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Managing Hydrogen Sulfide Exposure Risks in Oil and Gas Operations: A Barrier-Based Review of Gas Detection, Respiratory Protection, Confined Space Entry, and Emergency Response

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Abstract

Hydrogen sulfide (H_2S) remains one of the most severe acute toxic gas hazards in oil and gas operations. Its occupational relevance is driven by a combination of high toxicity, rapid incapacitation potential, accumulation in low-lying and confined spaces, flammability, and the unreliability of odor as a warning mechanism. This structured narrative review synthesizes open regulatory, toxicological, incident-investigation, and peer-reviewed evidence to develop a barrier-based framework for managing H_2S exposure risks in drilling, production, maintenance, tank, waterflood, and confined-space operations. Sources were selected from official occupational safety agencies, toxicological guidance, formal incident investigations, recognized risk-management frameworks, and peer-reviewed literature with verified DOI or PubMed indexing where applicable. The evidence indicates that effective H_2S risk management cannot rely on personal protective equipment or exposure-limit compliance alone. Instead, it requires integration of source identification, engineering controls, fixed and personal gas detection, pre-entry and continuous atmospheric monitoring, ventilation, work authorization, respiratory protection for immediately dangerous to life or health conditions, rescue readiness, training, and management-system assurance. Incident evidence further shows that missing or weak barriers can expose not only workers but also co-workers, responders, and nearby non-employees. The review proposes a six-element framework linking hazard identification, source and engineering controls, detection and verification, work authorization, protection and emergency response, and assurance and learning. The framework is intended to support quality, health, safety and environment (QHSE) managers, safety engineers, supervisors, and emergency planners in developing auditable H_2S risk-control programs for high-risk oil and gas environments.

Keywords: hydrogen sulfide, occupational safety, oil and gas, gas detection, confined spaces, emergency response

1. Introduction

Hydrogen sulfide (H_2S) is a colorless, highly toxic and flammable gas that occurs naturally in crude petroleum, natural gas, produced water and other sulfur-containing environments. In oil and gas operations, H_2S can be encountered during drilling, well servicing, production, waterflooding, maintenance, tank operations, opening of containment, pit work, and activities involving stagnant or sour fluids. Although H_2S is commonly associated with a rotten-egg odor at low concentrations, odor is not a reliable warning method because olfactory fatigue or paralysis may occur rapidly, especially at dangerous concentrations [1 - 3].

The acute risk profile of H_2S makes it distinct from many other occupational airborne hazards. The Occupational Safety and Health Administration (OSHA) identifies H_2S as one of the leading causes of workplace gas inhalation deaths in the United States and reports that H_2S caused 46 worker deaths between 2011 and

2017 [4]. OSHA also emphasizes that the gas is heavier than air, can accumulate in low-lying areas and confined spaces, and can overcome unprepared workers and rescue workers [4]. For oil and gas well drilling and servicing, OSHA identifies inhalation exposure as the primary safety concern [5]. These characteristics justify treating H_2S exposure not merely as a compliance issue but as a credible major-accident and fatality scenario in sour oil and gas operations.

The severity of H_2S exposure depends on concentration, duration, exposure route and the worker's ability to escape. OSHA and National Institute for Occupational Safety and Health (NIOSH) sources identify occupational exposure limits and immediately dangerous to life or health (IDLH) values, while toxicological guidance highlights effects on the nervous and respiratory systems [1,2,6,7]. High-level exposure can produce rapid unconsciousness, respiratory arrest and death, leaving little time for self-rescue or improvised response. This creates an operational requirement for prevention, early detection, evacuation readiness and protected rescue.

Despite the availability of gas detection technologies, respiratory protective equipment and established confined-space procedures, H_2S incidents continue to demonstrate recurrent weaknesses in barrier design and implementation. The U.S. Chemical Safety and Hazard Investigation Board (CSB) investigation of the Aghorn Operating waterflood station H_2S release found that one worker and one member of the public died following a release and issued recommendations addressing personal H_2S detectors, lockout/tagout (LOTO), ventilation and mitigation analysis, and comprehensive safety management [8]. Similarly, the UK Health and Safety Executive (HSE) reported H_2S concentrations up to 16,000 ppm in cargo and slop tank ullage spaces on some offshore units, noting that such concentrations may exceed the upper measuring limits of standard portable monitoring equipment [9].

