

H₂S in Battery Manufacturing Environments: Detection, Limits, Controls & Incident Response (Site-Neutral Note)

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Summary

Summary: Hydrogen sulfide (H₂S) is a highly toxic, flammable gas that may be present or generated in battery manufacturing environments (especially those involving sulfide materials). It has a characteristic “rotten egg” odor at low concentrations, but dangerous levels can deaden the sense of smell, making reliable **gas detection essential** ¹ ² . Table S1 below summarizes key exposure limits and default alarm setpoints. All sites

should **measure H₂S continuously** in relevant areas, adhere to strict **exposure thresholds**, implement multi-layer **controls**, and have clear **emergency response plans**. In dry rooms (ultra-low humidity), special attention is needed to sensor performance and potential H₂S generation from moisture-sensitive processes. **Default alarm thresholds** often use a Low alarm ~10 ppm and High alarm ~15 ppm, but these must be **site-tuned** to comply with local regulations and specific process risk levels ³. A conservative approach is warranted given H₂S's acute lethality: rapid evacuation is mandated if high levels are detected, and re-entry is only permitted after levels are confirmed below occupational limits and the area is declared safe by trained personnel.

Table S1 – Key H₂S Exposure Limits and Alarm Guidelines (JP/EU/US)

Region	Regulation/Guideline	Limit Type (Duration)	Limit Value
Japan	Oxygen Deficiency Hazard Rule	Ceiling (confined space)	10 ppm ⁴
(MHLW)	JSOH Recommended (OEL)	8-hr Time-Weighted Avg (TWA)	5 ppm ⁵
	Control Concentration (if H ₂ S process >1%)	Management level	1 ppm ⁶
United States	OSHA PEL (General Industry)	Ceiling (any time)	20 ppm (max 50 ppm <10 min) ^{7 8}
(OSHA/NIOSH/ACGIH)	OSHA PEL (Construction/Shipyard)	8-hr TWA	10 ppm ⁹
	NIOSH REL	10-min Ceiling	10 ppm ^{10 8}
	NIOSH IDLH	— (acute)	100 ppm ^{11 8}
	ACGIH TLV	8-hr TWA / 15-min STEL	1 ppm / 5 ppm ¹²
EU / UK	EU Indicative OEL (IOELV)	8-hr TWA / 15-min STEL	5 ppm / 10 ppm ¹³
(EU Commission / HSE)	UK HSE Workplace Exposure Limit (WEL)	8-hr TWA / 15-min STEL	5 ppm / 10 ppm ^{14 15}
Alarm Guidelines	Typical Gas Detector Settings	Low Alarm / High Alarm	10 ppm / 15 ppm (default) ³

Sources: See full References (Appendix B). Limits are cited from primary standards where available. Note regional variations: e.g. OSHA's ceiling vs. EU's TWA. **IDLH**: Immediately Dangerous to Life or Health (US NIOSH). **TLV**: Threshold Limit Value (ACGIH). **OEL**: Occupational Exposure Limit. **STEL**: Short-Term Exposure Limit. **TWA**: Time-Weighted Average. Alarm defaults are manufacturer typical settings – **sites must adjust** if stricter limits apply or if risk assessment requires lower thresholds.

Disclaimer: This note is for informational purposes. It is not a substitute for site-specific SOPs or regulatory requirements. Always follow local laws, official standards, and your company's safety procedures. In case of discrepancies, those official sources prevail.

1. Scope & Definitions

Scope: This safety note addresses **hydrogen sulfide (H₂S)** in battery manufacturing and R&D environments, with an emphasis on **dry-room operations** and adjacent process areas where **reactive or by-product gases** may be present. It is written to be **stack-agnostic** – applicable to various cell designs (no assumptions of a specific collector metal or electrode). In particular, it covers scenarios relevant to **sulfide-based solid electrolytes** (which can generate H₂S upon exposure to moisture or heat) as well as other processes (e.g. lead-acid battery charging, waste treatment) that might introduce H₂S. The focus is on **measurement, exposure thresholds, engineering controls, and incident response** rather than on the chemistry of H₂S generation. This note provides a consolidated view of **regulatory limits in Japan, the EU, and the US**, detection technologies suited for ultra-low humidity **dry rooms**, and best practices for controlling H₂S and responding to excursions.

Definitions:

- **Hydrogen Sulfide (H₂S):** A colorless, toxic gas with a rotten-egg odor at low concentrations. Heavier than air (vapor density ~1.19), it can accumulate in low-lying areas. H₂S is reactive and flammable (flammability range ~4.0–45% v/v in air). It is a broad-spectrum poison affecting the respiratory system and cellular respiration (cytochrome enzyme inhibition). Even brief exposure to high concentrations (hundreds of ppm) can cause immediate collapse (“knockdown”) and death ¹. Lower chronic exposures may irritate eyes, lungs, and nervous system ¹⁶ ¹⁷.
- **Dry-Room:** A controlled manufacturing environment with very low humidity (dew point often –40 °C or below). Used for handling moisture-sensitive battery materials (e.g. lithium metal or sulfide electrolytes). Dry-room conditions slow moisture-triggered reactions, but they can pose challenges for gas detection (e.g. sensor dehydration; see § 3.2).
- **Negative-Side Stack (NSS) vs. Solid-Electrolyte-Side Stack (SES):** Terms used to describe the two sides of an all-solid-state cell stack in a generic way. “NSS” refers to the stack side containing the negative electrode (which might be lithium metal or other anode material), and “SES” refers to the solid-electrolyte and positive electrode side. We use these terms to avoid assuming a particular chemistry (e.g. whether an anode is present or not, or what type of electrolyte is used). **Interface Zone (IZ)** refers to the interfacial region where the NSS and SES meet – essentially the battery’s internal interfaces (e.g. anode|electrolyte, electrolyte|cathode). In context of H₂S, the IZ might be impacted if H₂S infiltrates cell materials or if sulfide breakdown occurs at interfaces.
- **Exposure Limit Types:** For clarity, note that **TWA (time-weighted average)** is an average over a standard workday (usually 8 hours) and workweek; **STEL (short-term exposure limit)** is a 15-minute (or sometimes 10-minute) exposure that should not be exceeded even briefly; **Ceiling** means a concentration that must not be exceeded at any time. **IDLH** (Immediately Dangerous to Life or Health) is not a permissible exposure limit but a guideline indicating a concentration at which one could only escape without severe injury or death **if** proper PPE is worn – exposure to IDLH levels without protection is life-threatening in short order ¹.
- **Hierarchy of Controls:** A fundamental EHS concept referenced throughout this note. It ranks controls from most effective to least: **Elimination/Substitution** (remove the hazard – e.g. use non-sulfide materials if possible), **Engineering Controls** (isolate hazard – e.g. ventilation, scrubbers, containment), **Administrative Controls** (safe work practices – training, procedures, scheduling to limit exposure), and **PPE** (personal protective equipment – e.g. respirators). This

note will emphasize engineering and administrative controls for H₂S, with PPE as a last line of defense during emergencies or maintenance.

- **Excursion:** Any event where H₂S levels exceed normal operating range or approach/exceed alarm thresholds. “Excursion tagging in SPC” (Statistical Process Control) refers to logging and tracking these events as part of process monitoring, to correlate with any process deviations or product quality issues (especially relevant if an H₂S release might affect the battery interface or materials quality – see § 4.3).

2. Exposure Limits by Region

H₂S exposure limits are strictly defined by occupational safety regulations due to its acute toxicity. This section summarizes official limits in **Japan, the United States, and the European Union/UK**, noting differences in averaging times and enforcement. All values are given in parts per million (ppm). Where sources conflict or have been updated recently, ranges or notes on basis are provided. Table 2.1 consolidates these limits, with sources for cross-verification.

