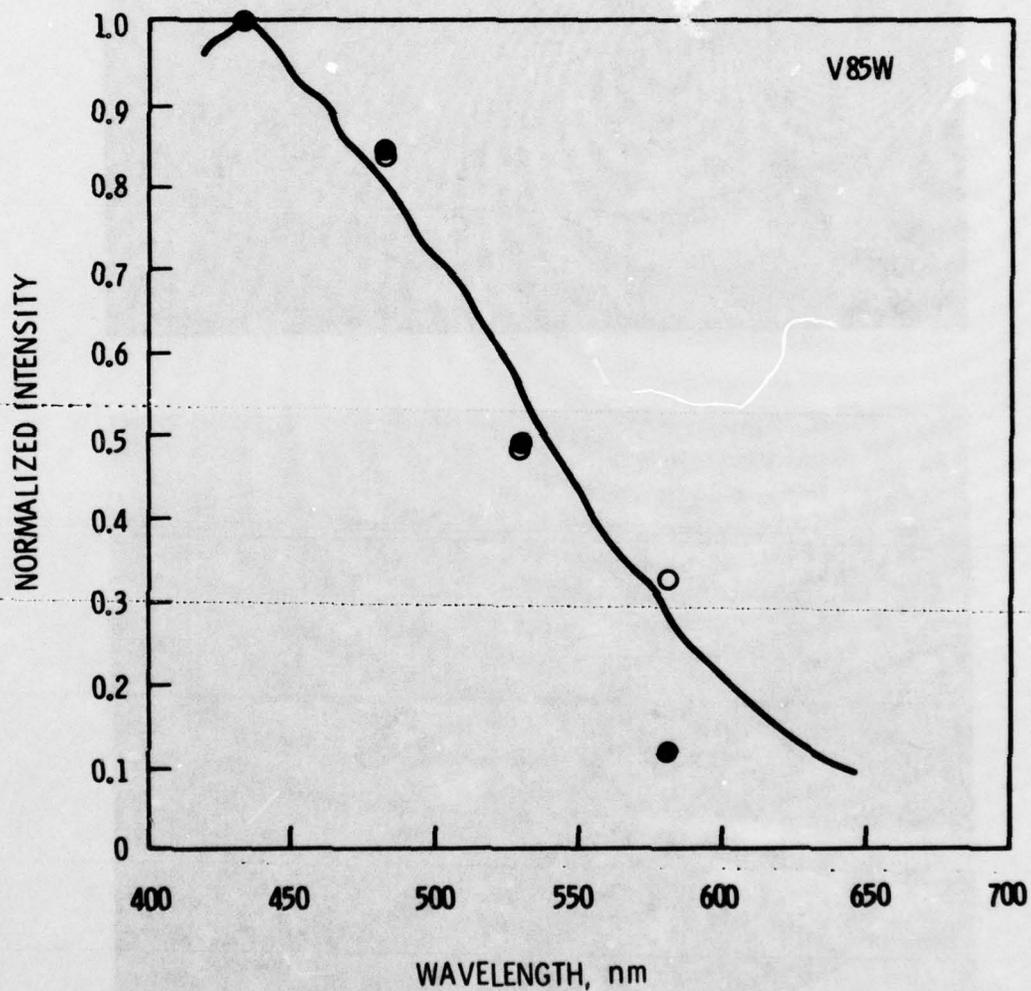


FIGURE 7.26. Fluorescence Spectra of Valvoline 85W140 Motor Oil Measured by the Active Scanner at Night, and by the Laboratory Spectrophotometer. The Dots are Normalized Scanner Signal Levels Obtained at an Altitude of 350 Feet. The Open Circles Represent Data Acquired at an Altitude of 230 Feet.