A further challenge is the risk to co-workers and would-be rescuers. Hendrickson et al. reviewed U.S. Bureau of Labor Statistics fatal occupational injury data from 1993 to 1999 and identified 52 occupational H_2S deaths; in 21% of cases, a co-worker died either simultaneously or while attempting rescue [10]. This evidence supports the need to integrate emergency response planning into the primary risk-control system rather than treating rescue as an informal or reactive activity.

This article aims to synthesize open regulatory, toxicological, incident-investigation and peer-reviewed evidence into a practical barrier-based framework for H_2S exposure risk management in oil and gas operations. The contribution of the article is not a new toxicological model or field measurement dataset. Instead, it integrates fragmented evidence into an operational framework that can be used by quality, health, safety and environment (QHSE) managers, safety engineers, operations supervisors and emergency planners to structure prevention, detection, work authorization, respiratory protection, rescue and assurance activities.

2. Materials and Methods

2.1. Review Design

This article uses a structured narrative review design. The approach was selected because the objective is to integrate regulatory requirements, toxicological evidence, incident lessons and occupational safety frameworks into a practical risk-management model. The review is not presented as a systematic review or meta-analysis. No pooled effect estimate or formal risk-of-bias assessment was attempted because the included materials differ substantially in type, purpose and evidentiary structure.

The source base was treated as an open evidence dataset. Each source was screened for relevance to H_2S exposure, oil and gas operations, occupational safety controls, confined spaces, respiratory protection, emergency response or risk-management systems. Extracted evidence was then mapped to manuscript sections and to the proposed barrier framework.

2.2. Source Selection

Sources were selected from five categories: official occupational safety and regulatory guidance; toxicological and medical guidance; formal incident investigation reports; recognized risk-management or occupational health and safety frameworks; and peer-reviewed scientific literature. Priority was given to official government or regulator sources, including OSHA, NIOSH and the Centers for Disease Control and Prevention (CDC), the Agency for Toxic Substances and Disease Registry (ATSDR), CSB and HSE. Peer-reviewed articles were included where they addressed fatality patterns, occupational exposure limits, or low-level and chronic H_2S exposure evidence. DOI, PMID or PMCID details were verified for the peer-reviewed literature where available.

Manufacturer marketing pages, law firm blogs, unsourced training websites, social media posts and unverified presentations were excluded. Official ISO pages were included only for high-level framework alignment because the full standards are paywalled; therefore, detailed standard clauses are not used in this manuscript unless available from open official summaries. Table 1 summarizes the source categories included in the review.

Table 1. Source categories included in the structured narrative review.

Source Category	Number of Sources	Examples	Evidence Extracted	Limitations
Official occupational safety and regulatory sources	7	OSHA H_2S overview, OSHA hazards, OSHA confined spaces, OSHA respiratory protection, NIOSH Pocket Guide.	Exposure values, IDLH values, confined-space requirements, respiratory protection requirements, monitoring and control practices.	Primarily U.S.-focused; legal applicability varies by jurisdiction.
Toxicological and medical guidance	2	ATSDR ToxGuide; ATSDR Medical Management Guidelines.	Health effects, exposure routes, target organs, acute medical concerns.	Broad toxicological guidance, not oil-and-gas-specific operational procedures.
Formal incident and safety notices	2	CSB Aghorn investigation; HSE ED2-2023 safety notice.	Incident lessons, barrier failures, high-concentration scenarios, monitoring limitations, control recommendations.	Incident-specific and context-dependent; not statistical evidence of prevalence.
Management-system and risk frameworks	3	NIOSH hierarchy of controls; ISO 45001; ISO 31000.	Control hierarchy, occupational health and safety risk management, risk identification and treatment logic.	ISO sources are limited to open official summaries.
Peer-reviewed literature	3	Hendrickson et al.; Elwood; Batterman et al.	Fatality patterns, co-worker rescue risk, exposure-limit interpretation, low-level exposure evidence and uncertainty.	Limited number of articles selected for targeted relevance rather than systematic coverage.
State agency practical guidance	1	Texas Department of Insurance H_2S guidance.	Practical oil and gas worker protection measures including monitoring, ventilation, PPE, emergency procedures and training.	Practical guidance rather than primary research.