2.1 Japan (JP): In Japan, H₂S is addressed both in general occupational exposure recommendations and in specific rules for confined spaces and certain chemical processes:

- **Oxygen Deficiency Hazard Regulation:** Under the Industrial Safety and Health Act’s enforcement orders (酸素欠乏症等防止規則), any area with potential for oxygen deficiency or H₂S accumulation is tightly controlled. The law defines an atmosphere containing H₂S > **10 ppm** as an “oxygen deficiency hazardous environment” (equivalent to a confined space hazard) ¹⁸ ⁴. Employers must ventilate such areas continuously to keep H₂S at or below 10 ppm (and oxygen ≥18%) before and during worker entry ⁴. In practice, this 10 ppm acts as a de facto ceiling for work areas like pits, tanks, or dry-room enclosures in Japan. If H₂S could exceed 10 ppm, specialized precautions are mandated (e.g. standby rescue with SCBA gear).
- **Permissible Concentration (許容濃度):** The Japan Society for Occupational Health (JSOH, 日本産業衛生学会) publishes recommended exposure limits akin to ACGIH’s TLVs. JSOH’s current recommended allowable concentration for H₂S is **5 ppm** (7 mg/m³) as an 8-hour TWA ⁵. This is intended to protect “nearly all workers” from adverse health effects during a workday ¹⁹. The 5 ppm value aligns with historical ACGIH values used in many countries (see § 2.3). Japan’s 5 ppm recommendation has been in place for many years; notably, older references sometimes list a 10 ppm value as “allowed” (e.g. older legal PELs), but **5 ppm is the consensus guidance** in modern occupational hygiene in Japan ¹⁹. There is no separate short-term (STEL) explicitly given by JSOH; however, good practice is to keep even brief exposures well below 10 ppm, given irritation can occur at those levels.
- **Specified Chemical Substance (特定化学物質) Threshold:** If H₂S is handled in concentrations >1% (**10,000 ppm**) – for instance, if using cylinders of H₂S or generating H₂S gas in process – it falls under Japan’s **Specified Chemical Substances** regulations (which impose stringent controls like mandatory local exhaust, health monitoring, etc.). In such cases, a “**control concentration**” of **1 ppm** is enforced ⁶. The control concentration (管理濃度) is an administrative target: workplaces must manage exposure at or below 1 ppm when working with H₂S in that high-hazard category. Essentially, 1 ppm becomes the internal alarm level in those operations. Note this 1 ppm is not because 1 ppm is “safe” per se, but because processes involving high % H₂S have potential for serious releases, so a very conservative control level is applied to ensure any leakage is detected and mitigated early.

- **Environmental/Odor limits:** (Not a primary focus for workplace safety, but worth noting) Japan's Offensive Odor Control Law classifies H₂S as a malodorous with stringent boundary limits of 0.02–0.2 ppm around facility perimeters ²⁰ ²¹. While these odor thresholds protect the public from nuisance and some health aspects, they are far below occupational limits. In a battery plant context, this could be relevant if H₂S from process exhaust could reach outside the facility – scrubbers may be needed to meet the 0.2 ppm or lower fence-line criteria (region-dependent).

2.2 United States (US): The US has multiple exposure limits set by different agencies and professional organizations. The key values are:

- **OSHA Permissible Exposure Limit (PEL):** In general industry, OSHA's PEL for hydrogen sulfide is a **ceiling of 20 ppm**, not to be exceeded during the work period ⁷. Additionally, OSHA allows a **peak up to 50 ppm** for a single brief period of up to 10 minutes, but only if no other exposure occurs in that shift ⁷. This essentially means: stay ≤20 ppm; one excursion to 50 ppm max is allowed for ≤10 min, as long as the rest of the 8 hours is 0 ppm. This PEL is from OSHA's Table Z-2 (29 CFR 1910.1000) and is legally enforceable ⁷. (Notably, an older OSHA attempt in 1989 to set 10 ppm TWA and 15 ppm STEL was vacated and is not in force ²², so the current federal PEL remains the ceiling value.) For construction and shipyard sectors, OSHA references a 10 ppm 8-hr TWA PEL ⁹, aligning with earlier ACGIH values – so in those contexts, treat 10 ppm as the long-term limit.
- **NIOSH Recommended Exposure Limit (REL):** The National Institute for Occupational Safety and Health recommends a much stricter limit: **10 ppm** as a 10-minute ceiling ¹⁰. This basically means NIOSH suggests no exposure above 10 ppm, even for 10 minutes, without respiratory protection. NIOSH's guidelines are not law, but are influential for best practices, especially in emergency planning. NIOSH also publishes the **IDLH** for H₂S as **100 ppm** ¹¹. 100 ppm H₂S is “immediately dangerous to life or health” – unprotected exposure to 100 ppm can knock someone down and be fatal in minutes ²³. Indeed, 100 ppm is the level where olfactory nerves are paralyzed (you can't smell the gas at all beyond that point ²⁴), so it is extremely hazardous.
- **ACGIH Threshold Limit Values (TLVs):** ACGIH (a professional body) recommends **1 ppm** (≈1.4 mg/m³) as the 8-hour TWA and **5 ppm** as the 15-min STEL ¹². This is a very conservative guideline reflecting newer toxicological data about low-level effects (ACGIH lowered the TLV to 1 ppm in the 2010s from its earlier 10 ppm). Many companies and even regulators use ACGIH TLVs as the basis for internal standards. For instance, some U.S. states or industry consensus standards may enforce similar 1 ppm limits in sensitive work areas (even though federal OSHA has not adopted them). **Important:** 1 ppm TWA is far below the OSHA PEL, indicating a margin of safety; it's advisable to design controls aiming for that 1 ppm level when feasible.
- **Other Guidelines:** The American Industrial Hygiene Association (AIHA) Emergency Response Planning Guidelines (ERPGs) and other agencies have values for community emergency scenarios (ERPG-3 = 100 ppm for 1 hour, etc.) ²⁵, but for manufacturing site purposes, the focus remains on occupational limits above.

2.3 European Union & United Kingdom (EU/UK): The EU establishes **Indicative Occupational Exposure Limit Values (IOELVs)** which member states then adapt into national laws. Hydrogen sulfide has IOELVs set in the 3rd list (2009/161/EU):

- **EU IOELV: 5 ppm** (7 mg/m³) as an 8-hour TWA, and **10 ppm** (14 mg/m³) as a short-term exposure (often 15 min) ¹³. These values were communicated in EU directives and are largely based on

earlier ACGIH recommendations and European scientific committee opinions. Most EU countries have adopted these or even stricter values.

- **United Kingdom:** The UK's HSE has Workplace Exposure Limits (WELs) identical to the IOELV: **5 ppm (long-term, 8h)** and **10 ppm (short-term, 15min)** ¹⁴ ¹⁵. (In HSE documents this is 7 mg/m³ and 14 mg/m³ respectively.) These limits are legally enforced in the UK. Notably, the UK had these limits even prior to Brexit and has maintained them.
- **Germany:** The DFG MAK value historically was 5 ppm as well. Germany's TRGS 900 (workplace limit) lists H₂S AGW at 5 ppm (with short-term factor 2 = 10 ppm) in line with the EU suggestion. Other EU countries: for example, France and Italy also use 5 ppm TWA. Some countries (Poland, etc.) may have slightly different approaches but generally in EU 5 ppm is the reference.
- **Comparison:** Thus, EU/UK limits for H₂S tend to be stricter for routine exposure (5 ppm TWA) than the current US OSHA PEL, but less strict on ceiling than NIOSH/ACGIH (which advocate 1 ppm TWA). Japan's 5 ppm (recommendation) aligns with EU/UK for chronic exposure, while Japan's absolute ceiling of 10 ppm for work entry aligns with NIOSH's ceiling concept.

2.4 Basis and Health Notes: All these limits are set with reference to preventing eye and respiratory irritation and systemic toxicity. Eye irritation in humans has been reported at 10 ppm and above (some sensitive individuals even at 5 ppm) ²⁶. NIOSH noted no significant adverse effects in healthy adults at 5–10 ppm for 30 minutes in tests, but asthmatics showed bronchial constriction at ~2 ppm ²⁷. The **olfactory warning** (rotten egg smell) is unreliable: odor detection threshold is ~0.01–0.3 ppm ²⁸, but at ~100 ppm one loses the ability to smell it (olfactory fatigue/paralysis) ²⁸. Therefore, instrument monitoring is critical – humans cannot safely gauge H₂S presence by smell, especially in a dry-room where background odors are minimal. The steep rise of toxicity with concentration (500 ppm can cause rapid death ²⁹) underpins the conservative alarm settings (see Summary and § 3.1).

