# Recommended Practice for Drilling and Well Servicing Operations Involving Hydrogen Sulfide

API RECOMMENDED PRACTICE 49
THIRD EDITION, MAY 2001

American
Petroleum
Institute

Helping You
Get The Job
Done Right.℠

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**Upstream Segment**

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# FOREWORD

This recommended practice was prepared by the API Subcommittee on Oil and Gas Well Drilling and Servicing Involving Hydrogen Sulfide. This standard is under the administration of the American Petroleum Institute Upstream Department's Executive Committee on Drilling and Production Operations.

It is intended that these voluntary recommended practices serve as a guide to promote and maintain integrity of oil and gas well drilling and servicing facilities and operations in the interest of public safety, personnel safety, and protection of the environment. Users of this publication are reminded that constantly developing technology, specific company requirements and policy, and specialized or limited operations do not permit coverage of all possible operations, practices, or alternatives. This standard is not so comprehensive as to present all of the recommended practices for oil and gas well drilling and servicing operations involving hydrogen sulfide. Alternative operating procedures and/or equipment are available and routinely used to meet or exceed recommended practices or performance levels set forth herein. Recommendations presented in this publication are based on industry experience and expertise involving a wide range of operating locations and conditions. Recommendations presented in this publication are not intended to inhibit developing technology and equipment improvements or improved operating procedures. This publication, or portions thereof, cannot be substituted for qualified technical/operations analysis and judgment to fit a specific situation.

There may be federal, state, or local statutes, rules, or regulations requiring oil and gas well drilling and servicing operations to be conducted in a safe or environmentally sound manner. Organizations and individuals using this standard are cautioned that requirements of federal, state, or local laws and regulations are constantly changing. These requirements should be reviewed to determine whether the practices recommended herein and the operations being planned or conducted are consistent with current laws and regulations.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet (MSDS).

Provisions of these voluntary recommended practices include use of the verbs "shall" and "should," whichever is deemed most applicable for the specific situation. For purposes of this publication, the following definitions are applicable:

Shall: Indicates the "recommended practice(s)" have universal applicability to that specific activity.

Should: Denotes a "recommended practice(s)" 1) where a safe comparable alternative practice(s) is available; 2) that may be impractical under certain circumstances; or 3) that may be unnecessary under certain circumstances.

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Suggested revisions are invited and should be submitted to the standardization manager, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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# Recommended Practice for Oil and Gas Well Drilling and Servicing Operations Involving Hydrogen Sulfide

## 0 Introduction

The petroleum industry, through many years of research and operating experience, has developed guidelines and standards for safe operations under conditions involving hydrogen sulfide. Continuing industry efforts, which include planning, prudent selection and layout of equipment, prudent selection of materials, operating and emergency procedures, specialized safety equipment, and appropriate personnel training, have contributed to successful and safe operations. Effective response to emergencies requires prior planning. Good engineering practice (engineering and administrative controls) dictates that operations systems be designed to minimize exposure of personnel and the public to hydrogen sulfide and sulfur dioxide.

## 1 Scope

Recommendations set forth in this publication apply to oil and gas well drilling and servicing operations involving hydrogen sulfide. These operations include well drilling, completion, servicing, workover, downhole maintenance, and plug and abandonment procedures conducted with hydrogen sulfide present in the fluids being handled. Coverage of this publication is applicable to operations confined to the original wellbore or original total depth and applies to the selection of materials for installation or use in the well and in the well drilling or servicing operation(s). The presence of hydrogen sulfide in these operations also presents the possibility of exposure to sulfur dioxide from the combustion of hydrogen sulfide. Refer to Section 4 for applicability of this standard.

This standard addresses personnel training, personnel protective equipment, contingency planning and emergency procedures, classification of locations, materials and equipment, operations, rig practices, special operations, offshore operations, characteristics of hydrogen sulfide and sulfur dioxide, and evaluation and selection of hydrogen sulfide monitoring equipment.

## 2 References

### 2.1 STANDARDS

The following standards contain provisions which, through reference in this text, constitute provisions of the standard. All standards are subject to revision, and users are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

| | |
|---|---|
| API | |
| Bull E1 | *Generic Hazardous Chemical Category List and Inventory for the Oil and Gas Exploration & Production Industry* |
| Bull E4 | *Release Reporting for the Oil and Gas Exploration and Production Industry as Required by the CWA, CERCLA, and SARA Title III* |
| Spec 5CT | *Specification for Casing and Tubing* |
| Spec 5D | *Specification for Drill Pipe* |
| Bull 6J | *Testing of Oilfield Elastomers, A Tutorial* |
| RP 7G | *Drill Stem Design and Operating Limits* |
| RP 14C | *Analysis, Design, Installation, and Testing of Basic Surface Safety Systems on Offshore Production Platforms* |
| RP 14F | *Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Division 1, and Division 2 Locations* |
| Spec 16A | *Specification for Drill Through Equipment* |
| Spec 16C | *Specification for Choke and Kill Systems* |
| RP 53 | *Blowout Prevention Equipment Systems for Drilling Wells* |
| RP 54 | *Occupational Safety for Oil and Gas Well Drilling and Servicing Operations* |
| RP 67 | *Oilfield Explosives Safety* |
| RP 500 | *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2* |
| RP 505 | *Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2* |
| Std 2015 | *Safe Entry and Cleaning of Petroleum Storage Tanks* |
| RP 2201 | *Procedures for Welding or Hot Tapping on Equipment in Service* |
| Spec 6A | *Specification for Valves and Wellhead Equipment* |
| ACGIH[1] | |
| | *Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices* |
| IES RP7-1990 | *Practice for Industrial Lighting* |
| Z88-2 | *Practices for Respiratory Protection* |

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[1] American Conference of Governmental Industrial Hygenists, Kemper Meadow Center, 1330 Kemper Meadow Drive, Cincinnati, Ohio 45240.

EPA[2]

| | |
|---|---|
| EPA/600/8<br>E86/026A | *Health Assessment Document for Hydrogen Sulfide* |
| 40 *CFR* | *Part 264, Subpart D, Contingency Plans and Emergency Procedures* |
| 40 *CFR* | *Part 302, Designation, Reportable Quantities, and Notification* |
| 40 *CFR* | *Part 355, Emergency Planning and Notification* |
| 40 *CFR* | *Part 370, Hazardous Chemical Reporting: Community Right-to-Know* |

ISA[3]

| | |
|---|---|
| S12.15 | *Performance Requirements for Hydrogen Sulfide Detection Instruments* |
| RP12.15 | *Installation, Operation, and Maintenance of Hydrogen Sulfide Detection Instruments* |

NACE[4]

| | |
|---|---|
| MR0175 | *Sulfide Stress Cracking Resistant Materials for Oilfield Equipment National Response Team* |
| NRT-1[5] | *Hazardous Materials Emergency Planning Guide*<br>*Technical Guidance for Hazards Analysis, Emergency Planning for Extremely Hazardous Substances* |

NFPA[6]

| | |
|---|---|
| NFPA 70 | *National Electrical Code* |

NIOSH[7]

| | |
|---|---|
| 74-111 | *Criteria for a Recommended Standard for Occupational Exposure to Sulfur Dioxide* (GPO No. 017-033-00029) |
| 77-158 | *Criteria for a Recommended Standard for Occupational Exposure to Hydrogen Sulfide* (GPO No. 017-033-00217-7) |

## 2.2 REGULATIONS

The following regulations are subject to revision, and users should determine the latest version to ensure compliance.

Bureau of Mines (DOI)[8]

| | |
|---|---|
| 30 *CFR* | *Chapter 1, Subchapter B, Part II, Subpart H, Respiratory Protection Devices* |

Coast Guard (DOT)[9]

| | |
|---|---|
| 33 *CFR* | *Parts 140to 146: Emergency Evacuation Plans for Manned OCS Facilities* |

DOT[10]

| | |
|---|---|
| 49 *CFR* | *Part 178, Subpart C, Shipping Container Specifications* |

MMS (DOI)[11]

| | |
|---|---|
| 30 *CFR* | *Parts 250 & 256, Oil, Gas, and Sulphur Operations in the Outer Continental Shelf* |

OSHA[12]

| | |
|---|---|
| 29 *CFR* | *Part 1910.38, Employee Emergency Plans and Fire Prevention Plans* |
| 29 *CFR* | *Part 1910.120, Hazardous Waste Operations and Emergency Response* |
| 29 *CFR* | *Part 1910.134, Respiratory Protection Standard* |
| 29 *CFR* | *Part 1910.146, Permit-Required Confined Spaces* |
| 29 *CFR* | *Part 1910.1000, 321Air Contaminants* |
| 29 *CFR* | *Part 1910 Subpart I, Personal Protective Equipment* |
| 29 *CFR* | *Part 1910.1200, Hazard Communication Standard* |

## 2.3 OTHER REFERENCES

1. Poda, George A., "Hydrogen Sulfide Can Be Handled Safely," Archives of Environmental Health, Vol. 12, 795–800, June 1966.
2. Ronk, Richard and White, M. K., "Hydrogen Sulfide and the Probabilities of Inhalation Through a Tympanic Membrane Defect," *Journal of Occupational Medicine,* Vol. 25, No. 5, 337–340, May 1985.
3. Pasquill, F., *Atmospheric Diffusion,* Second Edition, John Wiley & Sons, New York, NY, 1947.
4. Slade, D. H., Metrology and Atomic Energy NTIS-TID 24190 (1968), National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, VA 22161.
5. Wilson, D. J., "Release and Dispersion of Gas from Pipeline Ruptures," Department of Mechanical Engineering, University of Alberta, Edmonton, Canada.

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[2] U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460.

[3] Instrument Society of America, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, North Carolina 27709.

[4] NACE International, 1440 South Creek Drive, P.O. Box 218340, Houston, Texas 77218-8340.

[5] U.S. National Response Team, c/o EPA, MC 5101, 401 M Street, S.W., Washington, D.C. 20460.

[6] National Fire Protection Association, 1 Battery March Park, Quincy, Massachusetts 02269.

[7] National Institute of Occupational Safety & Health, 4646 Columbia Parkway, Cincinnati, Ohio 45226.

[8] U.S. Department of Interior, available from U.S. Government Printing Office, Washington, D.C. 20402.

[9] U.S. Department of Transportation, available from U.S. Government Printing Office, Washington, D.C. 20402.

[10] U.S. Department of Transportation, available from U.S. Government Printing Office, Washington, D.C. 20402.

[11] U.S. Department of Interior, available from U.S. Government Printing Office, Washington, D.C. 20402

[12] Occupational Safety and Health Administration, U.S. Deptartment of Labor, Washington, D.C. 20402.

6. Jann, P. R., "Evaluation of Sheltering In Place," *Journal of Loss Prevention in the Process Industry,* Vol. 2, No. 1, January. 1989, pp 33–38.

7. MacFarlane, D. R. and Ewing, T. F., "Acute Health Effects From Accidental Releases of High Toxic Hazard Chemicals," Journal of Loss Prevention in the Process Industry, Vol. 3, No. 1, January 1990, pp 167–176.

8. Wilson, D. J., "Stay Indoors or Evacuate to Avoid Exposure to Toxic Gas?," *Emergency Preparedness Digest,* Ottawa, Canada, January–March 1987, pp 19–24.

9. Davies, P. C. and Purdy, G.,"Toxic Gas Risk Assessments—The Effects of Being Indoors," North Western Branch Papers 1986 No. 1, Institution of Chemical Engineers, Health and Safety Executive, Major Hazards Assessment Unit, St. Annes House, Stanley Precinct,, Bootle, Merseyside, England.

10. Glickman, T.S. and Ujrhara, A. M., "Protective Action Decision Making in Toxic Vapor Cloud Emergencies," Center for Risk Management, Resources for the Future, Washington, D. C. 20036.

11. Wilson, D. J., "Variation of Indoor Shelter Effectiveness Caused by Air Leakage Variability of Houses in Canada and the USA," US EPA/FEMA Conference on Effective Use of In-Place Sheltering as a Potential Option to Evacuation During Chemical Release Emergencies, Emmitsburg, MD, November 30 – December 1, 1988.

### 2.4 BIBLIOGRAPHY

The following publications contain information related to this subject:

1. API RP 14F, *Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Divison 1, and Division 2 Locations,* API, 1220 L St., NW, Washington, D.C. 20005, 1999.

2. API RP 55, *Recommended Practices for Conducting Oil and Gas Producing and Gas Processing Plant Operations Involving Hydrogen Sulfide,* API, 1220 L St., NW Washington, D.C. 20005, 1995.

3. GPA 2145-85, *Physical Constants of Paraffin Hydrocarbons and Other Components of Natural Gas,* available from Gas Processors Association, 6526 E. 60th Street, Tulsa, Oklahoma 74145.

4. NIOSH, *Recommended Standard for Occupational Exposure to Hydrogen Sulfide,* available from US Government Printing Office, Washington D.C. 20402.

5. Public Health Service Publication 999-AP-26, *Workbook on Atmospheric Dispersion Estimates,* D. Bruce Tanner, available from U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio.

6. Texas Railroad Commission Rule 36, *Oil, Gas, and Geothermal Resources Operations Hydrogen Sulfide Areas,* Texas Railroad Commission, Austin, Texas.