2.3. Evidence Extraction and Synthesis

For each source, the following fields were extracted: source type, issuing organization or journal, access status, DOI/PMID/PMCID where applicable, operational topic, extracted evidence, use in the manuscript and expected contribution to the proposed framework. Evidence was grouped into four synthesis domains: toxicological and exposure characteristics; oil and gas exposure scenarios; prevention and protection barriers; and incident lessons and management-system implications.

The synthesis was guided by the NIOSH hierarchy of controls, which ranks elimination, substitution, engineering controls, administrative controls and personal protective equipment (PPE) in descending order of general effectiveness [11]. This hierarchy was used to avoid a PPE-centered interpretation of H_2S safety and to structure controls across source control, detection, work authorization, respiratory protection, emergency response and assurance.

3. Results: Evidence Synthesis

3.1. Toxicological and Operational Characteristics of H_2S

H_2S is primarily an inhalation hazard in occupational settings. The NIOSH Pocket Guide identifies inhalation as an exposure route and lists H_2S as a colorless gas with a strong rotten-egg odor, while warning that the sense of smell can become rapidly fatigued and cannot be relied upon to warn of continuous presence [2]. ATSDR similarly identifies inhalation as the most likely route of occupational exposure and identifies the nervous system and respiratory tract as key toxicity targets [6].

Exposure values provide important reference points but should not be interpreted as complete safety barriers. NIOSH lists an IDLH value of 100 ppm and a recommended exposure limit of 10 ppm as a 10-minute ceiling [2]. OSHA describes general industry ceiling and peak limits and provides concentration-effect guidance showing that higher concentrations can produce rapid unconsciousness and death [1]. Elwood's critical commentary on occupational exposure limits highlights scientific uncertainty in limit setting and supports the view that occupational exposure limits are necessary reference points but not sufficient substitutes for layered risk management [12]. Selected exposure values and their operational implications are summarized in Table 2.

Table 2. Selected H_2S exposure values, effects and operational implications based on verified open sources.

Value or Range	Meaning or Effect	Operational Implication	Primary Source
10 ppm ceiling	NIOSH recommended exposure limit over 10 minutes.	Use as a conservative reference value for work planning and monitoring in H_2S-prone areas.	[2]
20 ppm ceiling; 50 ppm peak (up to 10 minutes, once, if no other measurable exposure occurs)	OSHA general industry ceiling and peak values as reported by OSHA/NIOSH sources.	Use as compliance reference values; do not treat compliance as proof of adequate emergency readiness.	[1,2]
100 ppm	NIOSH IDLH value.	Unknown or potential IDLH atmospheres require appropriate respiratory protection and rescue planning.	[2]
100 - 150 ppm	Loss of smell due to olfactory fatigue or paralysis can occur.	Odor must not be used as a warning method or control barrier.	[1 - 3]
500 - 700 ppm	Staggering and collapse can occur within about 5 minutes; death may follow after 30 - 60 minutes of exposure.	Rapid evacuation and protected rescue are essential; unprotected rescue can create multiple casualties.	[1,10]
700 - 1000 ppm	Rapid unconsciousness, respiratory arrest and death within minutes may occur.	High-concentration release scenarios must be controlled by prevention, detection, isolation and emergency response rather than worker recognition.	[1,5]
Up to 16,000 ppm	HSE reported this level in cargo and slop tank ullage spaces on some floating production, storage and offloading (FPSO) and floating storage unit (FSU) installations.	Specialist monitoring and task-specific risk controls may be needed because standard portable instruments may not detect full concentration ranges.	[9]

3.2. Exposure Scenarios in Oil and Gas Operations

H_2S exposure scenarios in oil and gas operations can arise wherever sour gas, crude oil, produced water, sludge, biological generation or stagnant fluids are present. OSHA's eTool for well drilling and servicing likewise treats H_2S inhalation as a primary hazard in these operations [5]. Practical oil and gas guidance from the Texas Department of Insurance identifies exposure potential across upstream drilling and well operations, midstream maintenance and transportation activities, and downstream refining and petrochemical processes [13].