Table 2.1 – Occupational Exposure Limits for H₂S (Detailed by Region)

Jurisdiction	Agency/Standard	Limit Type	Limit Value (ppm)	Basis / Notes
Japan	MHLW (Law) Oxygen Deficiency Rule	Ceiling (hazardous area)	10 ppm	Atmosphere >10 ppm H ₂ S is “oxygen-deficient” hazard; require ventilation ⁴ .
	JSOH (2018) OEL Recommendation	TWA (8h)	5 ppm	Advisable max for 8h exposure; “no harm to almost all workers” ⁵ . No separate STEL given (use ≤10 ppm).
	Control Concentration (特化則)	Internal target (if >1% H ₂ S used)	1 ppm	Management level when H ₂ S handled as Specified Chem.; triggers additional controls ⁶ .

Jurisdiction	Agency/Standard	Limit Type	Limit Value (ppm)	Basis / Notes
United States	OSHA PEL (General Industry, 1910)	Ceiling (anytime)	20 ppm (peak) 50 ppm<10min	Legal limit ⁷ ; 50 ppm peak allowed once if no other exposure ³⁰ .
	OSHA PEL (Constr./ Maritime)	TWA (8h)	10 ppm	29 CFR 1926.55 and 1915.1000 incorporate 10 ppm TWA ⁹ .
	NIOSH REL	Ceiling (10 min)	10 ppm	Recommended limit for 10 min periods ⁸ ; basis for respirator use.
	NIOSH IDLH	Acute (escape only)	100 ppm	IDLH value ⁸ ; >100 ppm is deadly without SCBA.
	ACGIH TLV	TWA (8h) / STEL (15min)	1 ppm / 5 ppm	Guideline for chronic exposure ¹² ; very protective (updated TLV).
EU	EU IOELV (2009/161/EU)	TWA (8h) / STEL (15min)	5 ppm / 10 ppm	Indicative OEL, most countries adopt these ¹³ .
United Kingdom	HSE EH40 WEL	TWA (8h) / STEL (15min)	5 ppm / 10 ppm	Legally enforced limits in UK ¹⁴ ¹⁵ .
Germany	AGS TRGS 900 (AGW)	TWA (8h) / Peak (15min, Category I)	5 ppm / 10 ppm	E.g. DFG MAK 5 ppm; short-term factor 2 (15 min) = 10 ppm.
Others (sample)	France VLEP, Canada (Québec) etc	TWA / STEL	5 ppm / 10 ppm	Many align with 5/10 ppm. (E.g. Alberta OH&S: 10 ppm TWA, 15 ppm STEL).

Note: ppm = parts per million by volume. mg/m³ values omitted for brevity (7 mg/m³ ≈ 5 ppm). Always consult up-to-date national regulations; limits above are representative as of 2024. Where two values are given (TWA/STEL), both must be respected. In practice, the most stringent applicable limit should drive control measures (e.g. if following ACGIH, aim for <1 ppm 8h average). Alarm setpoints (see Summary) are usually set well below any ceiling to ensure time for response.

3. Detection & QA

Accurate **detection of H₂S** is the cornerstone of safety in environments where this gas may be present. This section covers the types of detectors suitable for battery manufacturing (especially dry-room conditions), how to deploy and maintain them, and quality assurance (QA) practices such as calibration and cross-sensitivity management. **Key goal:** ensure that any H₂S release, even minor, is quickly identified and quantified, allowing timely protective actions.

3.1 Detector Types and Performance: The primary technologies for H₂S detection in industrial settings are:

- **Electrochemical Sensors:** By far the most common for H₂S (used in personal clip monitors, area monitors, and fixed-point detectors). They consist of a small electrochemical cell where H₂S gas undergoes a redox reaction, generating a current proportional to concentration. Typical range is 0–50 or 0–100 ppm with resolution ~0.1 ppm ³¹ ³². Advantages: high sensitivity, relatively specific, compact, low power. They can detect very low ppm levels reliably. **Limitations:** sensor life (~2 years) and drift; need regular calibration; susceptible to extreme dryness or humidity (see § 3.2); cross-sensitivity to other gases (see § 3.4). Electrochemical H₂S sensors have response times on the order of seconds. They are ideal for both portable personal detectors worn by staff and for fixed installations in process bays or scrubber exhausts.
- **Infrared (IR) Sensors:** These use infrared absorption at specific wavelengths absorbed by H₂S. IR H₂S sensors are less common than electrochemical for low ppm detection, because H₂S's absorption bands and low ppm requirements make design challenging. However, NDIR sensors exist for broader range (0–1000 ppm or higher). Advantages: longer lifespan (no consumable electrolyte), not poisoned by gas exposure, and can tolerate dry conditions well. Disadvantages: generally higher cost, need baseline reference (zero) and can be skewed by temperature or other absorbing species. IR sensors also require at least a minimal concentration to register (ppm-level is fine, but sub-ppm might be tough). In battery facilities, IR might be used in line monitoring of a process exhaust where H₂S could spike to tens or hundreds of ppm (for example, a dedicated gas analyzer on a glove box vent).
- **Colorimetric Tubes (Draeger/Gastec style):** Glass detector tubes that change color when a specific volume of air is pumped through them (one-time use). These are useful for **spot measurements or confirmation**, not continuous monitoring. They have detection ranges typically like 1–600 ppm (different tubes for different ranges). They are simple and **do not require power or calibration**, but give only a snapshot. In QA, tubes might be used to double-check readings of an electronic sensor or to measure in a location where no fixed sensor is installed (e.g. inside a shipment container or a closet) by taking a sample. For H₂S, stain tubes can have sensitivities down to ~1 ppm. They are affected by other gases (some cross interference) and human error in reading the stain length.
- **Metal-Oxide Semiconductor (MOS) Sensors:** Solid-state sensors that detect gas via change in resistance of a semiconductor material when gas is adsorbed. MOS sensors for H₂S exist (often used in certain process or consumer monitors). They tend to be less selective – e.g. they might respond to any reducing gas. They also require a heated element. In a dry-room, MOS sensors could work but their baseline can drift with temperature/humidity. They are more often used for higher concentration ranges or where cost needs to be minimal. Given the emphasis on accuracy and low-level detection in battery manufacturing, MOS is not typically the first choice for H₂S safety monitoring, except perhaps as a backup or for detecting gross leaks (they are found in some multi-gas units as a durable sensor).
- **Photoionization Detectors (PID):** Generally used for volatile organic compounds, PIDs are not a primary tool for H₂S because H₂S has a high ionization potential (10.5 eV) which is slightly above the energy of standard PID lamps (10.0 eV). Specialized lamps (11.7 eV) can detect H₂S, but are not common due to lamp life issues. PIDs can however detect some H₂S if it co-occurs with other VOCs, but they are **not recommended for quantitative H₂S measurement** in our context.

Performance Considerations: Modern electrochemical H₂S sensors can detect down to ~0.1 ppm, but calibration typically happens at a few ppm (e.g. 5 or 10 ppm span gas). Response time $t_{>90\%}$ is often <30 seconds. They operate in -20 to 50 °C typical range ³³. In battery facilities, temperature is usually controlled (20–25 °C), which is ideal. **Alarm systems** should have multi-stage setpoints (discussed below in § 4.1 and Summary). Importantly, detectors should be **failsafe** – e.g. transmit a fault alarm if the sensor dies or if power is lost.