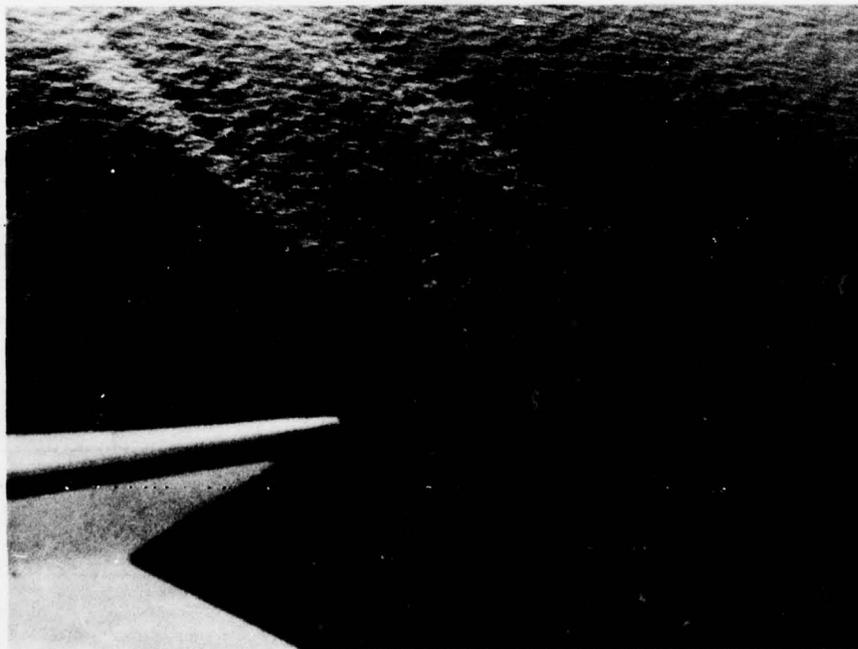
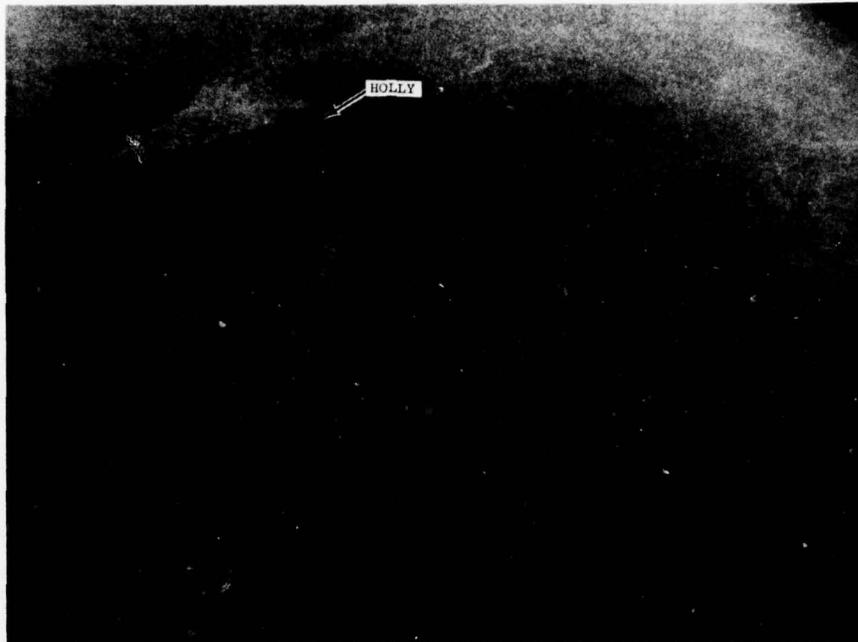


FIGURE 7.27. Oblique Aerial Photographs of Natural Oil Slicks in the Santa Barbara Channel. The Upper Photograph Shows Several Slicks Between Coal Oil Point and Platform Holly. The Lower Photograph Show a Much Thicker Slick Approximately Two Miles East of Holly.

collect passive multispectral daytime imagery over the oil. Due to a minor aircraft electrical problem the nighttime active tests were cancelled for June 4. Additional passive data were collected on June 5, again to pinpoint the greatest oil seep activity and to determine what oil movement, if any, had occurred from that observed on June 4.

All slicks that were observable visually appeared to be readily detectable in the passive scanner imagery. Strong signals were recorded on all channels at altitudes up to 10,000 feet, the maximum altitude flown. Figure 7.28 is a level sliced example of the passive imagery taken at 2600 feet. Platform Holly is visible in the image as a nearly square spot just to the right of the slick. This slick can be seen in Figure 7.27, just to the left of Holly. At the time these measurements were being made, the sky was clear and the sun was just on the horizon. Other flights showed that the time of day had no strong effect on the detectability of the oil.

The active aerial survey was conducted from 23:30 June 5 to 03:40 June 6. Two tests were run; the first with the four-channel detector and the other with a two-channel configuration similar to that used in the first tests of the scanner. As expected, the signal levels were extremely low and it was not possible during the test to determine whether or not oil was being detected. Numerous flight lines were flown in an attempt to detect a relatively thick slick previously observed approximately five miles east-southeast of Holly.

Computer processing of the active data did not yield definitive results. Several sections of the tape-recorded data are significantly brighter than the average background but slick boundaries are not well defined in the imagery. Figure 7.29 is an example of the active imagery obtained with the four-channel detector. It appears to show an oil slick but the intensity information obtained from the four channels is insufficient to evaluate its spectral character. This imagery was acquired at an altitude of 300 feet.