Confined and low-lying spaces are especially important because H_2S is heavier than air and may accumulate where natural dispersion is poor [2,4]. Examples include tanks, pits, sumps, sewers, underground vaults, cargo or slop tank ullage spaces, poorly ventilated rooms and enclosed production areas. HSE's ED2-2023 safety notice demonstrates that hidden high-concentration H_2S scenarios may exist in offshore cargo and slop tank ullage spaces, and that routine monitoring equipment may be inadequate when concentrations exceed its upper measuring range [9].

Maintenance and abnormal operations are also critical because they often involve breaking containment, opening equipment, changing flow paths, draining or venting systems, entering confined spaces, or responding to alarms. These activities can reduce the effectiveness of normal process containment and increase dependence on permit controls, atmospheric testing, isolation, gas detection and emergency response readiness.

3.3. Control Measures and the Hierarchy of Controls

The hierarchy of controls provides a useful structure for H_2S risk management because it prevents over-reliance on worker behavior and personal protective equipment. NIOSH identifies elimination, substitution, engineering controls, administrative controls and PPE as the preferred order for reducing or removing workplace hazards [11]. For H_2S, elimination or substitution may not always be feasible because H_2S can be naturally present in reservoirs or generated by operational conditions. Therefore, effective risk management often depends on a combination of engineering controls, administrative controls, detection, respiratory protection and emergency readiness.

OSHA's H_2S exposure-control guidance recommends evaluating exposure, identifying processes that may release or produce H_2S, testing air with appropriate equipment, monitoring before and during work activities, using ventilation, training workers, and establishing rescue procedures [3]. For confined spaces, OSHA requires atmospheric testing before entry and monitoring as necessary, including the testing sequence of oxygen, combustible gases and vapors, and toxic gases and vapors [14]. Respiratory protection guidance requires employers to identify and evaluate respiratory hazards and states that where exposure cannot be identified or reasonably estimated, the atmosphere must be considered IDLH [15]. Table 3 maps representative H_2S safety controls to the hierarchy of controls.

Table 3. Mapping of H_2S safety controls to the hierarchy of controls.

Hierarchy Level	H_2S Control Examples	Implementation Notes	Key Sources
Elimination / source avoidance	Avoid entry where remote operation or alternative work methods are feasible; eliminate unnecessary confined-space entry.	Most effective when built into planning and design; often limited by operational realities.	[3,11]
Engineering controls	Ventilation, fixed gas detection, containment integrity, isolation, pressure control, equipment design, corrosion/integrity management.	Should reduce exposure without depending primarily on individual action.	[3,8,9,11]
Administrative controls	Permit-to-work, confined-space permit, atmospheric testing sequence, LOTO, procedures, training, drills, restricted access, stop-work authority.	Essential but vulnerable to human and organizational failure if not verified.	[3,8,13,14]
Detection and monitoring	Personal H_2S monitors, fixed detectors, pre-entry testing, continuous monitoring, calibration and alarm response procedures.	Critical because odor is unreliable and high concentrations can incapacitate rapidly.	[2,3,8,9,13]
PPE and respiratory protection	Self-contained breathing apparatus (SCBA), supplied-air respirators (SAR) with auxiliary self-contained air supply, escape breathing devices.	Required for IDLH or unknown atmospheres; should be supported by training, rescue planning and exposure assessment.	[9,13,15]

3.4. Incident Lessons and Barrier Failures

The CSB Aghorn investigation provides a clear example of how H_2S risk can extend beyond the individual worker when barriers fail. The release led to the death of one worker and one member of the public [8]. CSB recommendations included use of personal H_2S detection devices where workers or visitors could be exposed to concentrations at or above 10 ppm, a site-specific lockout/tagout program, independent analysis of ventilation and mitigation systems, and a comprehensive safety management program focused on H_2S risk identification, assessment, mitigation and monitoring [8].