3.2 Placement and Environment (Dry-Room Considerations): Where to place H₂S sensors in a facility requires understanding H₂S behavior and the process layout:

- **Point sources:** Identify any process steps that could emit H₂S. In solid-state battery manufacturing, the **mixing, pressing, or heat-treatment** of sulfide electrolytes (e.g. Li₂S–P₂S₅ glass, argyrodite Li₆PS₅Cl, etc.) are potential H₂S sources, especially if moisture contamination occurs ². Sensors should be near these process tools (e.g. above a glove box, near a roller press, at the exit of low-vacuum drying ovens). If H₂S gas is used (less common, except maybe in some chemical synthesis), sensors go near cylinders, valves, or reaction vessels.
- **Room coverage:** In a dry room, air circulation is typically good (to maintain uniform dew point). H₂S, being slightly heavier than air, **may accumulate near the floor if there is no forced ventilation**. However, most dry rooms have airflow. A practical strategy: mount fixed detectors at about ~0.3 m above floor (1 ft) **AND** at about breathing zone height (1.5 m) in areas of concern ³⁴. Low placement covers the pooling scenario; mid-height covers general atmosphere. For example, Japan guidelines for confined spaces require sampling at different heights to not miss stratification ³⁵ ⁴.
- **Sampling systems:** In some cases, a pump draw system might be used – drawing air from multiple points to a central sensor. In a large dry room, one might have tubing from various corners or under-floor trenches feeding a single analyzer. These need careful calibration due to line losses of H₂S (it can adsorb slightly in tubing, though not as sticky as some gases).
- **Dry-room humidity effect: Electrochemical sensors and dryness:** Extremely low humidity can cause the electrolyte in electrochemical sensors to dry out over time ³⁶. The ideal humidity for such sensors is around 50–60% RH ³⁶. In a dry room (often <1% RH), sensors may exhibit slower response or loss of sensitivity as their internal electrolyte evaporates ³⁶. Manufacturers sometimes offer sensors with moisture reservoirs or recommend more frequent calibration in low RH. It's critical in dry-room use to **closely monitor sensor span and baseline**, possibly calibrating more often (e.g. monthly instead of quarterly). Alternatively, using IR sensors for fixed monitoring in extremely dry conditions can circumvent this (since IR sensors aren't dependent on an internal liquid). One strategy is to house the sensor in a tiny chamber that humidifies it slightly – but that's uncommon due to complexity. Accept that electrochemical cells may have shorter life in dry air and budget for replacements sooner.
- **Temperature:** Dry rooms are usually kept around 20–25 °C, which is within sensor optimal range. No special considerations there, except to avoid placing sensors directly in front of air conditioning outlets or heaters (to avoid localized extreme temp swings).
- **Calibration tags and accessibility:** Place detectors where they can be accessed for bump tests and calibration (not 6 meters up a ceiling if avoidable, or else provide remote calibration ports). Keep sensors away from directly being hit by powder or dust from processes (some solid electrolyte powders might clog filters). If necessary use a dust filter over the sensor, but ensure it

doesn't block H₂S (H₂S is a small molecule, most particulate filters won't stop it, but they may slow response a bit).

3.3 Calibration, Bump Testing & Maintenance: A robust QA program for gas detection is mandatory. Key practices include:

- **Bump Tests:** A bump test (functional test) is a brief exposure of the sensor to a known concentration gas to verify that it responds and alarms properly ³⁷. **Perform bump tests daily** or before each use for portable units ³⁷ ³⁸. For fixed systems, many sites do a bump check at least weekly (some do daily automated checks if hardware supports). For instance, before each shift in a dry-room, an operator can expose each personal H₂S monitor to a 10 ppm span gas for a few seconds to ensure it alarms. Bump testing ensures the sensor and audible/visual alarms all function – it is a quick “confidence check” and catches problems like a clogged inlet or a dead sensor. Record the bump test (pass/fail) in a log (see Appendix A1).
- **Calibration:** Calibration adjusts the sensor reading against a certified concentration. Typically, a **zero calibration** (using clean air or N₂) and a **span calibration** (using a standard gas, e.g. 10 ppm H₂S in air or nitrogen) are done. For critical safety, many manufacturers recommend at least **monthly calibration** for fixed detectors, and every **3–6 months for portable** detectors under normal conditions. In a dry-room, given the low humidity stress on electrochemical sensors, consider **increasing calibration frequency** (e.g. monthly for portables as well, or even biweekly checks). Always calibrate per manufacturer instructions; use **NIST-traceable standard gas mixtures** ³⁹. Document each calibration (date, result, technician). Many sites set a **calibration due date** on each detector. Our Appendix A2 provides a sample calibration checklist (including checking regulator flow rate, verifying the span gas concentration and expiry, etc.).
- **Sensor Replacement and shelf life:** H₂S sensors typically warrant 2 years life ⁴⁰. If a sensor fails calibration (cannot be adjusted to read correctly), replace it. Also be aware of **sensor poisoning**: certain compounds can irreversibly damage H₂S electrochemical sensors – for example, **solvent vapors** or silicone vapors can poison some sensors ⁴¹. Keep sensors capped or removed when painting or using solvents in the area.
- **Instrument maintenance:** Besides calibrating the sensor, maintain the whole device: battery (for portables), alarm sounders and lights, pump function (if applicable), and the event logging system. Fixed systems should be connected to an uninterruptible power supply (UPS) or have battery backup if power failure could coincide with H₂S risk (for example, if ventilation power fails, the risk of H₂S accumulation may increase just when detectors might also lose power – that's a dangerous combination; hence backup power or redundant battery-operated monitors are advised).
- **Span Gas and bump gas:** Use appropriate concentrations. Bump test can be done with a high concentration (e.g. 25–50 ppm) just to trigger alarms quickly ³⁷. Calibration usually uses a mid-range like 10 ppm so that both low and high accuracy is good. Ensure gas cylinders are not expired and are certified (H₂S blends can oxidize slowly even in cylinders, or the concentration can change over years).
- **Records and Traceability:** Maintain a **calibration log** (date, span gas lot, pre-cal reading, post-cal adjustment). Some quality systems require demonstrating detectors were in calibration if an incident occurs. Auditors (and investigators) will want to see that records.

3.4 Data Integrity and Cross-Sensitivity: Detection QA also means ensuring the data you get is truly H₂S and accurate:

- **Cross-Sensitivity:** Electrochemical H₂S sensors can respond to other gases. Common interferences: **sulfur dioxide (SO₂)**, which can cause a positive reading on H₂S sensor (because both are acidic gases reacting at the electrode). For example, 5 ppm SO₂ might induce ~1 ppm reading on an H₂S sensor ³². Carbon monoxide (CO) in high concentrations can also create a slight response (e.g. 300 ppm CO -> ~1.5 ppm false H₂S) ³². Nitric oxide (NO) can show a minor positive or negative interference ⁴² (some sensors show -1 ppm for 5 ppm NO₂, meaning a slight dip). Hydrogen (H₂) at very high levels (like 1% H₂) might register a few ppm on H₂S sensor ⁴³. In a battery plant context, **SO₂ could be present** if a fire or thermal runaway occurs (as a decomposition gas of electrolytes or sulfur), or if some processes use SO₂. **CO** might be present from forklifts (if not electric) or fires. **H₂** can be generated in battery charging rooms (lead-acid charging yields H₂ gas, which ironically could give a false H₂S reading if extremely high, but usually that's minor). **Mitigation:** Know your environment – if other gases are present, consider multi-gas monitors that also have CO, SO₂ sensors to differentiate. Some H₂S sensors have internal filters to scrub out SO₂ or other gases. Consult sensor spec sheets for cross-sensitivity data and select sensors with minimal interference for the expected background gases. In dry rooms, usually background air is very clean (no CO, no SO₂ normally), so cross-sensitivity might be minimal unless an internal combustion machine or a cleaning agent releases something. Still, be aware that a reading of a few ppm could, in theory, be something else if no H₂S source is known – so investigate any alarm, but also cross-verify with a secondary method (e.g. a colorimetric tube specific to H₂S to confirm, if in doubt).
- **Data Logging:** Ensure detectors (fixed systems) log concentrations over time and that these logs are captured. Many fixed setups output to a **SCADA or building management system**, or at least to a local panel. Storing this data allows correlation with events (e.g. an H₂S spike at 2 pm might align with a specific process step or a door opening). Portable detectors usually log peak values; workers should note if their personal H₂S monitor alarmed and report even if it cleared. Appendix A1's log template can be used to record daily maximum readings or alarm occurrences in each area.
- **False Alarms vs. Unreported Alarms:** It's better to have an occasional false alarm than a missed real alarm. Emphasize a culture that **never ignores an H₂S alarm**. If an alarm sounds and then stops (maybe it was transient or sensor glitch), still treat it as a potential exposure – investigate the area, check the detector. On the flip side, if false alarms are frequent (e.g. due to RF interference or sensor instability), that undermines trust. Thus, keep detectors well-maintained and perhaps use **dualconfirmation** (two detectors must agree) in critical decisions if practical.
- **Span and Zero Drift:** Track if calibration adjustments are often needed. Significant drift might indicate sensor nearing end of life or a problem like poisoning. For example, if every month you find the zero has drifted +1 ppm consistently, it may indicate background contamination or sensor issues.
- **Quality Audits:** Supervisors or EHS staff should periodically audit the H₂S detection program: e.g. check that bump tests are done, examine a random detector's calibration sticker, or perform an unannounced challenge test (release a small H₂S test gas in area – with precautions – to see if system detects it as expected). These ensure the system actually works as assumed.