## 3 Acronyms and Abbreviated Definitions

The following acronyms and abbreviations are used in this publication:

### 3.1 ACRONYMS

| | |
|---|---|
| ACC | acceptable ceiling concentration |
| ACGIH | American Conference of Governmental Industrial Hygienists |
| ANSI | American National Standards Institute |
| API | American Petroleum Institute |
| BOP | blowout preventer |
| CAS | Chemical Abstract Service |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CFR | Code of Federal Regulations |
| CGA | Compressed Gas Association |
| DC | direct current |
| DOI | U. S. Department of Interior |
| DOL | U. S. Department of Labor |
| DOT | U. S. Department of Transportation |
| EMI | electromagnetic interference |
| EPA | Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right-to-Know Act |
| FR | Federal Register |
| HAZWOPER | Hazardous Waste Operations and Emergency Response |
| $H_2S$ | hydrogen sulfide |
| IDLH | Immediately Dangerous to Life or Health |
| ISA | Instrument Society of America |
| LEL | lower explosive limit |
| MMS | Minerals Management Service |
| MSDS | material safety data sheet |
| NACE | National Association of Corrosion Engineers |
| NFPA | National Fire Protection Association |
| NIOSH | National Institute for Occupational Safety and Health |
| NRTL | Nationally Recognized Testing Laboratory |
| NTIS | National Technical Information Service |
| OCS | outer continental shelf |
| OSHA | Occupational Safety and Health Administration |
| PEL | permissible exposure limit |
| PG | Pasquill-Gifford |
| ppm | parts per million |
| RCRA | Resource Conservation & Recovery Act |
| REL | recommended exposure level |
| RFI | radio frequency interference |
| ROE | radius of exposure |
| RP | Recommended Practice(s) |
| RQ | reportable quantity |

| | |
|---|---|
| SARA | Superfund Amendments and Reauthorization Act |
| SCF | standard cubic feet |
| SERC | State Emergency Response Commission |
| $SO_2$ | sulfur dioxide |
| SSC | sulfide stress cracking |
| STEL | Short-Term Exposure Level |
| TLV | threshold limit value |
| TPQ | threshold planning quantity |
| TWA | time weighted average |

## 3.2 DEFINITIONS

For the purposes of this standard, the following definitions are applicable.

**3.2.1 acceptable ceiling concentration (ACC):** The designated level of an air contaminant to which an employee may be exposed at any time during an 8-hour shift, except for a time period and up to a concentration not exceeding the "acceptable maximum peak above the acceptable ceiling concentration for an 8-hour shift".

**3.2.2 action levels:** The levels at which the possibility of hydrogen sulfide atmospheric concentrations greater than 10 ppm or sulfur dioxide atmospheric concentrations greater than 2 ppm may be encountered.

**3.2.3 breathing zone:** Generally, a hemisphere forward of the shoulders with a radius of 6 in. to 9 in.

**3.2.4 continuous hydrogen sulfide monitoring equipment:** Equipment capable of continuously measuring and displaying the concentration of hydrogen sulfide in ambient air.

**3.2.5 enclosed facility:** A three-dimensional space enclosed by more than $^2/_3$ of the possible projected plane surface and of sufficient size to allow the entry of personnel. For a typical building, this would require that more than $^2/_3$ of the walls, ceiling, and floor be present. Refer to API RP 500 and RP 505.

**3.2.6 essential personnel:** Those individuals required to provide proper and prudent safe operations activities and those required to effect control of the hazardous hydrogen sulfide or sulfur dioxide conditions.

**3.2.7 gas detection instrument:** An assembly of electrical, mechanical, and chemical components designed to sense and respond continuously to the presence of chemical gases in atmospheric mixtures.

**3.2.8 hydrogen sulfide:** Chemical formula is $H_2S$. A flammable, toxic gas that is heavier than air and sometimes found in fluids encountered in oil and gas producing and gas processing operations.

**3.2.9 immediately dangerous to life and health (IDLH):** An atmospheric concentration of any toxic, corrosive, or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere. The ACGIH has established 300 ppm or greater of $H_2S$ as an IDLH exposure.

**3.2.10 inadequately ventilated:** Ventilation (natural or artificial) that is not sufficient to prevent the accumulation of significant quantities of toxic or inert gases such that a hazard is created.

**3.2.11 length-of-stain detector:** A specially designed pump and colorimetric indicator tube detector (length-of-stain), with a supply of detector tubes, that operates by using the pump to pull a known volume of air or gas through a detector tube. The tubes contain chemical reagents that are designed to detect the presence and display the concentration of specific gases or vapors in the sample. The length of the resultant color band in the tube indicates an instantaneous quantitative concentration of the specific chemical in the sample.

**3.2.12 permissible exposure limit (PEL):** TWA concentrations that must not be exceeded during any 8-hour work shift of a 40-hour work week. PELs are subject to change.

**3.2.13 shall:** Indicates the "recommended practice(s)" has universal applicability to that specific activity.

**3.2.14 shelter-in-place:** The concept of providing the public protection from exposure to toxic gas or vapor releases to the environment by having residents stay indoors until emergency evacuators arrive or the emergency is over.

**3.2.15 short term exposure limit (STEL):** A 15-minute TWA exposure that should not be exceeded at any time during a workday.

**3.2.16 should:** Denotes a "recommended practice(s)" 1) where a safe comparable alternative practice(s) is available; 2) that may be impractical under certain circumstances; or 3) that may be unnecessary under certain circumstances.

**3.2.17 special operations:** any service performed on or in a well other than the normal drilling or service operations that are accomplished in their entirety by a drilling or servicing rig.

**3.2.18 sulfur dioxide:** Chemical formula is $SO_2$. A toxic product of combustion of hydrogen sulfide, normally heavier than air.

*CAUTION:* Inhalation at certain concentrations can lead to injury or death. Refer to Appendix B.

**3.2.19 temporary safe haven:** Refer to "shelter-in-place" (3.2.14).

**3.2.20 threshold limit value (TLV):** Airborne concentrations of substances representing conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effects. These value may be expressed as 8-hour time weighted average (TWA), Ceiling Limits, or 15-minute Short-Term Exposure Levels (STEL). Refer to American Conference of Governmental Industrial Hygienists (ACGIH), Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. "TLV" is a trademarked term of ACGIH.

# 4 Applicability

## 4.1 PERSONNEL AND EQUIPMENT PROTECTION

In oil and gas well drilling and servicing operations, severity of the environment shall be assessed. As a minimum, the following measures shall be implemented:

a. Personnel protection should be provided if the work area concentration of hydrogen sulfide (refer to 3.2.8) exceeds 10 ppm 8-hour time weighted average (TWA) or 15 ppm as a Short Term Exposure Level (STEL) averaged over 15 minutes (refer to Appendix A); or the work area concentration of sulfur dioxide (refer to 4.16) exceeds 2 ppm as an 8-hour TWA or 5 ppm as a STEL averaged over 15 minutes (refer to Appendix B). Personnel safety provisions of this publication do not apply when:

1. the atmospheric concentration of hydrogen sulfide could not exceed 10 ppm (by volume) in the breathing zone; or
2. the atmospheric concentration of sulfur dioxide could not exceed 2 ppm (by volume) in the breathing zone.

b. Equipment and materials shall be selected on the basis of resistance to sulfide stress cracking and corrosion. Refer to NACE MR0175 for recommendations for selection of equipment and materials.

Some conditions may require extensive personnel safety measures but only the use of conventional equipment and materials; other conditions may require the use of special equipment and materials but only minimal personnel safety measures; still other conditions may require both.

Throughout this publication, "action levels" for various actions are used to ensure safety of employees and the public. These action levels have been established considering threshold limit values. These TLVs are subject to change and users should check applicable government standards and regulations. A good reference source is the latest edition of the ACGIH's Threshold Limit Values and Biological Exposure Indices.

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a hydrogen sulfide TLV of 10 ppm (8-hour TWA) and a STEL of 15 ppm averaged over 15 minutes and recommends 2 ppm as an 8-hour TWA TLV and 5 ppm as a STEL averaged over 15 minutes for sulfur dioxide. In the interest of safety and health, this standard recommends use of the ACGIH TLVs as action levels for employee safety (refer to Appendices A and B). Individual employers may set their own action levels after review and due consideration of site specific conditions, various regulatory requirements, and material safety data sheet (MSDS) information.

## 4.2 INITIATION OF PROCEDURES

Drilling and well servicing operations requiring special materials and equipment or personnel protection should utilize guidelines recommended in this publication. Safety procedures should be initiated and training completed in advance of penetrating the shallowest zone suspected to contain hydrogen sulfide. If hydrogen sulfide conditions specified in 4.1 are unexpectedly encountered, provisions of this publication should be implemented as soon as possible.

## 4.3 LEGAL REQUIREMENTS

This publication presents recommended practices and precautions deemed pertinent to protect personnel and the public from exposure to potentially hazardous concentrations of hydrogen sulfide and sulfur dioxide. These recommended practices recognize that owners, operators, contractors, and their employees have separate responsibilities that may be contractual in nature. It is not the intent of these recommended practices to alter the contractual relationship(s) between the parties. Some of the practices recommended herein are mandatory by local, state, or federal laws, rules, and regulations. Because of the functional and geographical diversity of these requirements, no attempt has been made in these recommended practices to designate which are optional and which are required. Furthermore, even if all the practices recommended herein are followed, there still may be existing or future legally imposed laws or regulations which would not be met. In the event of any omission or conflict between these recommended practices and legally required action(s), the requirements of laws and regulations must control. Some of the federal regulations (standards) pertinent to safe well drilling and servicing operations involving hydrogen sulfide are listed in Section 2. Users of this publication should review these regulations and other federal, state, and local laws to assure appropriate compliance in their specific operations.

# 5 Personnel Training

## 5.1 INTRODUCTION

Operators of potential hydrogen sulfide producing properties shall alert all personnel (including employer, service companies, and contractors) of the possibility of hydrogen sulfide atmospheric concentrations greater than 10 ppm and sulfur dioxide atmospheric concentrations greater than 2 ppm that may be encountered in the performance of their work.

All personnel working in an area where concentrations of hydrogen sulfide or sulfur dioxide may exceed the action levels should be provided with training prior to beginning the work assignment. All employers, whether operator, contractor, or subcontractor, shall be responsible for the training and instruction of their own employees. Personnel assigned to work in areas where they may be exposed to hydrogen sulfide or sulfur dioxide should be trained by a hydrogen sulfide safety instructor.

### 5.2 MINIMUM TRAINING

The value of training and periodic drills in oil and gas well drilling, servicing and workover operations cannot be over emphasized. The uniqueness or complexity of a specific operation will determine the extent of training deemed necessary for the assigned personnel. However, the following elements are considered a minimum level of training for personnel assigned to the operations:

a. The hazards, characteristics, and properties of hydrogen sulfide and sulfur dioxide.

b. Sources of hydrogen sulfide and sulfur dioxide.

c. Proper use of hydrogen sulfide and sulfur dioxide detection methods used at the workplace.

d. Recognition of, and proper response to, the warning signals initiated by hydrogen sulfide and sulfur dioxide detection systems in use at the workplace.

e. Symptoms of hydrogen sulfide exposure; symptoms of sulfur dioxide exposure

f. Rescue techniques and first aid to victims of hydrogen sulfide and sulfur dioxide exposure.

g. Proper use and maintenance of breathing equipment for working in hydrogen sulfide and sulfur dioxide atmospheres, as appropriate theory and hands-on practice, with demonstrated proficiency (29 *CFR* Part 1910.134).

h. Workplace practices and relevant maintenance procedures that have been established to protect personnel from the hazards of hydrogen sulfide and sulfur dioxide.

i. Wind direction awareness and routes of egress.

j. Confined space and enclosed facility entry procedures (if applicable).

k. Emergency response procedures that have been developed for the facility or operations.

l. Locations and use of safety equipment.

m. Locations of safe briefing areas.

### 5.3 ADDITIONAL TRAINING FOR ONSITE SUPERVISORY PERSONNEL

Those personnel assigned supervising responsibilities at the site shall have additional training in the following elements:

a. Supervisor responsibilities of the contingency plan.

b. Effects of hydrogen sulfide on components of the hydrogen sulfide handling system.

c. The importance of drilling fluid treating plans prior to encountering hydrogen sulfide.

### 5.4 HYDROGEN SULFIDE SAFETY INSTRUCTORS

Hydrogen sulfide safety instructors are persons who have:

a. Successfully completed a course in hydrogen sulfide instructor training; or

b. Received equivalent instruction from a company-designated hydrogen sulfide safety instructor/trainer.

A recurring training program shall be implemented to maintain proficiency of all hydrogen sulfide safety instructors.

### 5.5 TRAINING VISITORS AND OTHER NON-REGULARLY ASSIGNED PERSONNEL

Prior to entering a potentially hazardous area, visitors and other non-essential personnel shall be briefed on route(s) of egress, emergency assembly area(s), applicable warning signals, and how to respond in the event of an emergency, including use of personal protective equipment, if required. These personnel may be allowed in potentially hazardous areas only in the presence of trained personnel, after being briefed on emergency action and evacuation procedures. In the event of an emergency, these personnel shall be immediately evacuated.