HSE's safety notice on offshore cargo and slop tanks demonstrates a different but complementary lesson: H_2S may accumulate to concentrations beyond the measurement range of standard portable instruments, meaning that routine monitoring practices may create false confidence when not matched to the hazard scenario [9]. HSE recommends suitable monitoring, task risk assessment review, appropriate respiratory protective equipment, emergency escape breathing devices, personal gas monitoring, fixed monitoring consideration, training and integrity management [9].

Peer-reviewed fatality evidence shows that rescue attempts are a recurring risk multiplier. In the study by Hendrickson et al., co-worker death occurred simultaneously or during rescue attempts in 21% of identified occupational H_2S fatality cases [10]. This supports a central principle of H_2S emergency planning: rescue must be pre-planned, equipped and performed by trained responders using appropriate respiratory protection, not improvised by unprotected co-workers. Table 4 summarizes common failure modes and the corresponding preventive barriers.

Table 4. Common H_2S risk management failure modes and corresponding preventive barriers.

Failure Mode	Possible Consequence	Preventive Barrier	Source Evidence
No personal H_2S detector in a release-prone area.	Delayed warning, continued exposure, incapacitation.	Personal monitors as part of PPE kit for workers/visitors in H_2S-prone areas.	[8,13]
Inadequate ventilation or mitigation analysis.	Accumulation of toxic gas at dangerous concentrations.	Engineering review of ventilation and mitigation systems; fixed detection consideration.	[3,8,9]
Unknown or underestimated atmosphere.	Entry into IDLH conditions without adequate respiratory protection.	Pre-entry testing, continuous monitoring, and treating unestimated exposure as IDLH.	[14,15]
Reliance on odor to identify H_2S.	Failure to recognize dangerous concentration due to olfactory fatigue.	Instrument-based detection and training that odor is unreliable.	[1 - 3]
Unprotected rescue attempt.	Multiple fatalities involving co-workers or responders.	Pre-planned rescue, trained responders, SCBA/SAR, access control.	[3,10,15]
Monitoring equipment not suitable for high-concentration scenario.	False confidence and unrecognized extreme concentration.	Select equipment with appropriate range and use specialist monitoring where needed.	[9]

3.5. Training, Competence and Emergency Response Readiness

Training is often described as an administrative control, but in H_2S operations it has a direct connection to life-critical decision-making. Workers and supervisors must understand the limitations of odor recognition, the meaning of gas detector alarms, the importance of immediate evacuation, the need for respiratory protection in IDLH or unknown atmospheres, and the prohibition against unprotected rescue attempts. OSHA's H_2S control guidance identifies worker training and rescue procedures as part of exposure control [3], while the Texas Department of Insurance emphasizes training, emergency procedures and regular drills for oil and gas workers who may encounter H_2S [13].

Competence should be task-specific rather than limited to general awareness. Personnel who enter or supervise work in H_2S-prone environments need practical understanding of detector use, alarm response, evacuation routes, muster points, respiratory protective equipment, confined-space permits, atmospheric testing and communication protocols. Workers assigned to confined-space entry also need to understand the role of the entrant, attendant, entry supervisor and rescue service, including the requirement that rescue be planned rather than improvised [14].

Emergency response readiness must be evaluated through drills and scenario-based exercises. A written rescue plan has limited value if responders cannot reach the area, don respiratory protection, communicate effectively, control access and remove the exposed worker without creating additional casualties. The evidence of co-worker fatalities during rescue attempts demonstrates that the emergency phase should be considered part of the primary control system [10]. This means that rescue resources, SCBA or supplied-air respirators, escape devices, communication systems and medical response arrangements should be verified before high-risk work begins.