In summary, **reliable detection** in a dry-room battery facility likely involves a combination of continuous fixed H₂S monitors in the room/process, personal H₂S monitors for at-risk staff (maintenance personnel, etc.), and rigorous QA (daily bump tests ³⁷, frequent calibration, and data review). This multi-layer approach ensures that if H₂S is generated (for instance, by unexpected moisture contacting a sulfide electrolyte), it will be caught before reaching dangerous levels.

4. Controls & Excursions

Implementing the **Hierarchy of Controls** for H₂S is crucial to minimize both the likelihood of a release and the impact if one occurs. This section describes engineering controls (like ventilation and scrubbing systems), administrative controls (training, procedures), and the use of interlocks and excursion management. We assume that complete elimination of H₂S risk is not possible (since certain processes require materials that can generate H₂S), so we focus on controlling it at the source and protecting workers.

4.1 Engineering Controls (Ventilation & Scrubbing):

- **Ventilation:** Proper ventilation is the first line engineering control for H₂S. In Japan, as noted, regulation literally requires ventilation such that H₂S stays ≤ 10 ppm in any area where workers are present ⁴. In a dry room, the HVAC system usually recirculates dehumidified air; it should incorporate exhaust points near any potential H₂S source. Design goal: keep any H₂S emitted diluted and exhausted before it accumulates. **Local exhaust ventilation (LEV)** is ideal: for example, a fume hood or glove box for handling sulfide powders should be kept under negative pressure vented through treatment. If open handling occurs, overhead snorkel exhausts can capture H₂S (though H₂S being heavy means a low catch might be needed – some facilities use low-floor exhaust grates to capture sinking gases). Maintain general ventilation rate to achieve at least the air change rate that would, by dilution, keep worst-case H₂S release under limits (this can be calculated from release scenario modeling).
- **Dry-Room Air Handling and H₂S:** Dry rooms often recirculate air to save energy (dehumidifying is costly). Thus, if H₂S is generated inside, it could circulate. It is imperative to have **gas monitors tied to the HVAC**: if H₂S is detected above a low threshold (e.g. 1–5 ppm), the system should automatically purge (switch to 100% exhaust mode, shutting recirculation) to remove contaminated air. Some facilities incorporate an **emergency exhaust fan** that kicks on at high alarm to rapidly evacuate the air (like a super-charged ventilation mode). This can be interlocked with alarms (see § 4.3).
- **Scrubbers:** H₂S can be removed from air via chemical scrubbers. Two common types: (1) **Activated carbon** impregnated with caustic or metal oxides – H₂S chemisorbs and is converted to sulfur or sulfate on the carbon. These are often installed in exhaust streams. For instance, a **scrubbing unit** on the dry-room return air could capture H₂S before recirculating the air. (2) **Wet scrubbers** (packed towers) using a bleach (NaOCl) or caustic (NaOH) solution to neutralize H₂S to sodium sulfide/sulfate. Wet scrubbers are typically used in larger chemical plants or wastewater; for a battery plant, a dry chemisorption filter might be simpler. **Maintain scrubbing media** – they have finite capacity. A saturated carbon filter will no longer remove H₂S. Have a change-out schedule or breakthrough indicator. Some operations with expected continuous small H₂S generation (e.g. a sulfide electrolyte mixing glovebox) might vent through a small dedicated filter filled with zinc oxide or iron oxide which reacts with H₂S to form harmless solids.

- **Inerting and blanketing:** If H₂S is generated by moisture contact, one approach is to perform that process in an **inert atmosphere** (N₂ or Ar) inside a sealed enclosure, then scrub the enclosure off-gas. Dry rooms already are low in moisture, but not zero. For highly sensitive processes, a glovebox filled with N₂ at <1 ppm O₂/H₂O might virtually eliminate H₂S generation. This is more of a process change/engineering solution. It doesn't remove H₂S if generated, but prevents generation by eliminating reactants (moisture). It's mentioned here as part of elimination/substitution controls.
- **Explosion considerations:** While the focus is toxic exposure, recall that H₂S is flammable (LEL ~4% = 40,000 ppm). It's unlikely to reach that in a well-ventilated area (toxic levels will be hit far earlier), but any ventilation or gas detection system could double-purpose to also alarm at LEL thresholds (some sensors or systems have LEL monitoring; typically H₂S-specific sensors are for toxic range, but one could have an LEL sensor for H₂S if large releases are possible). Ensure electrical equipment in areas with potential for high H₂S is appropriately rated (H₂S is in gas group C for NEC classification, similar to ethylene, due to its flammability).

4.2 Administrative Controls (Training & Procedures):

- **Safe Work Procedures:** Develop clear SOPs for any task involving materials that could emit H₂S. For example, "Procedure for Opening a Glove Box that Processed Sulfide Electrolyte" – instruct to check H₂S levels inside before fully opening, etc. If maintenance on a piece of equipment that might have H₂S residue (like a filter change) is performed, require it to be treated as potentially H₂S environment: use portable H₂S monitor, ventilate the equipment, etc. **Confined Space Entry:** If there are pits, tanks, or gloveboxes large enough to climb into, treat them per confined space rules if H₂S could be present – meaning test the atmosphere first, continuous monitoring, rescue plan ready, etc. (This aligns with general confined space standards and the Japanese oxygen deficiency rule requiring a supervisor with specific training for "H₂S danger work" ⁴⁴ .)
- **Training:** All relevant employees should receive training on H₂S hazards. This includes recognizing alarm signals, symptoms of exposure, emergency evacuation routes, and use of protective equipment. In many jurisdictions, anyone who might be exposed to H₂S (even briefly) gets H₂S awareness training annually. Special training (like the "Oxygen Deficiency & H₂S Danger Work Chief" certification in Japan ⁴⁴) is legally required for supervisors of such work. Even in battery R&D labs, staff should know that sulfide materials can create H₂S. Training should emphasize that smell is not a reliable indicator and that monitors must be trusted.
- **PPE Use Policies:** While PPE is last resort, ensure that appropriate respiratory protection is available and workers know when to use it. For instance, **air-purifying respirators (gas masks) with specific H₂S cartridges** can protect up to certain concentrations (usually these cartridges are good for low-level escape or work under 10 ppm; above that, or if unsure, **SCBA (self-contained breathing apparatus)** is required) ⁴⁵ . Have rules like "If H₂S alarm high level sounds, don SCBA before attempting any shut-off or rescue." If the facility has H₂S risk, it should have SCBA or supplied-air respirators on hand (and people trained to use them). Japanese regs explicitly require having enough air respirators on site for all workers in case ventilation fails ⁴⁶ .
- **Work Permits and Gas Testing:** Implement a "hot work / cold work" style permit for any non-routine operation that could release H₂S. E.g., maintenance on a scrubber, opening a sulfide material storage container outside the dry room, etc., should require a permit where EHS signs off that monitoring is in place and it's safe. Part of the permit should be pre-job atmospheric testing

(with a calibrated H₂S meter) to ensure the area is <1 ppm before work starts. Continuous monitoring during the job should be mandatory if there's any risk of H₂S release during the task.