### 5.6 RECORDS

Dates, instructors, attendees, and subjects for all personnel training sessions shall be documented and appropriate records should be retained for a minimum of 1 year.

## 6 Detection Equipment and Personal Protection Equipment (PPE)

### 6.1 INTRODUCTION

This section describes detection equipment and personal protective equipment (PPE) that can be used in oil and gas drilling and well servicing and workover operations where the work area atmospheric concentration of hydrogen sulfide could exceed the action levels of 10 ppm of hydrogen sulfide or 2 ppm of sulfur dioxide. In addition to providing personal protective equipment,personnel should be trained in the selection, use, cleaning, inspection, and maintenance of the PPE.

### 6.2 DETECTION EQUIPMENT

Manufacturers' recommendations should be followed for the installation, maintenance, calibration and repair of detection equipment. If the atmospheric concentration could exceed action levels for hydrogen sulfide or sulfur dioxide, detection instruments shall be available on location. In those instances where the hydrogen sulfide atmospheric concentration may exceed the measurement range of the detection instruments in use, an alternative instrument shall be available on location that can measure atmospheric concentrations up to 300 ppm.

If sulfur dioxide levels could exceed the action level for sulfur dioxide (e.g., during flaring or other operations producing sulfur dioxide), either portable sulfur dioxide detection instruments or length-of-stain detectors, with a supply of detector tubes, shall be available on location for determining the sulfur dioxide concentration in the area and to monitor areas impacted by sulfur dioxide gas when fluids containing hydrogen sulfide are burned.

An adequate number of fixed or portable or both type detectors should be provided for the safety of personnel working. Prior to commencement of operations, there should be a clear understanding as to who will provide detection equipment.

## 6.3 FIXED (STATIONARY) HYDROGEN SULFIDE MONITORING DETECTION SYSTEMS

Fixed hydrogen sulfide atmospheric monitoring systems used in oil and gas well drilling, servicing and workover operations shall include visual and audible alarm(s), located where the alarm can be seen or heard throughout the work area. The batteries of direct current (DC) systems should be checked daily during operation unless an automatic low voltage alarm is provided.

## 6.4 SENSOR LOCATIONS AND SETTINGS AND EQUIPMENT CALIBRATION

**6.4.1** Monitoring equipment (fixed or portable) should be used during all drilling, workover, and well servicing operations where there is a possibility of hydrogen sulfide or sulfur dioxide exceeding the action levels.

Sensors should be located at the following locations as appropriate:

1. Bell nipple.
2. Mud-return line receiver tank (possum belly), and/or shale shaker.
3. Pipe-trip tank.
4. Well-control fluid pit area.
5. Driller's/operator's station.
6. Living quarters, if located in the close proximity to the well.
7. All other areas where hydrogen sulfide may accumulate that are not part of the confined space entry program.

**6.4.2** Visual low level alarms shall be set to activate at 10 ppm. High level alarms shall be set no higher than 300 ppm. The high level alarm shall activate an audible evacuation alarm. For single-set point monitors, the alarm shall be set at 10 ppm.

## 6.5 EQUIPMENT CALIBRATION AND TESTING

Monitoring equipment should be serviced, calibrated, and tested as recommended by the equipment manufacturer. Inspections, calibrations, and tests should be documented. The equipment alarms should be functionally tested at least once daily.

## 6.6 BREATHING (RESPIRATORY PROTECTION) EQUIPMENT

### 6.6.1 General

1. Respirators should be selected on the basis of the hazards to which workers are exposed.
2. The user shall be instructed and trained in the proper use of respirators and their limitations.
3. Respirators shall be cleaned and disinfected after each use.
4. Respirators should be stored in a convenient, clean, and sanitary location.
5. Respirators should be inspected during cleaning. Worn or deteriorated parts should be replaced. Respirators for emergency use should be thoroughly inspected at least once a month and after each use.
6. Appropriate surveillance of work area conditions and degree of employee exposure or stress should be maintained.
7. Persons should not be assigned to tasks requiring the use of self-contained breathing apparatus, (SCBA) unless it has been determined that they are physically able to perform the work and use the equipment.
8. Equipment needing repair shall be appropriately tagged and removed from equipment stock until it is suitably repaired or replaced.

*CAUTION:* Air purifying respirators and demand type (negative pressure) air supplied breathing equipment shall not be used in oil and gas well drilling, servicing, and workover operations when a hydrogen sulfide or sulfur dioxide level could exceed the action levels.

The following types of respiratory protection equipment, with full-face piece, shall be used where the work area atmospheric concentration exceeds the action levels:

1. Self-Contained Breathing Apparatus (SCBA) positive-pressure/pressure-demand breathing equipment that provides respiratory protection;
2. Positive-pressure/pressure-demand air line breathing equipment coupled with a SCBA-equipped low pressure warning alarm and rated for 15 minutes (minimum); or
3. Positive-pressure/pressure-demand, air-line breathing equipment, with an auxiliary self-contained air supply

(rated for a minimum of 5 minutes). This type unit can be used for entry as long as the air line is connected to a source of breathing air. The auxiliary self-contained air supply (rated for less than 15 minutes) is suitable only for escape.

#### 6.6.2 Storage, Inspection and Maintenance

Personal breathing equipment shall be located so that this equipment is quickly and easily available to essential personnel. Additional breathing equipment may be required by site specific contingency plans. When an alternative derrick escape means is not available, an escape-type air pack shall be readily available.

Breathing equipment shall be maintained and stored in a convenient, clean, and sanitary location. All breathing equipment should be stored to protect them from damage, contamination, dust, sunlight, extreme temperatures and damaging chemicals. The breathing equipment should be packed and stored to prevent deformation of the face piece and exhalation valve.

All breathing equipment shall be checked before and after each use and inspected at least monthly to ensure that it is maintained in satisfactory condition. A record of the monthly inspection results, including dates and findings should be retained for a minimum of 12 months.

#### 6.6.3 Face Piece Restrictions

Full-face piece breathing equipment-meeting requirements of 6.6.1 shall be used where the work area atmospheric concentration exceeds the action levels. The employer shall ensure that an employee using a tight-fitting face-piece respirator is fit tested prior to initial use of the respirator. The test should be preformed using the size, style, model, or make of respirator available to the employee. Fit testing should be done annually unless changes in size, style, model, or make of respirator or changes in the individuals facial scarring, dental changes, cosmetic surgery, or obvious changes in body weight requires additional fit testing.

Facial hair which would interfere with the face-piece seal is prohibited.

Personnel shall not wear eyeglasses with temple bars that extend through the sealing edge of the face piece. Using approved adapters, corrective prescription lenses may be mounted inside the breathing apparatus face piece.

#### 6.6.4 Respiratory Concerns

Based on recent studies it is unlikely that $H_2S$ could be inhaled through a perforated eardrum at quantities that would be harmful.

Personnel with known physiological or psychological conditions that impair normal respiration shall not be assigned to jobs involving potential exposure to a hydrogen sulfide or sulfur dioxide environment if use of the breathing equipment or exposure will complicate their respiratory problems. Personnel assigned job-related tasks requiring routine use of breathing equipment should have a periodic review to determine their physiological and psychological adequacy for use of this equipment.

#### 6.6.5 Air Supply

Breathing air quality shall meet the following requirements:

1. Oxygen content 19.5% – 23.5%.
2. Hydrocarbon (condensed) content of 5 $mg/m^3$ per cubic meter of air or less.
3. Carbon Monoxide (CO) contents of 10 ppm or less.
4. Carbon dioxide content of 1,000 ppm or less.
5. Lack a noticeable odor.

#### 6.6.6 Breathing Air Compressors

All breathing air compressors used shall meet the following requirements.

1. Prevent entry of contaminated air into the air-supply system. Inlet air for such compressors shall be monitored when conditions arise that permit possible contamination of the inlet by toxic, flammable, or combustible gases.
2. Minimize moisture content so that the dew point at 1 atmosphere pressure is 10°F below the ambient temperature.
3. Have suitable in line air purifying sorbent beds to further ensure breathing air quality. Sorbent beds and filters shall be maintained and replaced or refurbished periodically following the manufacturer's instructions. A tag containing the most recent change date and the signature of the person authorized by the employer to perform the change should be maintained at the compressor. Electronic documentation is an acceptable alternative.
4. For compressors that are not oil lubricated, the employer shall ensure the carbon monoxide levels in the breathing air do not exceed 10 ppm.
5. For oil lubricated compressors the employer shall use a high-temperature or carbon monoxide alarm, or both, to monitor carbon monoxide levels. If only high-temperature alarms are used, the air supply shall be monitored at intervals sufficient to prevent carbon monoxide in the breathing air from exceeding 10 PPM.

## 7 Contingency Planning, Including Emergency Procedures

### 7.1 INTRODUCTION

Operators shall evaluate operations involving hydrogen sulfide and sulfur dioxide to determine if contingency plans, special emergency procedures, and/or training are warranted or are required by applicable federal, state, or local regulatory agencies. The evaluation process shall identify potential emergencies and their impact on operating personnel and the general public. The contingency plan, if required, shall conform to all applicable local, state, and federal regulations regarding notifications, precautions, evacuations, and other requirements.

## 7.2 SCOPE

The contingency plan shall contain emergency response procedures that provide an organized immediate action plan for alerting and protecting operating personnel, contractor personnel, and the public. Contingency plans shall consider the severity and extent of the anticipated atmospheric hydrogen sulfide and sulfur dioxide concentrations. Contingency plans shall consider the dispersion characteristics of hydrogen sulfide and sulfur dioxide (refer to Appendix C or other recognized dispersion modeling techniques).

## 7.3 AVAILABILITY OF PLAN

The contingency plan shall be available to all personnel responsible for implementation.

## 7.4 PLAN INFORMATION

Contingency plan provisions may be contained in several plans or in a single plan. Contingency plans for offshore operations should contain greater detail concerning transportation requirements, evacuation of non-essential personnel, safe briefing areas and the accumulation of hazardous gases in machinery and personnel spaces. Contingency plans should contain information on the following subjects, as appropriate:

a. Emergency Procedures.
  1. Responsibilities of personnel.
  2. Immediate action plan.
  3. Notification list and communication methods.
  4. Diagram showing locations of nearby residences, businesses, parks, schools, churches, roads, medical facilities, athletics facilities, other facilities, including vessels offshore where population density may be unpredictable, etc.
  5. Evacuation routes and road block locations.
  6. Safety equipment and supplies available (e.g., number and location of breathing equipment).

b. Characteristics of Hydrogen Sulfide and Sulfur Dioxide.
  1. Refer to Appendix A for hydrogen sulfide characteristics.
  2. Refer to Appendix B for sulfur dioxide characteristics.

c. Facility Description, Maps, and Drawings.
  1. Water injection stations.
  2. Wells, tank batteries, gas conditioning facilities, and flowlines.
  3. Compression facilities.
  4. Safe briefing areas.

d. Training and Drills.
  1. Responsibilities and duties of essential personnel.
  2. Onsite or classroom (tabletop) drills.
  3. Informing nearby residents on protective measures in emergency situations, as appropriate.
  4. Training and attendance documentation.
  5. Briefing of public officials on issues.

## 7.5 IMMEDIATE ACTION PLAN

Each contingency plan should contain an "Immediate Action Plan," concise instructions to be followed by designated personnel any time they receive notice of a potentially hazardous hydrogen sulfide or sulfur dioxide discharge. For the protection of personnel (including the general public) and abatement of the discharge, this "Immediate Action Plan" should include the following provisions:

a. Alert and account for facility personnel.

Move away from the hydrogen sulfide or sulfur dioxide source and get out of the affected area.
  1. Don proper personal breathing equipment.
  2. Alert other affected personnel.
  3. Assist personnel in distress.
  4. Proceed to the designated safe briefing area.
  5. Account for onsite personnel.

b. Take immediate measures to control present or potential hydrogen sulfide or sulfur dioxide discharge and to eliminate possible ignition sources. Emergency shutdown procedures should be initiated as deemed necessary to correct or control the specific situation. When the required action cannot be accomplished in time to prevent exposing operating personnel or the public to hazardous concentrations of hydrogen sulfide or sulfur dioxide, proceed to the following steps, as appropriate for the site specific conditions.
  1. Alert the public (directly or through appropriate government agencies), who may be subjected to potentially harmful exposure levels.
  2. Initiate evacuation operations.
  3. Contact the first available designated supervisor on the call list (refer to 7.4a). Notify the supervisor of circumstances and whether or not immediate assistance is needed. The supervisor shall notify (or arrange for notification of) other supervisors and other appropriate personnel (including public officials) on the notification list.
  4. Make recommendations to public officials regarding blocking unauthorized access to the unsafe area and assist as appropriate.
  5. Make recommendations to public officials regarding evacuating the public and assist as appropriate.

c. Notify, as required, government agencies.

d. Monitor the ambient air in the area of exposure (after following abatement measures) to determine when it is safe for re-entry.