3.6. Assurance, Audit and Continuous Improvement

H_2S controls are only reliable when they are periodically verified. Assurance activities should include calibration and bump-test records for detectors, inspection records for respiratory protective equipment, training and drill records, permit audits, confined-space entry reviews, ventilation performance checks, management review of incidents and near misses, and verification that corrective actions have been closed. The CSB Aghorn recommendations emphasize safety management program elements including risk identification, assessment, mitigation, monitoring, maintenance, operating procedures and training [8].

Assurance should also test the interfaces between controls. For example, a personal monitor may function correctly, but the barrier is weak if workers do not understand alarm set points or if evacuation routes are unclear. A permit may be completed, but the barrier is weak if atmospheric testing is not performed in the required sequence or if the instrument is unsuitable for the concentration range. Respiratory equipment may be available, but the barrier is weak if workers are not fit-tested, trained, and medically cleared where required, or if the rescue team cannot deploy within the required time. These examples illustrate why H_2S risk management should be treated as a system of interacting barriers rather than a list of equipment and forms.

4. Proposed Barrier-Based Framework

Based on the evidence synthesis, an H_2S risk management framework should integrate six linked elements (Figure 1): hazard identification, source and engineering controls, detection and verification, work authorization, protection and emergency response, and assurance and learning. The framework is intended to organize existing good practices into an auditable structure rather than introduce a new regulatory standard.

Figure 1. Barrier-based framework for H_2S exposure risk management in oil and gas operations.

The framework begins with hazard identification because H_2S risk is strongly task- and location-dependent. A facility may include zones where H_2S is routine and visible in operating procedures, but also hidden or intermittent sources, such as tanks, pits, produced water systems, dead legs, low-ventilation areas or maintenance tasks involving opening containment. Hazard identification should therefore address both normal operations and non-routine tasks.

The second element emphasizes source and engineering controls. Where H_2S cannot be eliminated, exposure should be minimized through containment, isolation, ventilation, fixed detection, integrity management and control of hazardous energy. Engineering controls are especially important because they reduce dependence on the worker's ability to recognize a release, interpret an alarm, or use PPE correctly under stress.

The third element is detection and verification. Detection is not a single device but a system: correct sensor selection, placement, alarm set points, calibration, bump testing, pre-entry atmospheric testing, continuous monitoring and clear alarm response. The HSE offshore safety notice shows that monitoring equipment must be suitable for the concentration range and scenario under assessment [9].

The fourth element is work authorization. Permit-to-work systems, confined-space permits, lockout/tagout, atmospheric testing sequence, trained attendants and stop-work authority provide administrative structure for high-risk tasks. However, administrative controls depend on competence, supervision and verification. Their effectiveness should be audited rather than assumed.

The fifth element integrates respiratory protection and emergency response. For IDLH or unknown atmospheres, OSHA respiratory protection guidance identifies approved respirators such as full-face pressure-demand SCBA or combination full-face pressure-demand supplied-air respirators with auxiliary self-contained air supply [15]. Emergency response must include protected rescue and access control because unprotected rescue attempts can convert a single exposure into multiple fatalities [10].

The final element is assurance and learning. A functioning H_2S program should include training records, detector calibration records, drill performance, incident and near-miss learning, periodic procedure review, management review and continuous improvement. This aligns with broader occupational health and safety management and risk management principles described by ISO 45001 and ISO 31000 at the framework level [16,17]. Figure 2 summarizes the resulting exposure pathway and the corresponding control points.