7.3.6 EVALUATION AND POSSIBLE IMPROVEMENT OF SCANNER PERFORMANCE

The active scanner is a prototype system which is intended to test the feasibility of utilizing arc lamp illumination for nighttime, active, aerial



FIGURE 7.28 - Level Sliced, Passive, Multispectral Imagery
Collected at 1936 hrs, 6/4/76, from an Altitude
of 2600 ft over a Natural Oil Slick Near Platform
Holly.



FIGURE 7.29. Active Imagery Showing Probable Oil Slick in the Santa Barbara Channel East of Platform Holly

imagery. A significant and promising capability for detecting, mapping, and classifying fluorescent materials in water has been demonstrated in the laboratory and flight tests described above. In other tests, using a xenon arc lamp, nighttime reflectance imagery of the ground has been acquired from an altitude of 2000 feet.

A further estimate of the sensitivity of the prototype scanner can be obtained by comparing the recent flight test data to the fluorescence spectra measured in the laboratory (Figures 7.13-7.16, 7.19 and 7.20). From the fluorescence signal levels obtained in the local flight tests using Valvoline 85W140 gear oil, it is estimated that the minimum detectable fluorescence intensity is on the order of one rhodamine intensity unit for measurements at an altitude of 1000 feet. The apparent detection of the

Santa Barbara oil from an altitude of 300 feet supports this estimate. On this basis, at an altitude of 1000 feet the scanner can probably detect at least seven of the fourteen oils that were included in this study.

Several major design improvements are possible and would be implemented in the construction of a second generation or operational version of this scanner. At least a hundred-fold improvement in sensitivity is probably feasible. With this improvement, all of the oils and other chemicals included in this section would be readily detectable.

The most straight forward approach to upgrading the existing design is to increase the size of the collector optics. The diameter of the present collector mirror is six inches. A 12- or 14-inch system is reasonable and would increase the system's sensitivity by a factor of 4 or 5. In addition, the rotating mirrors in the present design have two reflecting surfaces, each inclined 45° to the scanner axis. This arrangement produces two scan lines per rotation, thereby reducing the need for high spin rates. But because each reflecting surface fills only half the field of view of the collector mirror, half the incident light is lost. In an active system, the use of single-faceted rotating mirrors will increase both the light transmitting and receiving efficiencies by a factor of 2 (a net gain of X4).

Important gains are also obtainable by improving the light source. In the present design, less than 7% of the UV light emitted by the arc lamp is collected and projected onto the ground by the projector optics. A specially designed, integrated lamp/mirror assembly could provide a substantially higher source efficiency.

It may be possible to obtain an improved arc lamp which, in comparison with a mercury-xenon lamp, emits a larger fraction of its optical energy at shorter wavelengths in the UV. This would provide at least two advantages. First, it would permit the spectral range for detection to be extended into the near UV, thereby enhancing the detection and classification capabilities of the scanner for light oils and other chemicals which fluoresce most strongly in the UV. Second, the fluorescent intensity, and therefore the detectability, of thin oil films increases markedly as the excitation

wavelength is reduced. Preliminary discussions have been held with arc lamp manufacturers to explore the possibility of developing a suitable arc lamp for this purpose, but it is not yet clear what options are available.

SECTION 8
SUMMARY AND CONCLUSIONS

8.1 ANALYSES OF CHRIS CHEMICALS AND SENSING TECHNIQUES

Although many of the techniques now being applied to water pollution monitoring are well known and have been previously used in other fields, the technologies of remote and in situ pollution sensing are still in their infancy. Little data is available, for example, on the capabilities of remote sensing instrumentation for detecting, identifying, or quantifying chemical spills other than oils. The analyses performed in this study are intended to help in defining the problem, to assess potential and current sensing capabilities, and to identify data and research needs.

The methods used in these analyses, the results that were obtained, and recommendations for further studies are presented and discussed in Sections 4-6. These results and recommendations can be briefly summarized as follows:

- Approximately 63% of the 400 CHRIS chemicals can be potentially or currently detected under some conditions by at least one of the twelve generalized sensing techniques considered in this study.
- Chemical identification requires the development of new, presently unavailable, instrumentation systems; for example, Raman scattering systems, vapor analyzers, and multi-sensor systems.
- Several sensing techniques have a limited quantification capability, but current capabilities are not well developed.
- In many field applications, environmental factors will severely limit or degrade the effectiveness of pollution sensing equipment.
- Planning studies are needed to identify pollution monitoring needs, to establish priorities for the development and deployment of sensor systems, and to determine optimum monitoring procedures and sensor network configurations.