### 7.6 NOTIFICATION LISTS

A list of emergency telephone numbers and/or emergency contacts should be prepared and maintained as a part of the contingency plan, considering the need to contact any of the following:

a. Emergency Services.
  1. Ambulances.
  2. Hospitals.
  3. Medical personnel (e.g., doctors).
  4. Helicopter services.
  5. Veterinarians.

b. Government Agencies and Contacts.
  1. Local emergency planning committee.
  2. National response center.
  3. State emergency response commission.
  4. State and local law enforcement agencies.
  5. Fire departments.
  6. Other applicable government agencies.

c. Operator and Contractors.
  1. Operator personnel.
  2. Contractor personnel.
  3. Applicable service companies.

d. Public.

Contacts to emergency services or law enforcement agencies should provide notification that a hydrogen sulfide or sulfur dioxide emergency condition exists.

### 7.7 COMMUNITY WARNING AND PROTECTION PLAN

When atmospheric exposures beyond the wellsite could exceed potentially harmful exposure levels, and could affect the general public, the contingency plans should also contain a community warning and protection plan. Appendix C or other recognized dispersion modeling techniques should be used to determine the radii of potential hydrogen sulfide concentrations around the wellsite. Under certain circumstances, consideration should be given to the use of the temporary safe haven or shelter-in-place concept of protection to provide additional time for safe extraction of people from the shelters.

#### 7.7.1 Community Warning and Protection Plan Content

The community warning and protection plan should contain information on, but not be limited to, the following subject areas.

a. A plan for the notification and evacuation of residents and occupants in the vicinity of the wellsite should the atmospheric concentration in their area reach potentially harmful exposure levels.

b. Diagrams and telephone lists showing an identification number, the location, and telephone number (if available) of all residences, schools, churches, and businesses, as well as locations of barns, pens, roads, animals, and anything else that might cause people to be present who might need to be warned or evacuated. Access and evacuation routes should be indicated on the map. Anyone requiring assistance for evacuation, such as bedridden, wheelchair bound, etc., should be noted on the list for priority evacuation assistance.

c. Recommendations to county authorities and local emergency service organizations for the initial response to protect the public.

d. The operating conditions under which the operator representative will contact local authorities and the recommended community protection measures to be taken under those conditions.

e. Description and location of safety equipment to be provided by (1) the operator, and (2) by local authorities or services, to support the community warning and protection plan.

### 7.8 WELL-IGNITION PLAN

A plan should be prepared for ignition of the well in the event such action becomes necessary. The person, with appropriate authority to ignite the well, preferably the operator representative, should be stipulated in the contingency plan.

The decision to ignite the well should be made only as a last resort, and only then in a situation where it is clear that:

a. human life and property are endangered; and

b. there is no hope of controlling the well under the prevailing conditions.

In any case, if time permits, an attempt should be made to notify the designated offsite operator supervisor of the plans to ignite the well. However, the operator representative must not delay the decision if human life is threatened.

If the well is ignited, the combustion of hydrogen sulfide will produce sulfur dioxide, which is also highly toxic (Appendix B). Sulfur dioxide atmospheric concentration should be carefully monitored. When the atmospheric concentration of sulfur dioxide in the work area exceeds action levels, non-essential personnel shall proceed to a safe area and all essential working personnel should use proper personal breathing equipment.

The well contingency plan should contain procedures for monitoring the presence of sulfur dioxide on an area-wide basis and notification of all persons within the area to evacuate to a safe area if the sulfur dioxide exposure exceeds potentially harmful exposure levels.

Ignition may not be possible due to high concentrations of carbon dioxide or other non-combustible gases in the well fluids. If a decision is made to ignite the well, all persons shall be kept in a safe briefing area or as far from the wellbore as necessary to provide safety. Also, ignition may sometimes not be advisable due to atmospheric conditions. These eventualities should be considered during preparation of the community warning and protection plan.

### 7.9 TRAINING AND DRILLS

The value of training and drills in emergency response procedures for oil and gas operations involving hydrogen sulfide or sulfur dioxide cannot be overemphasized. It is important that the training convey a full appreciation of the importance of each role and the effect that each person has on implementing an effective emergency response.

Exercises or drills that simulate an emergency in which personnel perform or demonstrate their duties are important tools that can convey the importance of contingency plans and result in their being kept current. The exercise can be a tabletop or classroom discussion; or can be a realistic drill in which equipment is deployed, communication equipment is tested, and "victims" are sent to hospital facilities with simulated injuries. Public officials should be informed of (and, preferably, involved in) these exercises. After a plan is tested, it should be revised and retested until those responsible for the plan are confident the plan is operational. Refer to NRT-1: *Hazardous Materials Emergency Planning Guide.*

### 7.10 UPDATING PROVISIONS

A contingency plan shall be periodically reviewed and updated periodically.

Operating personnel should be observant for changes that would make reconsideration and possible revisions advisable in contingency plan coverage, location(s) of monitoring or detection equipment, and location(s) of lease equipment. Some changes that should be observed and considered are new residences or residential areas, churches, stores, businesses, parks, schools, or roads; changes in well operations; and changes in lease facilities.

## 8 Classification of Locations

### 8.1 GENERAL

Locations should be evaluated on the basis of the confinement presented by the area of the site and the specific environmental conditions. Land locations may be confined by the restriction of area, method of ingress and egress, terrain, surrounding population distribution, location proximity to municipalities or public facilities, etc. Locations with unconfined boundaries make it possible to obtain maximum safety benefits from rig configurations that take advantage of terrain and prevailing winds. Rig components should be arranged on location such that prevailing winds blow across the rig in a direction that will disperse any vented gas from the areas of the wellhead, choke manifold, flare stack or line, mud/gas separator, drilling or workover fluid tanks, reserve pits, and degasser away from any potential ignition sources e.g., engines, generators, compressors, and crew quarters) and areas used for personnel assembly.

Vehicles not involved in the immediate operations should be a minimum of 100 ft from the wellbore or a distance equal to the height of the derrick or mast, whichever is greater, and in all cases should be outside the derrick or mast guyline perimeter. Comparable safety measures should be taken when terrain, location, or other conditions do not permit this spacing.

### 8.2 LOCATIONS WITH UNCONFINED BOUNDARIES

#### 8.2.1 Access to Location

All means of access to the location should be designed so that they can be barricaded at a predetermined location if hydrogen sulfide or sulfur dioxide emergency conditions arise. An auxiliary access should be available so that a shift in wind direction would not preclude escape from the location. Appropriate caution signs (black on yellow, or equivalent) shall be displayed at all location entrances when the atmospheric concentration of hydrogen sulfide could exceed action levels, so as to indicate a potential danger might be encountered. If warning flags or flashing lights are utilized, colors should be displayed in accordance with the following conditions:

Legible warning signs, such as "HYDROGEN SULFIDE OPERATIONS—ENTER ONLY WHEN MONITORING SHOWS THE AREA TO BE SAFE" or "RESPIRATORY PROTECTION EQUIPMENT MUST BE WORN BEYOND THIS POINT," should be prominently posted at appropriate locations (e.g., entrance points) for operations where hydrogen sulfide may be encountered.

*CONDITION I:* Potential Danger To Life and Health: Well Operations Under Control.
Warning Device: Green (hydrogen sulfide concentration < 10 ppm).
Characterized By: Routine well operations in zones containing hydrogen sulfide. Hydrogen sulfide may be present at concentrations below action levels.

General Action:

a. Check safety equipment for proper functioning. Keep it available.
b. Be alert for a condition change.
c. Follow instructions of onsite operator representative.

*CONDITION II:* Moderate Danger To Life and Health: Critical Well Control Operations.

Warning Device: Yellow (hydrogen sulfide concentration 3: > 10 ppm and < 30 ppm).

Characterized By: Hydrogen sulfide is or potentially may be present up to 30 ppm on the well location.

General Action:

a. Stay in the "SAFE BRIEFING AREA" if not working to correct the situation.
b. Follow instructions of the onsite operator representative.
c. The onsite operator representative will follow community warning and protection plan procedures.

*CONDITION III:* Extreme Danger To Life and Health: Loss Of Well Control

Warning Device: Red (hydrogen sulfide concentration > 30 ppm).

Characterized By: Hydrogen sulfide concentration is above or potentially may be above 30 ppm.

General Action:

a. Stay in the "SAFE BRIEFING AREA" if not working to correct the situation.

b. Follow instructions of the onsite operator representative.

c. The onsite operator representative will make appropriate notifications, activate the audible alarm and initiate the community warning and protection plan.

d. If the well is ignited, the burning hydrogen sulfide will be converted to sulfur dioxide, which is also dangerous to life and health. Therefore, DO NOT assume that the area is safe after the gas is ignited. Continue to observe applicable emergency and safety procedures and follow the instructions of the onsite operator representative.

#### 8.2.2 Briefing Areas

Prevailing wind data shall be considered in locating briefing areas on either side of the location at a safe distance considering prevailing winds, or at a 90-degree angle for wind direction shifts in this area. When wind is from the prevailing direction, all briefing areas should be accessible. If the wind is quartering, one briefing area shall always be accessible.

#### 8.2.3 Wind Direction Indicators

Windsocks, wind streamers, flags, or other suitable device(s) shall be placed at points around the wellsite location. A wind direction device should be readily visible to personnel on or approaching the work location and from any briefing area. Possible locations for installations are guylines, vertical poles around the work site, the briefing areas, and the road entrances. Where practical and necessary, wind direction devices should be placed in illuminated areas.

#### 8.2.4 Electrical Equipment

All areas should be classified in accordance with API RP 500 or RP 505.

#### 8.2.5 Mechanical Ventilation

Mechanical ventilation (e.g., blowers or fans) may be desirable to help reduce hydrogen sulfide concentrations in the work area. Use of such ventilation equipment should be considered on the rig floor, around the derrick substructure, at the fluid tanks, and at any other low areas where hydrogen sulfide or sulfur dioxide might accumulate.

#### 8.2.6 Burn Pits, Flare Line(s), and Flare Stack(s)

All burn pits, flare lines, and flare stacks should be located considering the prevailing wind direction. Additionally, flare lines and vents should not be pointed into the prevailing wind. Space around flares and burn pits should be cleared of brush and grass. Flare stacks should permit dispersion of sulfur dioxide, which may be generated by combustion of fluid(s) containing hydrogen sulfide.

### 8.3 LOCATIONS WITH CONFINED BOUNDARIES

Space is often very restricted in mountainous or urban areas and in arctic, marsh, and water locations where operational requirements may dictate the use of special equipment such as barges, jack-up units, or similar support components. In addition to those recommendations made for unconfined locations, consideration should be given to confined locations considering limitations imposed by confinement of personnel and restricted distribution of equipment.

## 9 Well Materials and Equipment

### 9.1 MATERIALS CONSIDERATIONS

When exposed to an environment containing hydrogen sulfide, many materials may suddenly fail in a brittle manner. Failure occurs by a form of embrittlement known as sulfide stress cracking (SSC). Susceptibility of a given material to SSC increases as strength and tensile stress (residual or applied) increase. Material hardness frequently is used as an indirect measure of strength and sometimes is referenced as a limiting parameter. The failure of certain well drilling and/or servicing and production equipment used in the SSC regime could result in the uncontrolled release of hydrogen sulfide to the atmosphere. Such components should be made from SSC resistant materials.

Note: Due to the limited availability of qualified equipment for sour service, consideration should be given for backup equipment.

### 9.2 MATERIALS SELECTION

Metallic materials satisfactory for use in hydrogen sulfide environments and the conditions under which they should be used are described in NACE MR0175. The latest revision of this standard should be consulted when selecting materials for use in hydrogen sulfide environments. The provisions of NACE MR0175 should be considered minimum standards, with the equipment user free to apply more stringent specifications. The material requirements of NACE MR0175 offer resistance to SSC; however, other forms of corrosion and modes of failure (such as pitting, hydrogen-induced cracking, and chloride cracking) should be considered in the design and operation of equipment. Control of failures by mechanisms other than SSC should be mitigated by chemical inhibition, material selection, and environmental controls (refer to NACE MR0175).

**9.2.1** Compliance with NACE MR0175 for equipment intended for hydrogen sulfide service may be required by the user, depending on severity of the service. Adequate quality assurance procedures should be followed to verify compliance by the manufacturer for the original equipment and for any subsequent equipment modifications.

**9.2.2** Materials not covered in NACE MR0175 that have been qualified for hydrogen sulfide environment service by the user or manufacturer, using recognized and acceptable testing procedures, may be used. Recognized and acceptable testing procedures are those that demonstrate that the material(s) performs as well as or superior to similar material(s) set forth in NACE MR0175, using laboratory procedures or procedures for which testing has been completed under actual or simulated environmental conditions. The suitability of materials must be supported by appropriate documentation, that should include a complete description of the materials, processing, and testing procedure. Laboratory, field, or other environmental testing results or service performance should be recorded in writing. Full documentation supporting the suitability of material(s) for the selected service should be maintained by the user, manufacturer, or both.

**9.2.3** Non-metallic, resilient, rubber-like materials used in the sealing mechanisms of the various components of equipment shall be capable of sustaining the designated operating pressure, temperature, and hydrogen sulfide environment exposure for that particular component or assembly. Careful consideration should be given to effects of chemical elements or other conditions of the well fluids that may have detrimental effects on the seal materials. The equipment manufacturer should be consulted in selecting seals for use in hydrogen sulfide environments (refer to API Bull 6J).