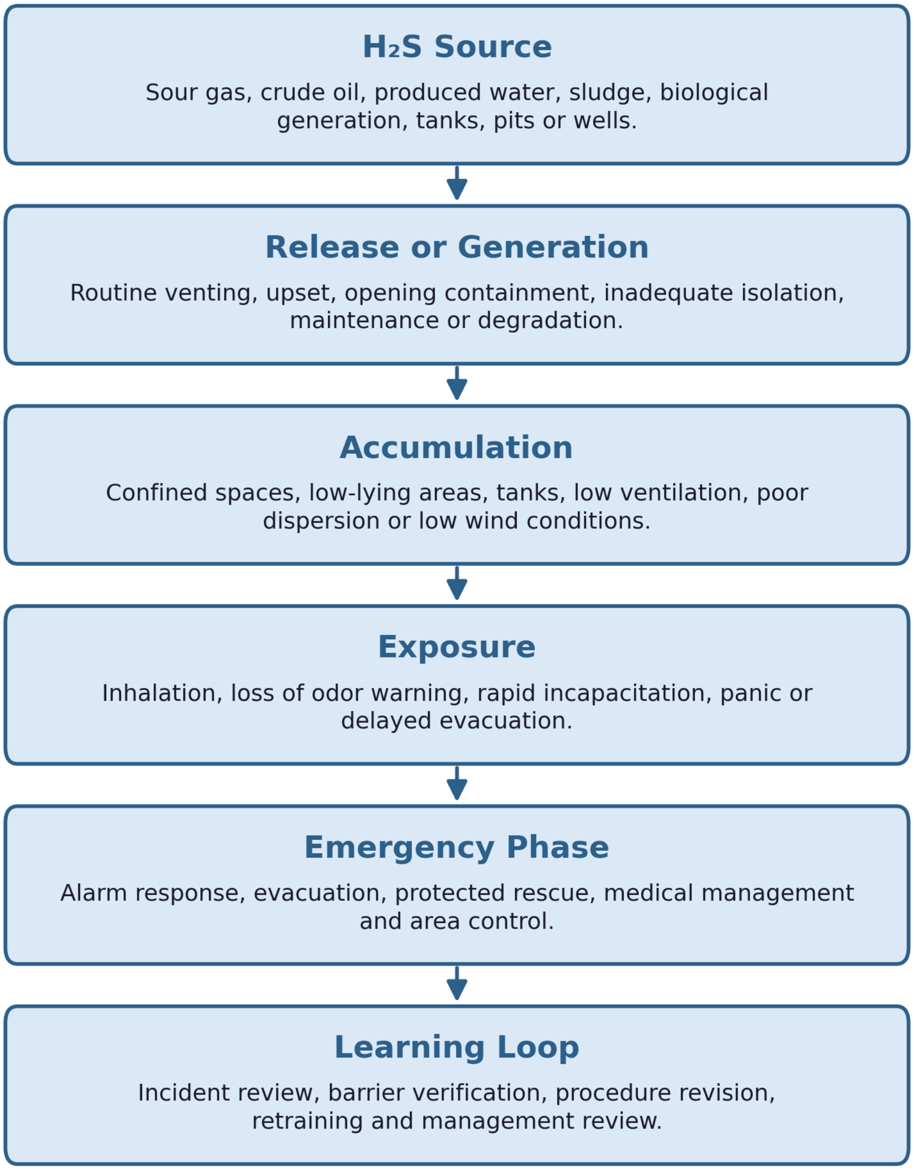

Figure 2. Exposure pathway and control points for H_2S risk management in oil and gas operations.

5. Discussion

The evidence reviewed in this article supports a layered approach to H_2S risk management. No single barrier is sufficient. Exposure limits provide essential reference values, but they do not address sudden release scenarios, failed isolation, confined-space accumulation, monitoring limitations, worker incapacitation or unprotected rescue attempts. Similarly, respiratory protection is essential in IDLH or unknown atmospheres but should not be treated as a substitute for hazard identification, engineering control, atmospheric testing, ventilation and work authorization.

A recurring theme is the gap between the presence of safety equipment and the reliability of the safety system. Personal gas detectors, fixed monitoring systems, ventilation, SCBA, confined-space permits and training are all familiar controls, but incidents occur when these controls are absent, mismatched to the scenario, poorly maintained, misunderstood, bypassed or not integrated into a coherent response plan. The CSB Aghorn investigation and HSE offshore safety notice both illustrate that the effectiveness of controls depends on systematic design, implementation and verification [8,9].