- Research programs covering a wide range of topics are needed. These include environmental effects; the physical, chemical, and optical properties of the CHRIS chemicals in water; and chemical transport and dispersal processes in natural water bodies.
- Major efforts are needed to develop effective and reliable field instrumentation systems. New remote and in situ sensing systems should incorporate and utilize state-of-the-art electronic data processing techniques.

8.2 ACTIVE SCANNER

The combination of laboratory spectral measurements and flight tests has demonstrated that the design concept of the active scanner is practicable for both the detection and classification of chemical spills. It is also feasible and practical to construct an operational version of the active scanner which would have at least 100 times the sensitivity of the prototype.

Battelle's active scanner system can provide a wide areal coverage of the ground or water surface and produce a two-dimensional nighttime image of a fluorescent chemical spill, whereas proposed and developmental laser fluorosensor systems are designed to operate in only a one-dimensional profiling mode. An operational version of the active scanner would provide an effective nighttime, multispectral, aerial survey capability for most of the 40 fluorescent chemicals in Table 5.6. In addition, it would provide a passive, daylight survey capability for some fluorescent chemicals and for the 84 chemicals in Table 5.2 which are detectable by optical reflectance in the near UV-visible spectral range.

APPENDIX
LIST OF INSTRUMENTATION MANUFACTURERS*

- 1) Wild Hurbrugg Instruments, Inc.
Farmingdale, NY
- 2) International Imaging Systems
Commack, NY
- 3) Top Flight, Inc.
Oklahoma City, OK
- 4) Hasselblad-Paillard, Inc.
Linden, NJ
- 5) Bendix Corp.
New York, NY
- 6) Daedalus Enterprises, Inc.
Ann Arbor, MI
- 7) Honeywell, Inc.
Lexington, MA
- 8) Block Engineering
Cambridge, MA
- 9) Alpha-Metrics
Winnepeg, Canada
- 10) Exotech, Inc.
Gaithersburg, MD
- 11) RAMCO
Dalles, TX
- 12) HRB Singer
State College, PA
- 13) Texas Instruments
Dallas, TX

*This list is based on information available within the scope and time frame of this project and is not necessarily complete.
Use of manufacturers' names does not imply Battelle endorsement of their products.

- 14) Electro Optics
Santa Barbara, CA
- 15) Barnes Engineering
Stanford, CT
- 16) Optronics Labs
Silver Spring, MD
- 17) AGA Corp.
Secaucus, NJ
- 18) Impulsphysik
Hamburg, Germany
- 19) Spectrogram Corp.
North Haven, CT
- 20) UniLoc
Irvine, CA
- 21) Chemtrix
Hillsboro, OR
- 22) Beckman Instruments
Fullerton, CA
- 23) Ecologic Instruments
Bohemia, NY
- 24) Great Lakes Instruments
Milwaukee, WI
- 25) Leeds & Northrup
North Wales, PA
- 26) Martek Instruments, Inc.
Newport Beach, CA
- 27) Pennwalt Corp.
Belleville, NJ

- 28) Aquatronics, Inc.
Philadelphia, PA
- 29) Dupont Instruments
Willmington, DE
- 30) Rexnord, Inc.
Malvern, PA
- 31) Astro Ecology Corp.
Houston, TX

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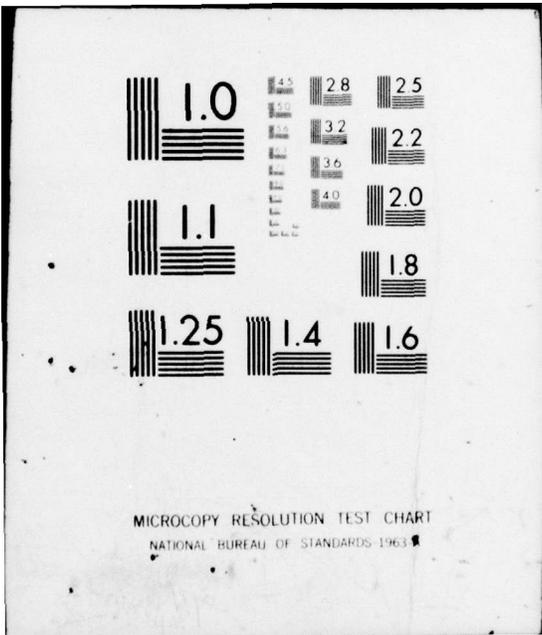
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