## 9.3 WELL FLUIDS

The following measures will aid in the control of SSC:

1. Minimize formation fluid influx where appropriate.
2. Use of chemical scavengers. Fluids should be closely monitored for residual scavengers.
3. Maintenance of pH 9 or higher to prevent reversible action that can release hydrogen sulfide from the drilling or servicing fluid. The susceptibility to SSC increases as the pH decreases.
4. Use of a drilling or servicing fluid with diesel oil or other protective fluid as the continuous phase.

## 9.4 EQUIPMENT SELECTION AND INSTALLATION

### 9.4.1 Blowout Prevention Equipment

Blowout prevention equipment for hydrogen sulfide service is described in API RP 53. API Spec 16A contains product purchase specifications for annular and ram-type blowout preventers and related equipment, as well as recommended operations characteristics tests for blowout preventer equipment.

### 9.4.1.1 Choke Manifolds

Recommendations for selection, installation, and testing of choke manifold assemblies for use in hydrogen sulfide service can be found in API RP 53 and Spec 16C.

### 9.4.1.2 Testing

Recommended blowout preventer equipment field acceptance inspection and testing procedures are shown in API RP 53. Suggested blowout prevention equipment tests for hydrogen sulfide locations are contained in API RP 53.

### 9.4.2 Wellhead Equipment

Wellhead equipment for hydrogen sulfide service is described in API Spec 6A.

### 9.4.3 Tubular Goods

### 9.4.3.1 Casing and Tubing

Casing and tubing should be manufactured using materials specified in NACE MR0175 and/or API Spec 5CT. Materials not covered in NACE MR0175, which have been qualified for hydrogen sulfide service by the user or manufacturer following recognized and acceptable procedures may be used.

### 9.4.3.2 Drill Pipe

Drill pipe used as work string should be manufactured using materials specified in NACE MR0175 and API Spec 5D. Materials not covered in NACE MR0175, which have been qualified for hydrogen sulfide service by the user or manufacturer following recognized and acceptable procedures. may be used.

### 9.4.4 Work String Tubulars

For improved SSC resistance, work string tubular products having actual (not the specified minimum) yield strengths higher than 95,000 psi should be properly quenched and tempered. However, normalized and tempered lower strength tubulars (e.g., J-55 or L-80 tubing and Grades E and X drill pipe) used as work strings and normalized and tempered kellys are acceptable. The suitability of materials for hydrogen sulfide environment service can be assessed by evaluation of hardness testing results or tensile test data. As pipe yield strength and service stresses increase, consideration should be given to controlling SSC. High-strength tubulars (e.g., Grades P110 tubing and S135 drill pipe) should not be used for a work string in potential hydrogen sulfide environments unless a properly maintained drilling or servicing fluid is used. Recommendations for minimizing sulfide stress cracking of the work string are addressed in API RP 7G.

## 10 Wellsite Safety

### 10.1 INTRODUCTION

The intent of this subsection is to promote personnel safety, protection of the environment, and integrity of the facilities through use of prudent practices and methods in well drilling, completion, servicing, and workover operations.

Due to the toxic nature of hydrogen sulfide and sulfur dioxide, precautions must be taken to ensure personnel safety during any operation (refer to 4.1 and Appendices A and B). When protective breathing equipment must be worn by all working personnel, all nonessential personnel shall proceed to a safe briefing area. All operations shall be conducted in accordance with applicable laws, rules, and regulations.

### 10.2 PLANNING

An operations work plan consistent with the recommendations in this document should be established. Prior to starting operations, operating company, contracting company, drilling company, service company, and other job-related representatives should discuss pertinent well data and information pertaining to the operations.

The operator or his representative should provide and review the hydrogen sulfide contingency plan with the drilling or servicing company representative prior to rig up of equipment. The operator should also review the service company's immediate action plan to ensure coordinated response in the event of a hydrogen sulfide emergency.

**10.3** Daily checks should be performed by the designated wellsite supervisor prior to beginning work each day. The following items should be checked:

a. The work site for the presence of hydrogen sulfide.

b. Wind direction indicators. The results of this check may require redesignating the safe briefing areas.

c. Hydrogen sulfide monitoring or detection equipment and alarm (function test).

d. Placement of personal protective breathing equipment.

e. Placement of fire protection equipment.

f. Appropriate first aid equipment.

### 10.4 FLUID STORAGE

Hydrogen sulfide gas breaking out of stored fluid can be hazardous to personnel, especially if located in an enclosed space. Extreme caution should be exercised where there is potential that the fluid has been exposed to hydrogen sulfide and is stored in "mud or workover" pits, trip tanks, reserve pits, slug tanks, or other tanks.

Hydrogen sulfide may be generated by chemical reaction between stored fluids and other materials (residual or added). Personnel should take appropriate safety precautions when entering any enclosed or restricted ventilation area which contains or has contained stored fluid. Contaminated fluid should be disposed of in a safe manner or properly treated.

### 10.5 HYDROGEN SULFIDE FROM PRESSURE MAINTENANCE AND/OR WATERFLOODING OPERATIONS

Pressure maintenance and/or waterflooding operations may introduce bacteria that can cause water soluble hydrogen sulfide to develop within the producing formation over time and be present in produced fluids. Operators of such producing properties should be alert to this possibility and should warn drilling or well servicing personnel that hydrogen sulfide may be encountered in the performance of their normal work.

### 10.6 SPECIAL PRECAUTIONS

Special precautions should be taken during well drilling or servicing work, such as blowing the well down, dismantling wellhead equipment and flow lines, circulating the well, pulling pumps and packers, and swabbing after acidizing operations so that hazards due to the release of trapped hydrogen sulfide can be avoided. All drilling and/or servicing personnel should be trained in the potential dangers of hydrogen sulfide and precautions to be taken when it is encountered. Continuous hydrogen sulfide monitors/detectors should be available when drilling, working over or servicing a well with a potentially hazardous concentration of hydrogen sulfide. Protective breathing equipment shall be located so that it is quickly and easily available. Mechanical ventilation equipment may be used to direct vapors in the desired direction as protection against calm or light winds. Particular emphasis should be placed on low-lying work areas, such as cellars, where hazardous concentrations may develop because of the heavier hydrogen sulfide or sulfur dioxide settling in these areas.

### 10.7 HYDROGEN SULFIDE AND SULFUR DIOXIDE DRILLS

In addition to hydrogen sulfide and sulfur dioxide training for personnel, periodic emergency drills shall should be held. These drills should include those steps necessary to implement the emergency procedures. Records of personnel training and emergency drills shall be documented and should be retained for a minimum of 1 year.

### 10.8 HYDROGEN SULFIDE IGNITION SOURCES

When mixed with air, hydrogen sulfide can be explosive. To minimize potential sources of ignition, the following items should be considered:

a. Enforce "No Smoking" rules.
b. Locate portable generator units, dog houses, and change rooms as far from the wellbore as practical, or take appropriate safety measures.
c. Prohibit vehicles equipped with catalytic converters in the immediate vicinity of the wellbore unless measures have been taken to ensure that the area is safe from the potential of ignition. Vehicles not involved in the immediate operations should be a minimum of 100 ft (30.5 m) from the wellbore or a distance equal to the height of the derrick or mast, whichever is greater, but in all cases should be outside the derrick or mast guyline perimeter. Comparable safety measures should be taken when terrain, location, or other conditions do not permit this spacing.
d. Spark arrestors or equivalent equipment should be provided on all internal combustion engine exhausts located within 100 ft of the wellbore.
e. Restrict open flame stoves, open fires, welding operations, or other possible sources of ignition (electrical power tools, two-way radios, etc.) to designated areas.

## 11 Special Operations

### 11.1 INTRODUCTION

Although some special operations may require or be enhanced by the use of a drilling or servicing rig, most special operations can be accomplished with or without a rig on location. Adequate lighting should be provided in the work area(s) when special operations are required to be performed during the hours of darkness. Operators of potential hydrogen sulfide producing properties shall alert employees and special operations service contractors of the possibility of hydrogen sulfide and sulfur dioxide atmospheric concentrations greater than action levels may be encountered in the performance of their work.

Hydrogen sulfide and sulfur dioxide monitoring equipment shall be provided at the work location during special operations.

Special operations include, but are not limited to, the following operations:

a. Venting Operations.
b. Wireline operations, which include all types of wireline such as multi-strand conductor (electrical) line, multi-strand non-conductor line, and single-strand (slick) line.
c. Perforating operations.
d. Snubbing operations.
e. Continuous reeled (coiled) tubing operations.
f. Freezing (plug).
g. Valve drilling and hot tapping operations.
h. Coring operations.
i. Well evaluation and testing operations.

### 11.2 VENTING OPERATION

In addition to the other provisions of this recommended practice, when opening or bleeding a tool, lubricator, or any other device which has the potential to release hydrogen sulfide, appropriate piping should be installed to vent to a suitable remote location.

### 11.3 WIRELINE OPERATIONS

**11.3.1** Wireline Lubricator Equipment If the well is capable of flowing, the minimum lubricator equipment should consist of:

a. Wireline valve (blowout preventer).
b. Lubricator (riser) section(s).
c. Pressure bleed valve.
d. Stuffing box or control head.

When opening or bleeding a tool, lubricator, or any other device that has the potential to release hydrogen sulfide, appropriate piping should be installed to vent to a remote location. Otherwise, proper personal protective breathing equipment shall be worn by all personnel involved in the operation and with a potential to be exposed to hydrogen sulfide.

#### 11.3.2 Wireline Materials

Wireline materials should be suitable for the environment to which they will be subjected. Where hydrogen sulfide is the single chemical factor involved, several wire materials are available that are highly resistant to SSC. Consideration should be given to pretreating wirelines and slicklines with corrosion inhibitor(s) prior to running them in the well. In addition, consideration should be given to onsite inspection and field ductility testing of the wireline to detect pitting, surface damage, or embrittlement of the material that may have been incurred during operations. Some wire materials that are resistant to the effects of a hydrogen sulfide environment may not be adequate if other chemical elements, such as halides, are present. Halides include a class of chemical compounds commonly occurring in oil and gas wells. Examples of halide compounds that may be present in well fluids are hydrochloric acid, salt water, calcium chloride, and zinc bromide. Halides at elevated temperatures, such as are commonly present in the lower regions of the tubing string, can embrittle stainless steel wirelines. Metallurgical consultation may be required prior to running stainless steel wireline into well fluids containing halides.

#### 11.3.3 Well Swabbing Operations

The swabbing unit should be placed upwind from the wellbore, swabbing tanks, and pits. On a still day, the prevailing wind direction should be considered in positioning the swabbing unit.

### 11.4 PERFORATING OPERATIONS

Refer to API RP 67 and RP 54 for information regarding safety in perforating operations.

### 11.5 SNUBBING OPERATIONS

Snubbing operations should be restricted to daylight hours, excepting where existing emergency or environmental conditions dictate that such operations be performed in hours of darkness. Operations in the basket should be performed with the minimum number of essential personnel required. When working atop snubbing equipment (in the basket), an escape device shall be provided for each employee at the work level. No employee shall be allowed in the snubbing workbasket without proper equipment (e.g., self-contained air supply for escape or emergency use or an escape device being immediately available for use).

### 11.6 CONTINUOUS REELED (COILED) TUBING OPERATIONS

Refer to Section 9, "Well Materials and Equipment," for information regarding selection and use of equipment used in continuous reeled tubing operations. Cold working of continuous reeled tubing can affect material hardness. A quality control program should be implemented to monitor tubing condition.

#### 11.6.1 Placement of the Reel Unit

The continuous reeled tubing unit should be placed upwind of the well, considering the prevailing wind direction and specific wellsite conditions. The reel unit and its conveyance should be adequately secured so as to prevent any unwanted movement.

#### 11.6.2 Special Equipment

When possible, a flanged type connection should be used on the bottom connection of the coiled tubing blowout preventer. In pressured operations, consideration should be given to a dedicated pump cross and a second set of tubing ram preventers located below the pump cross. Wellbore fluids should not be routed to the coiled tubing operation enclosure for the purpose of instrumentation or other uses.

### 11.7 FREEZING OPERATIONS (PLUG)

Some materials may become brittle at low temperature. Prior to plug freezing operations, steel specifications should be determined to prevent low temperature damage to the material.

### 11.8 VALVE DRILLING AND HOT TAPPING OPERATIONS

Equipment used in valve drilling and hot tapping operations shall be suitable for hydrogen sulfide service. The rated working pressure of all equipment used in these operations should exceed the anticipated pressure inside equipment being drilled or tapped. Refer to API RP 2201 for additional general information regarding hot tapping operations on equipment in service.

The bleed-off ports on the lubricator and lubricator assembly should be equipped with two (2) valves in series on each port. These valves should be suitable for hydrogen sulfide service and shall have a rated working pressure that equals or exceeds the rated working pressure of the lubricator assembly. The outer valve should be used as the operational valve in order to conserve the innermost valve for emergency use.