- **Exposure Monitoring & Health:** Conduct routine exposure monitoring (e.g. a personal badge or real-time monitor data logging) for workers in roles that might have ongoing low-level H₂S exposure. In a well-controlled battery facility, ideally no one is chronically exposed at all. But if, say, a particular process emits ~1–2 ppm regularly (which is above background but below limits), one might check personnel TWA exposure via personal monitors over a shift to ensure it's well below limits (preferably <1 ppm 8h TWA per ACGIH). Also, any worker who had a significant H₂S exposure incident (even non-injurious) should be medically evaluated for lingering effects (especially eye exams, respiratory check).
- **Signs and Communication:** Post warning signs “H₂S GAS – Toxic Hazard – Authorized Personnel Only” at entrances to areas where H₂S might be present, such as a door into a sulfide materials dry room. Also, ensure alarm signals are distinguishable (e.g., H₂S alarm sounds different from fire alarm) and that the muster points for H₂S evacuation are known (preferably **upwind** of the building – see § 5.2).
- **Drills:** Include H₂S leak scenarios in emergency drills. For example, simulate a small H₂S release from a glovebox and practice evacuation and response. This builds muscle memory so that if the real alarm goes off, people react correctly (don't hesitate to evacuate, etc.). Given H₂S's fast-acting nature, drill scenarios should emphasize speed and not going back in for any reason until cleared.

4.3 Interlocks and SPC Excursion Tagging:

- **Interlocks:** Critical engineering controls should be tied to H₂S detection. Some examples:
- **Ventilation Interlock:** If any fixed H₂S detector reads above a pre-set threshold (for example, 5 ppm), automatically ramp up exhaust fans to maximum and cut off recirculation dampers. This can dramatically reduce the peak concentration by quickly flushing the area.
- **Process Shutdown:** For processes that could generate large H₂S (e.g. a reactor processing Li₂S that could decompose), an interlock could halt the process (close valves, stop heating) if H₂S exceeds X ppm. In battery solid electrolyte mixing, this might not be straightforward (hard to “turn off” a reaction in a solid state), but you could stop a milling machine or heating routine if gas is detected.
- **Entry/Access Controls:** If H₂S is detected, doors could magnetically unlock open (to ventilate) or conversely, anterooms might lock to prevent entry until cleared (depends on scenario – generally you want people out, so you wouldn't lock egress doors; more likely you would interlock to prevent someone entering a room that is in alarm). Some facilities use red beacon lights outside room doors to indicate toxic gas alarm inside – so no entry.
- **SPC (Statistical Process Control) and Excursion Tracking:** Treat an H₂S excursion as both a safety and a quality event. For instance, if at time T a spike of H₂S 8 ppm occurred in the dry room, and at that same time a batch of cells was being assembled, one should flag that batch in the quality system. Reason: H₂S indicates something abnormal (moisture ingress? material contamination?) which could potentially affect the cell interface (IZ) or performance. Perhaps trace amounts of H₂S reacted with lithium metal or other cell components. Those cells might merit additional testing (or at least be noted in the lot history). By tracking excursions against product lots (“anonymous cohort” implies not singling out workers, but looking at product outcome), over time you can analyze if H₂S events correlate with any yield or performance issues in cells. This is an advanced quality concept: linking EHS data with product data.

Example: If a particular glovebox shows frequent 1–2 ppm H₂S spikes (maybe suggesting a slight moisture leak each time), and later, cells from that line show higher interfacial resistance, one might investigate the correlation. Even if no direct harm to workers occurred (levels under OEL), it could hint at subtle degradation of sensitive materials (sulfide electrolytes exposed to H₂S might change surface chemistry).

- **Excursion Reporting:** Every H₂S alarm (even brief) should trigger an incident report or at least an entry in a log that is reviewed by EHS and production leads. Root cause analysis should be done for any significant excursion (e.g. > 5 ppm or any case where PPE was needed). Was it caused by an equipment failure (e.g. a vacuum pump leaked), human error (opened container outside hood), or sudden material reaction? Then implement corrective actions to prevent recurrence (this is classic EHS incident management, integrated with process improvement).
- **Anonymous Data Sharing:** Within an organization, share lessons from any H₂S incidents between sites (without blaming individuals). For example, “Site A observed H₂S release when transferring sulfide electrolyte to furnace – recommend all sites purge furnaces with N₂ before loading.” This knowledge sharing can prevent similar issues elsewhere.

In summary, **engineering controls** like ventilation and scrubbers handle H₂S at the source and in the air, while **administrative controls** ensure safe behaviors and preparedness. Interlocks provide automatic safeguarding if things go wrong, and thorough logging/analysis of any **excursion** ensures continuous improvement and ties into both safety and product quality. With these controls, even if H₂S is an inherent hazard of a given process, it can be managed to keep workplace concentrations well below harmful levels and to rapidly mitigate any accidental releases.

5. Response & Re-entry

Even with all preventive measures, the possibility of an H₂S release or incident remains. A swift and effective emergency response can mean the difference between a minor event and a serious injury or fatality. This section outlines how to respond when H₂S is detected above normal levels, including evacuation procedures, rescue plans, medical response, and criteria for safely re-entering an area after an incident.

5.1 Incident Response Hierarchy: In any H₂S emergency, **human life and health come first**, process/equipment second. The response priorities can be summarized as: **Alarm – Protect Personnel – Mitigate Source – Rescue – Inform Authorities – Medical Aid – Incident Analysis**. To break it down:

1. **Alarm/Alert:** The moment an H₂S detector triggers an alarm (or anyone suspects H₂S release due to symptoms or odor), that is the trigger for emergency mode. Modern systems will emit audible sirens and flashing lights in the area. There should also be an automated alert to a manned control room or EHS personnel (via SCADA or even SMS text to safety officers for off-hours). Some facilities have distinct alarm stages: e.g. **Low Alarm** at 10 ppm triggers local response (don masks, prepare to leave) and **High Alarm** at 15 ppm triggers full evacuation. Ensure these thresholds and actions are clearly defined in the emergency response plan.
2. **PA Announcement:** If the facility has a PA system or alarm beacons, announce “H₂S gas leak in [Location]. Evacuate immediately to muster point [X].” This should be done without causing undue delay – many alarm systems have pre-recorded voice messages that play for toxic gas alarms.

5.2 Evacuation Triggers & PPE:

- **Evacuation:** For any alarm above low level, non-essential personnel should evacuate the area immediately. H₂S can overcome a person in seconds at high concentrations, so there is no “wait and see” period. Evacuation means moving to a safe muster point **upwind** of the release, if outdoors, or outside the building if it’s an indoor area. (Companies often have wind socks installed – a practice borrowed from oil & gas – so evacuees can identify wind direction ⁴⁷ . If H₂S is venting, go crosswind or upwind to avoid the plume ⁴⁷ .) If indoors and H₂S was released in one room, muster somewhere in fresh air, and ensure doors to the affected area are closed after people exit (to prevent gas spreading). In our scenario of a dry-room, likely it’s indoors, so evacuate that room and adjacent rooms if shared HVAC.
- **Personal Protective Equipment (PPE) for Responders:** Who are responders? Typically, an in-house emergency response team or trained engineers who will attempt to shut off the source if safe, or firefighters if it’s severe. **Absolutely no one should re-enter or stay in an H₂S-rich environment without proper PPE.** Proper PPE for H₂S above IDLH is positive-pressure SCBA ⁴⁸ . Cartridge respirators (full-face masks with H₂S filters) are acceptable only up to certain low levels (often 10 ppm in practice, some cartridges say up to 100 ppm but relying on them in emergencies is risky). In an alarm scenario where levels are unknown, the rule is use SCBA. So, the facility’s emergency team should have SCBAs ready. They should also operate in buddy pairs with lifelines if going into an H₂S area to attempt a rescue – but note that untrained individuals should not attempt rescue. Tragically, many H₂S fatalities are would-be rescuers who went in without SCBA and were themselves overcome. **Rescue rule:** Do not enter the hazard zone unless you are equipped and trained (this usually means an SCBA and another person backing you up).
- **Donning Masks:** For staff who have escape respirators (some sites issue small escape SCBA or disposable emergency masks), if an alarm sounds and H₂S is confirmed, workers should don their escape respirator immediately while evacuating. (If no such PPE is provided, they must evacuate immediately without trying anything else – holding one’s breath and running is not a plan, but in extreme cases getting out quickly is the priority). For instance, some dry rooms might have wall-mounted escape packs that provide 5–10 minutes of air.
- **Headcount (Muster roll call):** At the muster point, conduct a roll call to ensure everyone is out ⁴⁹ . This is critical – if someone is missing and was last known in the H₂S area, it might mean they are unconscious inside. But no one should re-enter to find them unless equipped with SCBA and at least one backup rescuer ⁵⁰ . Instead, call the emergency rescue team (on-site if available, or local fire department HAZMAT) for a high-risk rescue. Never send in a lone person or someone without air supply – H₂S has killed “rescuer” victims who went in on instinct ⁵⁰ .
- **Incident Command:** As people evacuate, an incident commander (often the senior EHS or supervisor) should take charge at a safe location. They coordinate with responders, ensure no one re-enters prematurely, and handle communication.