The proposed framework also highlights the importance of considering non-routine and low-frequency tasks. Many high-risk H_2S scenarios occur during maintenance, opening of containment, tank monitoring, response to alarms, confined-space entry, or work near pits and sour fluids. These tasks may fall outside routine operating patterns and can therefore expose weaknesses in permit-to-work, lockout/tagout, monitoring and rescue arrangements.

Human factors and organizational learning are central to H_2S safety. Workers must understand that odor is unreliable, that alarms require immediate action, that confined-space entry requires authorization and atmospheric testing, and that unprotected rescue is dangerous. Supervisors and QHSE personnel must ensure that these expectations are supported by equipment, staffing, procedures, drills and verification. A safety culture that encourages stop-work decisions is especially important because H_2S risk can escalate rapidly and may leave little time for correction after exposure occurs.

For QHSE implementation, the proposed framework can be translated into an audit structure. The first audit question is whether H_2S sources and scenarios have been identified for normal, non-routine and emergency conditions. The second is whether source and engineering controls are in place and matched to the hazard. The third is whether gas detection is suitable, calibrated and linked to clear alarm responses. The fourth is whether work authorization controls are used for confined spaces, maintenance and other high-risk tasks. The fifth is whether respiratory protection and rescue resources are available, suitable and practiced. The sixth is whether incidents, near misses, detector alarms and drill findings are reviewed and used to improve the system.

The article also supports a distinction between compliance and resilience. Compliance-based programs may focus on meeting exposure limits, completing permits and issuing PPE. A more resilient H_2S program verifies whether controls remain effective when conditions change, when a worker is alone, when a detector alarms, when a task becomes non-routine, when a confined-space atmosphere changes after entry, or when a rescue decision must be made under time pressure. This distinction is important because H_2S accidents often develop rapidly and may involve multiple victims if the initial response is poorly controlled.

Another implication is that H_2S safety should be integrated with process safety and asset integrity rather than treated only as personal safety. Produced water systems, tanks, vents, pits, sour fluid handling and ventilation systems can create exposure conditions that are shaped by process design, maintenance, corrosion control, operating discipline and management of change. The HSE notice on offshore tank ullage spaces and the CSB Aghorn investigation both demonstrate that worker exposure is connected to equipment, systems and operational decisions [8,9]. A narrow focus on personal monitors and breathing apparatus may miss upstream causes that should be controlled at the source.

The review has limitations. It relies on open sources and selected peer-reviewed literature rather than proprietary incident data or field exposure measurements. The evidence base is not a systematic review of all H_2S literature, and the framework has not yet been validated through field application or quantitative risk assessment. In addition, regulatory sources are jurisdiction-specific; OSHA-based requirements should not be assumed to apply directly in all countries. Nevertheless, the selected sources are highly relevant to oil and gas H_2S risk because they combine official occupational safety guidance, toxicological evidence, incident investigation findings and peer-reviewed fatality and exposure-limit literature.

6. Conclusions

H_2S exposure in oil and gas operations remains a critical occupational and process safety concern because high concentrations can rapidly incapacitate workers, odor is unreliable as a warning mechanism, and toxic gas can accumulate in low-lying and confined spaces. The reviewed evidence shows that effective risk control requires a layered barrier system rather than reliance on exposure-limit compliance or PPE alone.

The proposed framework organizes prevention, detection, work authorization, protection and emergency response, and organizational learning into six linked, auditable barrier elements. This structure provides a practical basis for QHSE programs in drilling, production, waterflood, tank, maintenance and confined-space operations where H_2S may be present. It also reinforces the need for protected rescue planning, because co-worker and responder fatalities are a documented risk in H_2S incidents.

Future work should validate the framework through field audits, incident data analysis, emergency drill assessment and integration with quantitative risk assessment methods. Additional research is also needed on low-level and chronic exposure [18], detector performance in complex environments, and the effectiveness of training and permit-to-work systems in contractor-heavy oil and gas operations.

Declarations

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Conflicts of Interest. The author declares no conflict of interest.

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