### 11.9 CORING OPERATIONS

Precautions should be implemented prior to pulling cores from known or suspected hydrogen sulfide bearing zones. Crew members should don protective breathing equipment at least 10 stands before the core barrel reaches the surface or sooner if the action levels are reached. Portable hydrogen sulfide monitoring equipment should be used to check the core barrel when it is opened and when the core sample is removed. Personnel should continue to utilize protective breathing equipment until the atmosphere is determined to be below action levels. Appropriate precautions should be employed for the handling and transportation of samples containing hydrogen sulfide. Sample containers should be made of hydrogen sulfide resistant materials and appropriately labeled.

### 11.10 WELL EVALUATION AND TESTING OPERATIONS

#### 11.10.1 Personnel Safety Precautions During Well Testing and Evaluation

In addition to recommendations set forth in Sections 5 and 6, the following personnel safety precautions should be considered:

a. Operations should be performed with the minimum number of essential personnel required. These personnel shall utilize the necessary equipment to safely perform the operation(s) and maintain related equipment and services. Protective breathing equipment shall be located so that it is quickly and easily available to essential personnel. Atmospheric conditions should be monitored with appropriate hydrogen sulfide detection equipment.

b. Prior to initiation of such operations, special safety meetings shall be conducted for all personnel who will be on the rig facility, with particular emphasis on the use of proper protective breathing equipment, first aid procedures, and emergency response procedures. Only $H_2S$ qualified personnel may perform work.

c. All produced gases shall be vented and/or flared in such a manner as to ensure personnel safety. Gases from stored test fluids should also be safely vented.

d. "No Smoking" rules shall be vigorously enforced.

e. Personnel handling fluid samples from known or suspected hydrogen sulfide zones should exercise caution until such operations are completed. Appropriate precautions should be employed for the handling and transportation of samples containing hydrogen sulfide. Sample containers should be made of hydrogen sulfide resistant materials and appropriately labeled.

# APPENDIX A—PHYSICAL PROPERTIES AND PHYSIOLOGICAL EFFECTS OF HYDROGEN SULFIDE

## A.1 Physical Data

Chemical Name: Hydrogen Sulfide
CAS Number: 7783-06-4
Synonyms: Sulfureted hydrogen, hydrosulfuric acid, dihydrogen sulfide
Chemical Family: Inorganic sulfide
Chemical Formula: $H_2S$
Normal Physical State: Colorless gas, slightly heavier than air. Vapor density (specific gravity) at 59°F (15°C) and 1 atmosphere = 1.189.
Autoignition Temperature: 500°F (260°C)
Boiling Point: –76.4°F (–60.2°C)
Melting Point: –117.2°F (–82.9°C)
Flammable Limits: 4.3 – 46 percent vapor by volume in air.
Solubility: Soluble in water and oil; solubility decreases as the fluid temperature increases.

Combustibility: Burns with a blue flame to produce sulfur dioxide ($SO_2$). Refer to Appendix B. Odor and Warning Properties: Hydrogen sulfide has an extremely unpleasant odor, characteristic of rotten eggs, and is easily detected at low concentrations; however, due to rapid onset of olfactory fatigue and paralysis (inability to smell), ODOR SHALL NOT BE USED AS A WARNING MEASURE.

## A.2 Exposure Limits

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a Threshold Limit Value (TLV)® of 10 ppm (8-hour TWA) and a short term exposure limit (STEL) of 15 ppm averaged over 15 minutes. (Action Level) Exposure at the STEL should not be repeated more than 4 times per day with at least 60 minutes between successive exposures in this range.

## A.3 Physiological Effects

Inhalation at certain concentrations can lead to injury or death. The 300 ppm is considered by the ACGIH as Immediately Dangerous to Life and Health (IDLH). Hydrogen sulfide is an extremely toxic, flammable gas that may be encountered in the production of gas well gas, high-sulfur-content crude oil, crude oil fractions, associated gas, and waters. Since hydrogen sulfide is heavier than air, it can collect in low places. It is colorless and has a foul, rotten-egg odor. In low concentrations, $H_2S$ sometimes can be detectable by its characteristic odor; however, smell cannot be relied on to forewarn of dangerous concentrations because exposure to high concentrations (greater than 100 ppm) of the gas rapidly paralyzes the sense of smell due to paralysis of the olfactory nerve. A longer exposure to lower concentrations has a similar desensitizing effect on the sense of smell.

It should be well understood that the sense of smell will be rendered ineffective by hydrogen sulfide, which can result in an individual failing to recognize the presence of dangerously high concentrations. Exposure to hydrogen sulfide causes death by poisoning the respiratory system at the cellular level. Symptoms from repeated exposures to low concentrations usually disappear after not being exposed for a period of time. Repeated exposures to low concentrations that do not produce effects initially may eventually lead to irritation if the exposures are frequent.

## A.4 Respiratory Protection

Respiratory protection shall be worn above the action level. Refer to 6.6 for proper breathing equipment recommendations for oil and gas well drilling and servicing operations involving hydrogen sulfide.

# APPENDIX B—PHYSICAL PROPERTIES AND PHYSIOLOGICAL EFFECTS OF SULFUR DIOXIDE

## B.1 Physical Data

Chemical Name: Sulfur Dioxide

CAS Number: 7446-09-05

Synonyms: Sulfurous acid anhydride, sulfurous oxide, sulfuroxide

Chemical Family: Inorganic

Chemical Formula: $SO_2$

Normal Physical State: Colorless gas normally heavier than air.

Boiling Point: 148°F.

Flammable Limits: Non-flammable (produced from burning hydrogen sulfide).

Solubility: Readily soluble in water and oil; solubility decreases as the fluid temperature increases.

Odor and Warning Properties: Sulfur dioxide has a pungent odor associated with burning sulfur. It produces a suffocating effect and produces sulfurous acid on membranes of the nose and throat.

## B.2 Exposure Limits

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends 2 ppm as an 8-hour TWA Threshold Limit Value (TLV)® and 5 ppm as a STEL averaged over 15 minutes for sulfur dioxide.

## B.3 Physiological Effects

### B.3.1 ACUTE TOXICITY

Inhalation at certain concentrations can lead to injury or death. 100 ppm is considered by the ACGIH as Immediately Dangerous to Life and Health (IDLH).

## B.4 Respiratory Protection

Respiratory protection shall be worn above the action level. Refer to 6.6 for proper breathing equipment recommendations for oil and gas well drilling and servicing operations involving $SO_2$.

# APPENDIX C—A SCREENING APPROACH TO DISPERSION OF HYDROGEN SULFIDE

Note: The exposure radii shown in Figures C-1 through C-4 represent estimates developed by API's Air Modeling Task Force (AQ7) using simple screening models and modeling techniques. These models should be reasonably accurate for low velocity releases of neutrally-buoyant mixtures of hydrogen sulfide and carrier gas. Figures C-1 through C-4 are useful as a conservative screening tool for high velocity releases and for light hydrogen sulfide carrier gas mixtures. Figures C-1 through C-4 are not recommended for low velocity releases of heavier-than-air hydrogen sulfide/carrier gas mixtures or of potential aerosol- generating mixtures, since these illustrations sometimes will underpredict exposure radii for these mixtures. Site specific conditions should be assessed to determine the need for additional, more rigorous modeling techniques. Users should evaluate their operations and select proper modeling applications for their specific emergency planning purposes.

## C.1 Introduction

*CAUTION:* The material presented in Appendix C is generic in nature and is intended for emergency response planning purposes to arrive at conservative hydrogen sulfide dispersion estimates. Figures C-1 through C-4 present the screening-level, model-predicted radius of exposure (ROE) for atmospheric concentrations of hydrogen sulfide at 10, 30, 100, 300, and 500 ppm for both continuous and puff (instantaneous) releases of pure hydrogen sulfide. The ROE represents the distance from the emission source to the concentration of interest measured along the plume's centerline at ground level. Equations were developed for predicting the ROE as a function of the quantity/rate of hydrogen sulfide released for each of the hydrogen sulfide concentrations modeled and the type of release (continuous and puff). The equations and corresponding coefficients are presented in C.8 and Table C-1. Meteorological conditions typical of worst-case daytime and nighttime conditions were modeled.

Various regulations dealing with hydrogen sulfide operations prescribe a method(s) or technique(s) for ROE predictions. Such methods must be taken into account because specific compliance actions may require use of a method(s) specified by the regulation, unless use of other methods is allowed.

## C.2 Methodology

Note: The ROEs shown in Figures C-1, C-2, C-3, and C-4 were predicted using standard EPA- approved modeling procedures based on Gaussian dispersion theory. The ROEs shown in Figures C-1 and C-2 were predicted by modeling a continuous, steady-state point source release of 100 percent hydrogen sulfide. The ROEs shown in Figures C-3 and C-4 were predicted by modeling an instantaneous hydrogen sulfide release. Both hydrogen sulfide release types were modeled as releases of a neutrally buoyant material under steady-state meteorological conditions. An effective plume height (release height plus plume rise) of 10 ft was used in all the modeling work. It was assumed that the predicted ROEs do not vary significantly with effective plume height in the range of 0 – 50 ft.

For the purposes of dispersion modeling, the amount of turbulence in the ambient air is categorized into defined increments or stability classes. The most widely used categories are the Pasquill-Gifford (PG) Stability Classes A, B, C, D, E, and F (Pasquill, F., *Atmospheric Diffusion,* Second Edition, John Wiley & Sons, New York, New York, 1974). PG Stability Class A denotes the most unstable (most turbulent) air conditions and PG Stability Class F denotes the most stable (least turbulent) air conditions. PG Stability Class D denotes neutral atmospheric conditions where the ambient temperature gradient is essentially the same as the adiabatic lapse rate. Under neutral conditions, rising or sinking air parcels cool or heat at the same rate as the ambient air, resulting in no enhancement or suppression of vertical air motion.

Table C-1—Linear Regression Coefficients for Mathematical Predictions of ROE as a Function of Downwind Hydrogen Sulfide Concentration and Release Quantity/Rate

| Time | Type of Release | Concentration (ppm) | Coefficients | |
|---|---|---|---|---|
| | | | A | B |
| Day | Continuous | 10 | 00.61 | 0.84 |
| Day | Continuous | 30 | 00.62 | 0.59 |
| Day | Continuous | 100 | 00.58 | 0.45 |
| Day | Continuous | 300 | 00.64 | – 0.08 |
| Day | Continuous | 500 | 00.64 | – 0.23 |
| Night | Continuous | 10 | 00.68 | 1.22 |
| Night | Continuous | 30 | 00.67 | 1.02 |
| Night | Continuous | 100 | 00.66 | 0.69 |
| Night | Continuous | 300 | 00.65 | 0.46 |
| Night | Continuous | 500 | 00.64 | 32.00 |
| Day | Puff | 10 | 39.00 | 2.23 |
| Day | Puff | 30 | 39.00 | 2.10 |
| Day | Puff | 100 | 39.00 | 1.91 |
| Day | Puff | 300 | 39.00 | 1.70 |
| Day | Puff | 500 | 00.40 | 1.61 |
| Night | Puff | 10 | 39.00 | 2.77 |
| Night | Puff | 30 | 39.00 | 2.60 |
| Night | Puff | 100 | 00.40 | 2.40 |
| Night | Puff | 300 | 00.40 | 2.20 |
| Night | Puff | 500 | 00.41 | 2.09 |

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Notes:

1. Day Meteorological Conditions: Stability Class PG D (Neutm 1) 1 mph Wind Speed.
2. Night Meteorological Conditions: Stability Class PG F (Stable) 2.2 mph Wind Speed.