5.3 Mitigation of Source & Rescue:

- **Shutting down the source:** If it’s known what is causing the H₂S (e.g. a reactor, a gas cylinder leak, a broken pipe), efforts should be made to stop the release if it can be done safely. Many systems have emergency shutoff buttons. For example, a **gas cylinder** leak: one could close the cylinder valve (with SCBA on). Or if a specific chemical reaction is overheating, hit the emergency stop. In battery labs, a typical scenario might be a furnace containing sulfide material that is

venting H₂S – the response might be to purge it with nitrogen (some furnaces have emergency purge ability) or to simply cut power and let it cool (stopping further decomposition). Only attempt source mitigation under the guidance of the incident commander and with proper PPE.

- **Rescue of affected persons:** If someone is unconscious in the H₂S zone, a trained rescue team with SCBA must enter. Time is critical; H₂S knockout can cause respiratory arrest quickly ¹. Rescuers should use lifelines (ropes) so that if they succumb or are in trouble, others can pull them out without entering the space. Often, confined space tripod and winch are used if it's a pit/tank scenario. In a room scenario, two rescuers can go, one to rescue, one backup, both on air. Remove the victim to fresh air as quickly as possible. Start **CPR/artificial respiration** if the person is not breathing (after ensuring you're not exposed yourself). Note: H₂S poisoning can cause pulmonary edema and needs prompt oxygen therapy. **Medical emergency services** should be called immediately in any case of suspected H₂S exposure (even if the person is awake but symptomatic).
- **Medical response:** While waiting for EMTs, provide 100% oxygen to exposed persons if available (many industrial sites keep oxygen resuscitators for H₂S incidents). There is no specific antidote for H₂S; treatment is supportive (oxygen, possibly hyperbaric oxygen in severe cases, treating acidosis, etc.). Remove contaminated clothing from the victim (H₂S gas doesn't really stick to clothes, but any liquid sulfide on clothes should be removed to stop off-gassing). If eyes are irritated, rinse with water. Anyone who was unconscious or had serious symptoms must be sent for medical evaluation even if they seem to recover after a few breaths of fresh air – aftereffects like pulmonary edema can develop hours later.
- **External communication:** If the release could affect the outside community (for instance, if a large amount of H₂S got out of the building), authorities must be notified. In the US, that could mean calling 911 and possibly the local emergency planning commission, as H₂S is an extremely hazardous substance (for large quantities >100 lb releases, there are reporting requirements under EPA laws). In Japan/EU similarly notify fire brigade or local city office if off-site impact. The incident commander or designated person should handle this once life-safety immediate actions are underway. As noted in one CSB investigation, a refinery H₂S release led to city shelter-in-place orders ²³ – our context is smaller, but even a battery plant might have neighbors to warn if a significant leak occurs.
- **'All Clear' vs Continued Response:** Only after the source is shut off and no more H₂S is being emitted can we turn to recovery. Keep monitoring the air; use portable detectors to verify levels going down.

5.4 Re-entry Criteria & Monitoring: Before anyone is allowed back into the affected area after an H₂S incident, the following conditions should be met:

- **Concentration below safe level:** The area must be ventilated until H₂S readings are **consistently back to near 0 ppm** (at least below 1 ppm, or whatever site-specific clearance level is set, which might be 5 ppm if one is aligning with TWA limits – but best practice is zero or background). Typically, using direct-reading instruments, an EHS professional will do a sweep of the area. Check near the floor, at corners, or any area H₂S might linger (it usually doesn't stick around too long once ventilation is good, as it disperses or is absorbed on surfaces slightly). If any pockets of gas remain (for instance, inside equipment), continue ventilating. Only when **multiple readings at different spots over a period (say 5-15 minutes)** all show safe levels, can you declare an all-clear.

- **Engineering fix in place:** If the incident was caused by a specific failure (like a leaking valve), re-entry should ideally wait until that is isolated or fixed or the area is made safe from that hazard (for example, the leaking cylinder is moved out or capped by hazmat team). In other words, don't send workers back next to an uncontrolled source. You might allow re-entry for repair crews in SCBA to address the fix, but normal operations shouldn't resume until the issue is resolved.
- **Re-entry team protocol:** The first people to re-enter (to assess or do repairs) should do so in pairs with appropriate PPE (in case the readings were mistaken or something changes). For example, after a big H₂S release, even when our detectors read zero, a maintenance crew with SCBAs might go in to double-check equipment and ensure there are no surprises. Once they confirm it's truly clean, then general staff can re-enter without SCBA.
- **Re-entry decision and announcement:** The incident commander or EHS lead will make the call that it's all-clear. Announce "All clear, H₂S levels are safe. Area [X] may be re-entered." This should be communicated officially; no one should just drift back in because they think it's okay.
- **Medical clearance for workers:** Anyone who has been exposed to H₂S (especially if above limits or if they had symptoms like dizziness, headache, etc.) should be sent for medical check and not resume work that day. They may feel fine but could have latent effects. This is part of re-entry in the sense of "don't let potentially compromised individuals resume work without clearance."
- **Investigation before normal operation:** It is often wise to keep the process stopped until a quick root-cause evaluation is done. For example, if a certain reactor caused H₂S, maybe keep it offline until you figure out why and address it. That might involve an engineering team, so operations might be partially paused even if the area is clear.
- **Post-Incident Review:** After the incident, do a debrief with all involved. What went right/wrong in the response? Did alarms function, did everyone evacuate to the correct spot, was anyone confused? Use this to improve training or procedures.
- **Reporting:** Fill out incident report forms (see Appendix A3 template). If required by law, submit reports to government (in the US, OSHA must be notified if there was a serious injury or fatality; chemical release reporting if threshold exceeded; in EU, authorities under Seveso III if applicable, etc.). Even if not legally required, internal reporting up the management chain is important.

Incident Case Studies (examples): To underline the importance of proper response, consider two real scenarios: - Refinery Incident 2024 (Deer Park, TX): ~27,000 pounds of H₂S were accidentally released during maintenance, killing 2 workers and injuring 13 ²³. Workers opened the wrong pipe segment containing H₂S which led to a massive release. The incident commanded a shelter-in-place for the surrounding community ²³. Key lessons were the critical need for strict permit-to-work, proper isolation (lock-out) of equipment, and emergency comms. In our context, while quantities are much smaller, the principle stands: one mistake (opening something without verifying it's safe) can be fatal with H₂S – meticulous procedures and emergency readiness are life-savers. - Laboratory Incident (Lead-Acid Battery Charging): A university lab report noted that overcharging lead-acid batteries can produce H₂S gas, identified by rotten egg odor ⁵¹. In one case, a sealed battery exploded and released H₂S, causing a fire alarm and building evacuation (no serious injury, but a close call). This illustrates that even battery-related operations not involving exotic sulfides can generate H₂S. The response was proper ventilation and evacuation; the takeaway is to be vigilant about **any** process that can off-gas H₂S and ensure alarms/ventilation are in place.