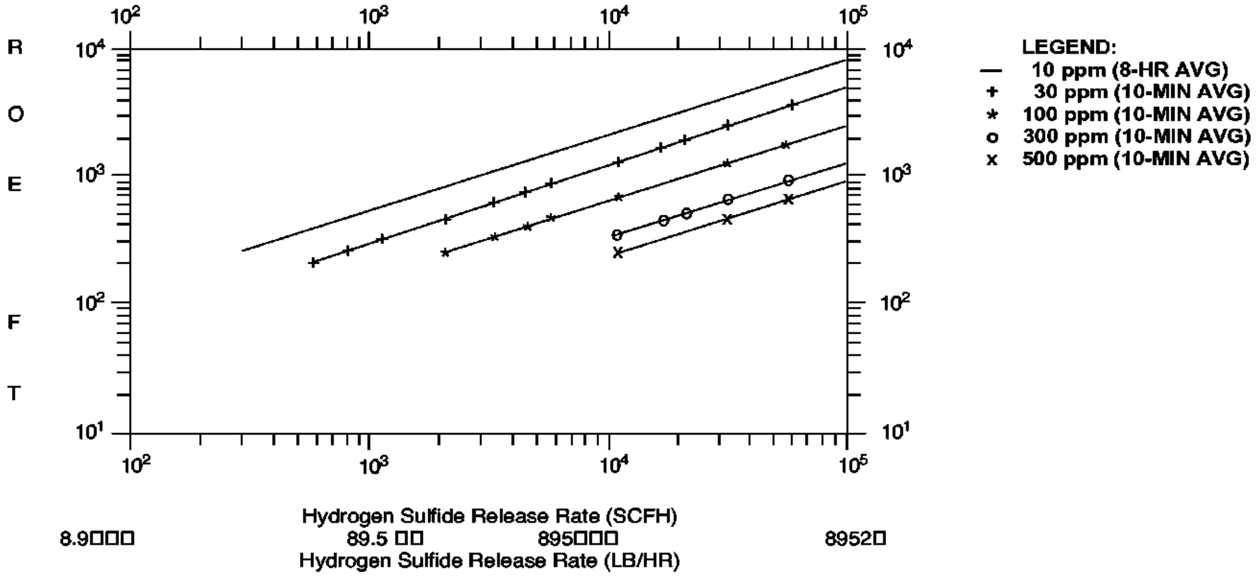

Figure C-1—Radius of Hydrogen Sulfide Exposure, Continuous Daytime Hydrogen Sulfide Releases [PG F (Stable)—2.2 MPH Wind Speed]

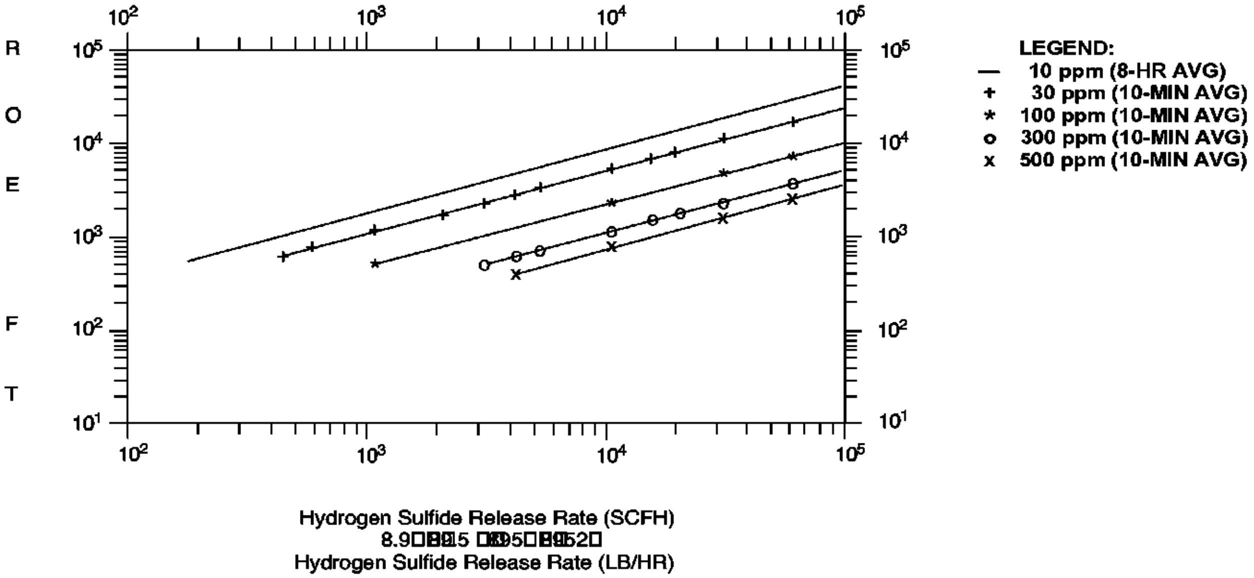

Figure C-2—Radius of Hydrogen Sulfide Exposure, Continuous Nighttime Hydrogen Sulfide Releases [PG F (Stable)—2.2 MPH Wind Speed]

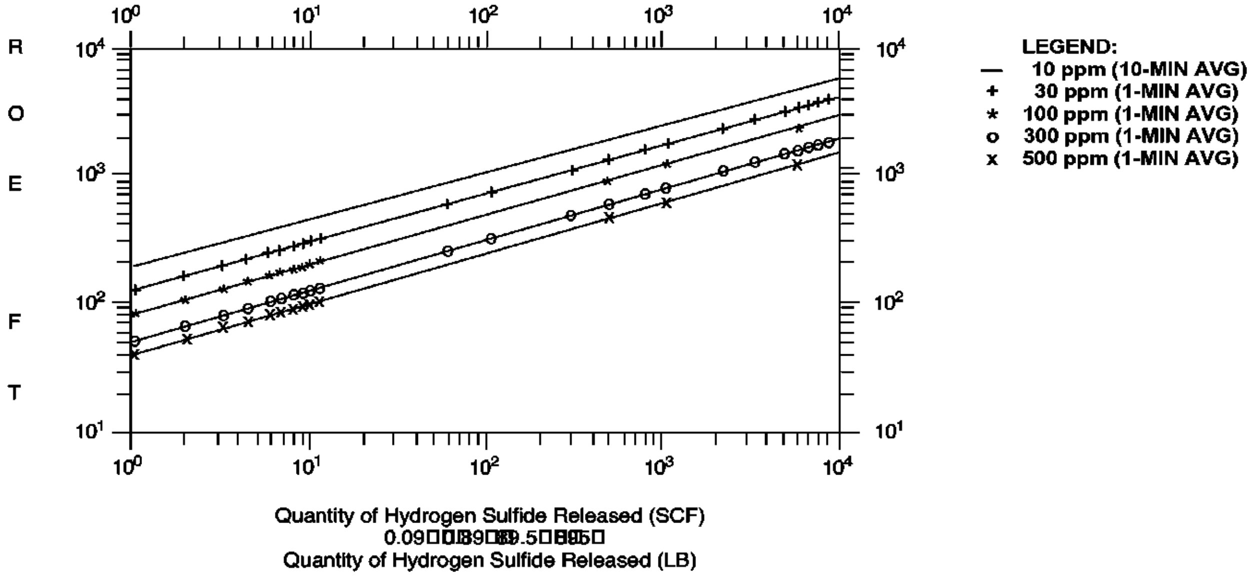

Figure C-3—Radius of Hydrogen Sulfide Exposure, Instantaneous Daytime Hydrogen Sulfide Releases [Slade A (Slightly Unstable)—5 MPH Wind Speed]

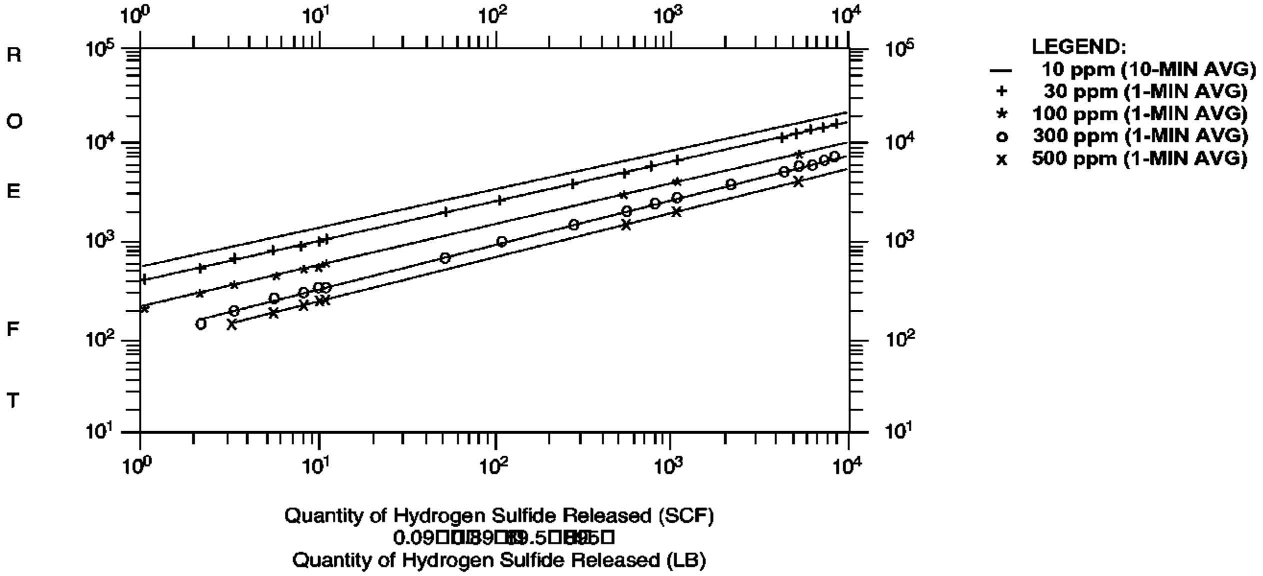

Figure C-4—Radius of Hydrogen Sulfide Exposure, Instantaneous Nighttime Hydrogen Sulfide Releases [Slade B (Neutral)—2.2 MPH Wind Speed]

Standard Pasquill-Gifford (PG) dispersion coefficients for flat, open grassland were used in the continuous hydrogen sulfide release model. The Slade (refer to NTIS-TID 24190: Slade, D.H., Meteorology and Atomic Energy, 1968) dispersion coefficients for flat, open grassland were used in the puff (instantaneous) release model. When modeling instantaneous hydrogen sulfide releases it was assumed that the downwind (x) and the crosswind (y) dispersion coefficients were equivalent. This assumption results in conservative (worst case) estimates of the ROEs. The following meteorological conditions were assumed to be representative of worst case daytime and nighttime conditions. For continuous daytime releases a neutral Stability Class (PG D) and 5 mph wind speed were chosen. For continuous nighttime releases, a stable Stability Class (PG F) and a 2.2 mph wind speed were chosen. For instantaneous (puff) daytime releases, a slightly unstable Stability Class (Slade A) and a 5 mph wind speed were chosen. For instantaneous nighttime releases, a neutral-to-stable Stability Class (Slade B) and a 2.2 mph wind speed were chosen.

The ROEs for continuous hydrogen sulfide releases at 30, 100, 300, and 500 ppm are valid for averaging times of 10 minutes to 1 hour. The ROEs shown for 10 ppm (continuous hydrogen sulfide release) are based on an 8-hour average concentration, since 10 ppm represents the 8-hour time weighted average (TWA) for hydrogen sulfide. To obtain the 8-hour 10 ppm average concentration a factor of 0.7 was used to convert the 1-hour concentrations (refer to EPA-450/4-88-009): A Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants). The ROEs for the puff (instantaneous) hydrogen sulfide releases at 30, 100, 300, and 500 ppm are valid for averaging times of 1 to 10 minutes. EPA's 0.7 conversion factor was used to obtain the 10-minute 0-ppm time averaged concentrations from instantaneous peak concentrations predicted by the model. For continuous releases, the EPA considers 10-minute and 1-hour averaging times to be equivalent. The modeling reported herein assumed that an instantaneous release would be of a very short duration (10 to 15 minutes maximum).

Brief descriptions of the models used to predict the ROEs for both continuous and puff (instantaneous) hydrogen sulfide releases are presented in C.13.

## C.3 Results

ROEs for atmospheric plume-centerline, ground-level concentrations of hydrogen sulfide resulting from instantaneous and continuous hydrogen sulfide releases were predicted and are presented in Figures C-1 through C-4. Figures C-1 and C-2 present the predicted ROEs for continuous hydrogen sulfide releases during worst case daytime and nighttime meteorological conditions, respectively. Figures C-3 and C-4 present the predicted ROEs for instantaneous hydrogen sulfide releases during worst case daytime and nighttime meteorological conditions, respectively. The ROEs for concentrations of 10, 30, 100, 300, and 500 ppm were modeled for both release types. The 10 ppm concentration ROEs represent an 8-hour averaging time for the continuous hydrogen sulfide release and a 1-minute averaging time for the instantaneous release. The 30, 100, 300, and 500 ppm concentration ROEs represent a 10-minute averaging time for the continuous hydrogen sulfide release and a 1-minute averaging time for the instantaneous release. A hydrogen sulfide release rate range of 10 to 10,000 lb/hr (111.8 to 111,768 SCFH) was modeled for the continuous type release. For the puff (instantaneous) type hydrogen sulfide release, a release quantity range of 0.1 to 1,000 pounds (1.1 to 11,177 SCF) was modeled. If the hydrogen sulfide release is based on pounds, standard cubic ft (SCF) can be obtained by multiplying pounds by a factor of 11.2.

Note: The ROEs presented in Figures C-1 through C-4 are plotted against the amount of hydrogen sulfide released. For the release of a multi-component gas stream, the actual amount of hydrogen sulfide released should be used to determine the ROE.

Equation coefficients based on linear regression for predicting the ROE as a function of the release type (continuous/puff) and quantity/rate of hydrogen sulfide released for both daytime and nighttime meteorological conditions are presented in Table C-1. The equation is shown. The coefficients are applicable only over the ranges presented in Figures C-1 through C-4, and extrapolation could result in overly conservative estimates of the ROEs. Any release lasting significantly longer than 15 minutes should be interpreted as a continuous release. The modeling work presented in Appendix C assumes steady-state meteorological conditions. ROEs predicted for a long averaging time (8-hour) and long downwind distances are conservative because it is unlikely that the same meteorological conditions will persist during that time period.

## C.4 Additional Considerations

The modeling work presented in Appendix C assumes a neutrally buoyant, gaseous hydrogen sulfide release in flat, rural terrain under steady-state meteorological conditions. Also, the ROEs shown in Figures C-1 through C-4 are for a generic class of hydrogen sulfide releases covering a wide range of site and release conditions. Actual ROEs will be dependent on the specifics of the type of release, release conditions, and release site. For instance, the ROEs for a release in a more urban setting where structures, buildings, etc., are present will be reduced significantly due to structure-induced turbulence. Some other conditions that could significantly affect the actual ROE include: a liquid/aerosol release, dense cloud behavior, a buoyant cloud (plume liftoff, jet release), time-dependent release (well blowout, pipeline ruptures, etc.), and complex terrain. If any of these phenomena are present, then more rigorous modeling may be necessary.