Re-entry After Minor Excursions: If the H₂S alarm was a brief low-level spike (say 5 ppm for 1 minute) and it cleared quickly by itself, one might not do a full evacuation. However, it should still be treated with caution: investigate cause, maybe have people step out for a short time while checking the area. In some facilities, a 5 ppm alarm might trigger an automatic stop of a machine but not a full site evacuation – then operators with portable monitors check and decide to continue. The emergency plan can define what levels trigger full evacuation vs. what triggers heightened alert. For instance, “If H₂S < 10 ppm and drops within 1 minute, ventilate and investigate – no evacuation needed; if ≥ 10 ppm or sustained, evacuate.”

Finally, **psychological and follow-up:** H₂S incidents can be frightening. Provide support to workers, and if anyone had symptoms or was hospitalized, ensure they’re healthy before returning to work. Use the incident as a learning tool, not to assign blame (unless egregious violation, focus on system fixes). Refining the emergency response plan after a real event is crucial – often gaps are revealed only under real stress.

In conclusion, a well-planned and drilled response ensures that if H₂S does get released, everyone knows what to do: **alarms sound, people get out/upwind quickly, responders with SCBA handle the source and any rescue, and no one goes back until it’s truly safe** ⁵⁰ ⁵². Time is of the essence with H₂S, and disciplined execution of the emergency plan will prevent injuries.

Limitations & Disclaimer: This document provides a general technical overview and guidance. It may not cover all specific scenarios or local regulatory nuances. Always refer to current official regulations, standards, and site-specific risk assessments. Implementation of any practices should be done by qualified professionals. Site management must ensure compliance with all applicable laws (in each jurisdiction) and adapt the recommendations to their specific processes and materials. Interface Lab Research and the author assume no liability for the application of these guidelines in the field – they are to supplement, not replace, formal training and safety engineering. When in doubt, consult an occupational hygienist or safety engineer. Your site’s established SOPs and emergency plans supersede any generic advice given here.

Appendix A – Templates and Checklists

(The following templates are provided as examples to aid in documentation. They should be customized to fit the specific operations and forms of each site.)

A1. Daily H₂S Gas Detector Log – Sample Template

Date	Detector ID / Location	Bump Test (Pass/Fail)	Calibration Due Date	Daily Peak Reading (ppm)	Operator	Initials	Comments
2025-09-20	Personal #112 (Dry Room A)	Pass	2025-10-01	0.0 ppm	JS	–	2025-09-20 Fixed #5 (Mixing Station) Pass 2025-11-01 0.5 ppm HK Peaked 0.5 ppm @14:30, investigated, likely due to momentary bag opening. 2025-09-21 Personal #112 (Dry Room A) Fail (no alarm) 2025-10-01 – JS Failed bump – removed from service, replaced sensor, re-test OK.

Columns explanation: **Detector ID/Location** – unique identifier and where it is used (or who carries it). **Bump Test** – result of functional test at start of shift. **Calibration Due** – as labeled on device. **Daily Peak** – highest reading observed (can be obtained from device memory or noted by operator). **Comments** – any alarms, actions, maintenance performed. This log is reviewed by EHS weekly. A failed bump test means the unit must not be used until fixed.

A2. H₂S Detector Bump Test & Calibration Checklist (Example)

- **Bump Test Procedure:** (Performed daily or before use)

1. Verify test gas cylinder label: H₂S concentration (e.g. 25 ppm) and expiry date.
2. Attach regulator and tubing to test gas. Set flow ~0.5 L/min.
3. In fresh air, turn on detector, ensure it reads 0 ppm.
4. While detector is in normal mode, briefly apply gas to sensor inlet (1–2 seconds is usually enough) ⁵³.
5. Check that audible alarm, visual strobe, and vibrator (if equipped) all activate when gas is applied. Confirm display shows presence of H₂S (does not need to read exact value for bump, just detection).
6. Remove gas, ensure reading returns to 0 and alarms silence.
7. Outcome: **Pass** if alarms functioned and reading changed appropriately. **Fail** if no response or incorrect response (e.g. low sensor response not triggering alarm).
8. If Fail: remove device from service. Attach “Do Not Use – Calibration Required” tag. Use backup detector if available. Investigate (may need full calibration or sensor replace).

• **Calibration Procedure:** (Performed monthly or as needed)

- Gather calibration equipment: zero gas (or ambient air if no H₂S in air), span gas (e.g. 10.0 ppm H₂S in N₂), regulator, tubing, calibration cap (for devices that need one).
- Check span gas certificate to ensure accuracy (NIST traceable). Record lot number.
- Zero the detector: in clean air or attach zero gas. Activate zero calibration mode per the device manual. Wait until device confirms zero set.
- Span calibration: Attach the calibration cap and tubing. Flow span gas (e.g. 10 ppm) to the sensor. Activate span calibrate mode. The device will adjust its reading to match the known value (10 ppm). When stable, it should indicate calibration complete.
- Remove gas and cap. Ensure device reads back to 0 ppm after flush.
- Perform a quick post-calibration bump (flow span gas again briefly) to ensure reading is correct (should show ~10 ppm and alarm).
- Document: date, time, span gas used, before/after readings (if any drift), and sign off. Update the “Calibration Due” label on detector if applicable.
- If unable to calibrate (sensor won’t span or zero properly): replace sensor or unit and retry, or send for servicing.
- **Maintenance Tips:** Check sensor inlet for blockages. Replace filters as needed. Keep spare sensors and batteries in stock. After calibration, do not immediately stow the detector in an air-tight case if it’s still off-gassing calibration gas – let it clear first.

A3. H₂S Excursion Incident Report – Template

(To be completed for any H₂S concentration excursion above normal operating levels, e.g. alarm events.)

- **Date/Time of Incident:** 2025-09-30, approx. 14:35 local time
- **Location:** Dry Room A, Mixing Station #2
- **Description of Event:** Fixed H₂S detector #5 alarmed High (15 ppm alarm) at 14:35. Personal monitors of two operators showed 10 ppm and 11 ppm concurrently. Operators reported a “burnt rubber” smell just before alarms (possibly H₂S odor mixed with other process fumes). All personnel (4 people) evacuated room within ~30 seconds to outdoor muster point. One operator experienced mild throat irritation, others no symptoms. Alarm duration ~2 minutes; levels dropped below 1 ppm by 14:45 after ventilation ramp-up.
- **Actions Taken:**
 - Evacuation and headcount (all accounted).
 - Emergency response team donned SCBAs and entered at 14:50 to survey – readings 0 ppm, no obvious vapor. They secured the process equipment.

- Source identified: A mixing vessel containing Li_3PS_4 electrolyte had an argon purge failure; a leak allowed moist air in, causing H_2S release. Vessel lid seal found partially dislodged.
- Seal fixed and purge re-established before restart. Impregnated carbon filter in exhaust was replaced as precaution (it had adsorbed H_2S).
- Affected operator given oxygen for 15 min as precaution on site; no hospital treatment needed.
- **Exposure Levels:** Max 15 ppm (per fixed detector) for approx 1–2 minutes. Personal TWA for shift estimated <0.1 ppm after dilution with rest of day (negligible).
- **Root Cause:** Procedural lapse – purge gas cylinder had run empty unbeknownst to operators, and the vessel was opened without verifying inert atmosphere. Moisture ingress led to H_2S generation from the sulfide electrolyte. Seal design also contributed (could allow ingress when no positive pressure).
- **Corrective Actions:**
 - Install low-pressure alarm on argon purge line to give warning if purge fails.
 - Update SOP to require confirming active purge and proper seal before mixing sulfide compounds.
 - Provide refresher training on H_2S hazard and response (completed 2025-10-05).
 - Increase frequency of checking scrubber cartridges; add H_2S sensor near scrubber outlet to detect any breakthrough.
 - Quality: Flag batch #2025-09-30-A produced during event – will perform additional cell impedance tests to see if H_2S exposure affected interface.
- **Notifications:** Internal EHS incident report filed. Local authority notification not required (quantity below reportable, no offsite impact), but reported to corporate EHS database.
- **Prepared by:** J. Smith, EHS Coordinator
- **Reviewed by:** A. Tanaka, Plant Manager – Date: 2025-10-01

End of Report

Appendix B – References

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