The ROE curves of Figures C-1 through C-4 should not be used when the mixture of hydrogen sulfide and carrier gas being dispersed is significantly heavier than air and the mixture is released at a low velocity. If the hydrogen sulfide/carrier gas mixture specific gravity exceeds approximately 1.2, Figures C-1 through C-4 may not give conservative ROEs for all release rates and meteorological conditions. Hydrogen sulfide, as encountered in the petroleum industry, is usually a minor constituent of carrier gas, such as natural gas or carbon dioxide. Carbon dioxide has a specific gravity of 1.52. Dispersion predictions for hydrogen sulfide/carbon dioxide mixtures, using a dense gas model sometimes underpredict hydrogen sulfide ROEs for low velocity gas releases. Low velocity gas releases would include those with initial velocities less than 200 ft/sec and releases greater than 200 ft/sec involve impact of the gas jet from the leak with a nearby surface, thereby breaking the jet's momentum. Likewise. Figures C-1 through C-4 should not be used with any hydrogen sulfide/carrier gas release that potentially could form an aerosol.

Figures C-1 through C-4 can also substantially overpredict ROEs. In the case of hydrogen sulfide/carrier gas mixtures significantly lighter than air (i.e., specific gravity less than 0.8) released at low velocity, use of these illustrations may overpredict ROEs by a factor of 2 to 3. Use of these illustrations can result in overestimation of ROEs for high velocity hydrogen sulfide/carrier gas releases (i.e., gas release velocities greater than 200 ft/sec) regardless of the orientation of the release; however, this overprediction is particularly significant in the case of vertical, high-velocity releases. In such situations, the overprediction can be two orders of magnitude. The user should consult more rigorous atmospheric dispersion models.

When calculating the ROE for dilute concentrations of hazardous gases, a significant overestimation can result. For example, it would not be practical to expect higher downwind atmospheric concentrations than are present in the released gas stream. The user should consult more rigorous atmospheric dispersion models.

In summary, the composition of the hydrogen sulfide/carrier gas and the velocity and orientation of the release are critical variables, dramatically affecting predicted hydrogen sulfide ROEs. Also, other variables, such as released gas temperature and flashing or aerosol formation involving liquid containing dissolved hydrogen sulfide, can have significant impacts on ROE predictions. Accurate atmospheric dispersion techniques are, of necessity, complex. Under some circumstances, such as those mentioned above, more rigorous modeling may be required.

References and models are available to address special release scenarios. A partial list of models that may be used in such cases is shown in C.5 and C.6. API does not endorse any one particular model. Further guidance on appropriate model selection and application can be obtained from the model developers as well as other individuals experienced in this field. A specific reference to address well blowout and pipeline ruptures is "Release and Dispersion of Gas from Pipe Line Ruptures," Wilson, D.J., Department of Mechanical Engineering, University of Alberta, Edmonton, Canada.

In the event that hydrogen sulfide release quantities calculated by the user are below the ranges shown in Figures C-1 through C-4, extensions of the ROE curves are allowed to a minimum ROE of 50 ft. In some cases, ROEs of less than 50 ft may be inferred from extrapolation of the curves. Figures C-1 through C-4 were developed using an assumed release height plus plume rise of 10 ft. Actual release heights of other than 10 ft will result in different ROEs.

## C.5 Proprietary Dispersion Models

Note: Users should carefully evaluate applicability of these models to prevailing conditions. A list of some proprietary models that can be used to address special site-specific scenarios follows:

CHARM (Radian Corporation): CHARM is a Gaussian puff model for continuous and instantaneous releases of gases or liquids. The model is configured to handle chemicals that are buoyant, neutrally buoyant, and heavier than air. Heavy gas dispersion is estimated using the Eidsvik model. Source components in the model include a modified version of Shell Oil Company's SPILLS model. (Radian Corp., 850 MOPAC Blvd., Austin, Texas 78759.)

FOCUS (Quest Consultants, Inc.): FOCUS is a modeling package that includes both emission rate models (two-phase discharges, pool evaporation, jet vapor releases, etc.) and dispersion models for both neutrally-buoyant and dense-gas plumes. The models can be run separately or in a linked mode. (Quest Consultants, Inc., 908 26th Avenue, NW, Suite 103, Norman, Oklahoma 73069-6216.)

TRACE (Dupont): TRACE uses a multiple Lagrangian Wall dispersion model to handle both puff and continuous releases. Wind channeling can be incorporated. Liquid evaporation and buoyancy effects are considered also. (E.I. Dupont de Nemours & Company, 5700 Corea Avenue, Westlake Village, California 91362.)

WHAZAN (Technica International): WHAZAN is a package of dispersion models for both neutrally buoyant and dense-gas plumes. Submodels are included to handle two-phase discharges, evaporation, and vapor dispersion as a free jet. The model can be run both individually and in a linked mode. (Technica International Associates, Inc., Box 187, Woodstock, Georgia 30128-4420.)

## C.6 Publicly Available Models

Note: Users should carefully evaluate applicability of these models to prevailing conditions. A list of some publicly available models that can be used to address special site-specific scenarios follows:

DEGADIS (U.S. Coast Guard): DEGADIS, the Dense Gas Dispersion Model, is designed to simulate dispersion of heavier-than-air gas releases. It can handle both evaporative emissions from liquid spills and jet emissions. It is basically steady-state but simulates transient conditions by a series of steady-state calculations. Vapor generation rate, spill area, and meteorological parameters are important inputs to the model. Information available through National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, Virginia 22161.

HEGADAS (Shell Research B.V.): HEGADAS is a dispersion model for neutrally-buoyant and dense gases. The basic model components are solutions to the advection/diffusion equations and are in the standard form of Gaussian dispersion models. The model can handle a wide variety of source types, including transient horizontal jets. Information available through National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, Virginia 22161. SLAB (Lawrence Livermore National Laboratory): SLAB is designed for application to dense gases that are emitted from liquid spills. The model considers the concentration integrated over a cross-section perpendicular to the plume centerline. The downwind variation of the integrated concentration is calculated. The size and emission rate of the liquid spill are required inputs to the model. Information available through Lawrence Livermore National Laboratory, Box 808, Livermore, CA 94550, or contact The American Petroleum Institute, Health & Environmental Sciences Department, 1220 L Street, NW, Washington, D.C. 20005.

## C.7 Sample Calculations for Figures C-1 through C-4

The following calculations may be used to estimate volume and mass of hydrogen sulfide when total gas volume and its hydrogen sulfide content are known:

Continuous Release.

Assume: Release 5,000,000 SCFD of natural gas containing 8,000 ppm (by volume) of hydrogen sulfide.

Note: The user must know both the volume (or flow rate) of natural gas and its hydrogen sulfide concentration so that Figures C-1 through C-4 can be effectively used. To determine standard cubic ft per hour (SCFH) of hydrogen sulfide released, the following calculations should be performed using appropriate values for the conditions being evaluated:

5,000,000 SCFD × 8,000 ppm $H_2S$
24,000,000 – 1,667 SCFH of $H_2S$ released

To determine the pounds of hydrogen sulfide released per hour, the following calculations should be performed using appropriate values for the conditions being evaluated:

5,000,000 SCFD × 8,000 ppm $H_2S$
267,605,634 – 150 lb./hr of $H_2S$ released.

Instantaneous Release.

Assume: Release of 100,000 SCF of natural gas containing 8,000 ppm (by volume) of hydrogen sulfide. Also, assume this example is a daytime release, 5 mph wind speed (refer to Figure C-3).

To determine the volume (SCF) of hydrogen sulfide released the following calculations should be performed using appropriate values for the conditions being evaluated:

100,000 SCFD × 8,000 ppm $H_2S$
1,000,000 – 800 SCF of $H_2S$ released.

After applying the appropriate calculations and using known factors to arrive at either hydrogen sulfide release rate or quantity of hydrogen sulfide released, refer to the appropriate chart (Figures C-1 through C-4) or the equation in C.8 (example calculations in C.9 through C.12) for obtaining radius of exposure (ROE) information.

The following equation can be used to convert percent hydrogen sulfide to parts per million on a volume basis:

Percent $H_2S$ x 10,000 = ppm $H_2S$

## C.8 Radius of Exposure (ROE) Calculation

Using the values of coefficients "A" and "B" in Table C-1, the radius of exposure (ROE) for various hydrogen sulfide release rates ($H_2S$) can be mathematically predicted using the following equation:

$$\text{ROE} = \text{Antilog}\,[A \times \log(H_2S) + B]$$

For a continuous release, enter the hydrogen sulfide release rate ($H_2S$) in standard cubic ft per hour (SCFH). For a puff (instantaneous) release, enter the quantity of hydrogen sulfide ($H_2S$) released in standard cubic ft (SCF).

## C.9 Sample Calculation—Continuous Release (Daylight)

Determine the ROE100 ppm for a continuous release of 100 percent hydrogen sulfide gas at a rate of 11,170 SCFH in daylight (RG D stability) conditions and 5 mph wind speed. Using Table C-1, the coefficients applicable to this scenario are: A = 0.58; B = 0.45. Using the equation in C.8:

$$\text{ROE100 ppm} = \text{Antilog}\,[0.58 \times \log(11{,}170) + 0.45]$$
$$= 628 \text{ ft}$$

## C.10 Sample Calculation—Continuous Release (Nighttime)

Determine the ROE for a continuous release of 100 percent hydrogen sulfide gas at a rate of 11,170 SCFH in nighttime (PG F stability) conditions and 2.2 mph wind speed. Using Table C-1, the coefficients applicable to this scenarios are: A = 0.66; B = 0.69. Using the equation in C.8:

$$\text{ROE100 ppm} = \text{Antilog}\,[0.66 \times \log(11{,}170) + 0.69]$$
$$= 2{,}300 \text{ ft}$$

## C.11 Sample Calculation—Instantaneous Release (Daylight)

Determine the ROE100 ppm for an instantaneous release of 100 percent hydrogen sulfide gas of 1,117 SCF in daylight (Slade A stability) conditions and 5 mph wind speed. Using Table C-1, the coefficients applicable to this scenarios are: A = 0.39; B = 1.91. Using the equation in C.8:

$$\text{ROE100 ppm} = \text{Antilog}\,[0.39 \times \log(1{,}117) + 1.91] = 1{,}255 \text{ ft}$$

## C.12 Sample Calculation—Instantaneous Release (Nighttime)

Determine the ROE100 ppm for an instantaneous release of 100 percent hydrogen sulfide gas of 1,117 SCF in nighttime (Slade B stability) conditions and 2.2 mph wind speed. From Table C-1, the coefficients applicable to this scenarios are: A = 0.40; B = 2.40. Using the equation in C.8:

$$\text{ROE100 ppm} = \text{Antilog}\,[0.40 \times \log(1{,}117) + 2.40] = 4{,}161 \text{ ft}$$

## C.13 Descriptions of Gaussian and Puff Dispersion Models

### C.13.1 INTRODUCTION

The emergency response Gaussian and Puff screening models are designed to predict the downwind dispersion (plume-centerline, ground-level concentration and maximum ground- level plume width as a function of downwind distance) of a neutrally buoyant, steady-state point source gaseous release under steady-state meteorological conditions. Classical EPA-approved Gaussian dispersion theory is applied in the models. The programs are in BASIC and are designed for use on personal computers. The models are described below. The program listings and runs should use the IDLH, ERPG-2, and TLV and STEL levels as the concentrations of interest because they usually are the concentration values of concern. Both models can be run for other concentrations by substituting the values of interest in place of the values for IDLH, ERPG-2, and TLV and STEL in the computer programs. Copies of the example program listings and computer runs are available on request from API, Upstream Segment, 1220 L St., NW, Washington, D.C. 20005.

### C.13.2 GAUSSIAN MODEL

This model calculates the plume-centerline, ground-level concentration, and maximum ground-level plume width for a single, steady-state, continuous-point release at user- specified steady-state meteorological conditions and downwind distances. The model uses standard Gaussian dispersion modeling with Pasquill-Gifford dispersion coefficients. The user inputs the release rate, effective release height (release height plus plume rise), nominal wind speed, incremental downwind distance for which calculations are to be made, type of material released, and the stability class. A total of eight compounds are currently accepted by this model. Additional compounds can be entered by replacing compounds presently in the model. The model uses a default D Stability Class, but can be run with any of the standard Pasquill-Gifford Stability Classes (A, B, C, D, E, or F—with A being the most unstable and F being the most stable).

### C.13.3 PUFF MODEL

This model calculates the plume-centerline, ground-level concentration, and maximum ground-level plume width for a single, instantaneous-point release at user-specified steady-state meteorological conditions and downwind distances. The modes uses standard Gaussian dispersion theory for an instantaneous (puff) release with Slade dispersion coefficients. User inputs to the model are the same as those used in the Gaussian model except that the total amount of material released is entered rather than the rate of release. Three values are accepted for the Stability Class (A, B, or C—with A being unstable, B being neutral, and C being stable).

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