

Hydrogen-Peroxide Emissions Safety in the Sterile Processing Department/ Central Sterile Supply (SPD/CSSD)

PART 2

Visualize the Invisible: Elevating Safety through Gas
Monitoring and Plasma Technology



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Key Points

- ▶ **As established in Part 1 of this series, hydrogen peroxide vapor fugitive emissions are high concentration peaks, not steady-state elevations.** The primary occupational hazard in the SPD/CSSD is not chronic background exposure but the brief, high-concentration plumes of hydrogen peroxide vapor released during chamber door opening. An 8-hour TWA does not effectively capture or control this risk. Due to the risk of brief but high concentration exposures, many countries have adopted a Short-Term Exposure Limit (STEL).
- ▶ **The “Wait-to-vent” approach potentially creates inefficiency in the department.** Allowing staff to step back and wait for hydrogen peroxide vapor to dissipate is a behavioral workaround that depends on perfect compliance. Odor is not a reliable safety monitor [Hydrogen Peroxide | Medical Management Guidelines | Toxic Substance Portal | ATSDR “Odor does not provide a warning of hazardous concentrations.”] ^[1]. Under production pressure, adherence to wait-to-vent practices could become inconsistent over time, potentially causing significant annual workflow losses and negatively impacting staff safety. Repeated exposure to an invisible, odorless hazard—managed by waiting and individual judgment rather than objective measurement, lessens the culture of safety that modern standards (AAMI ST58 and The Joint Commission 360) instill. Another aspect is that human error may be an issue if waiting-to-vent periods create distraction from workflows.
- ▶ **Continuous monitoring provides objective, real-time data to better protect staff.** Hydrogen peroxide vapor is odorless at hazardous concentrations, therefore reliance on smell alone is not an adequate safety measure. Only continuous monitoring with real-time displays can identify acute exposure events, giving SPD/CSSD staff the information needed to stay safe and informing preventive maintenance decisions.
- ▶ **Plasma technology decomposes residual hydrogen peroxide into water and oxygen before door opening.** Vaporized hydrogen peroxide (vH_2O_2) with plasma decomposes residual chamber hydrogen peroxide to water and oxygen before the door opens, reducing door-plane fugitive emission peaks approximately 19-fold versus non-plasma systems.

Summary:

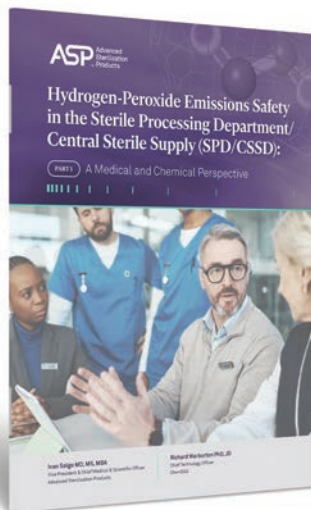
Together, continuous monitoring and plasma create an integrated safety system. Monitoring detects and quantifies hydrogen peroxide vapor events. Plasma reduces them at the source. Together they form a detect–analyze–intervene–verify cycle that satisfies AAMI ST58:2024’s engineering control mandate and generates the outcome data that Joint Commission Accreditation 360 rewards.

Key Scientific Methodology Points

Hydrogen-Peroxide Emissions Safety in the Sterile Processing Department/ Central Sterile Supply (SPD/CSSD):

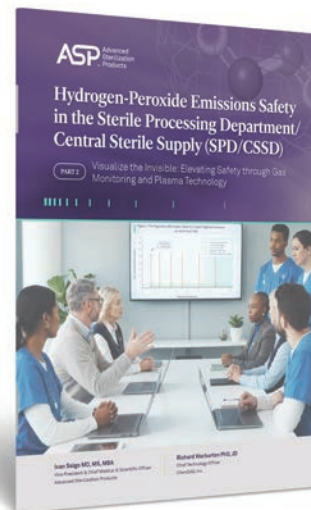
PART 1

A Medical and Chemical Perspective



PART 2

Visualize the Invisible: Elevating Safety through Gas Monitoring and Plasma Technology



Both Emissions White Papers Parts 1 and 2 contain information:

- ▶ Derived from **Scientific Peer Reviewed Journal Evidence**
- ▶ Derived from **Regulatory Body Released Devices**
- ▶ Derived from **Real Time Measurements of Emissions**
- ▶ Listing of **Emerging International Governmental Standards** (Short Term Exposure Limits)

Introduction

Low-temperature sterilization using vH_2O_2 is essential for processing heat-sensitive surgical instruments in the modern Sterile Processing Department (SPD) / Central Sterile Supply Department (CSSD). It is effective, rapid, and widely adopted. However when vapor emissions are insufficiently mitigated, they can present a safety challenge for staff.

Hydrogen peroxide vapor fugitive emissions are the vH_2O_2 that escape the sterilizer boundary into the occupational environment—primarily when the chamber door is opened after cycle completion, but also through equipment that may need maintenance [2].

This paper presents the integrated response to hydrogen peroxide vapor fugitive emissions: the two-pillar **Peak Emissions Management (PEM) framework built on continuous electrochemical monitoring and plasma-phase decomposition technology**. It also addresses a dimension that occupational hygiene data alone cannot fully capture: the operational, economic, and environmental costs of the most common informal response to hydrogen peroxide vapor fugitive emissions—the “wait-to-vent” workaround.



“Detection of odor does not provide adequate warning of hazardous concentrations of hydrogen peroxide vapor.” [1]

Figure 1. The Blind Spot: Peak H_2O_2 Vapor Fugitive Emissions vs. the 8-Hour TWA

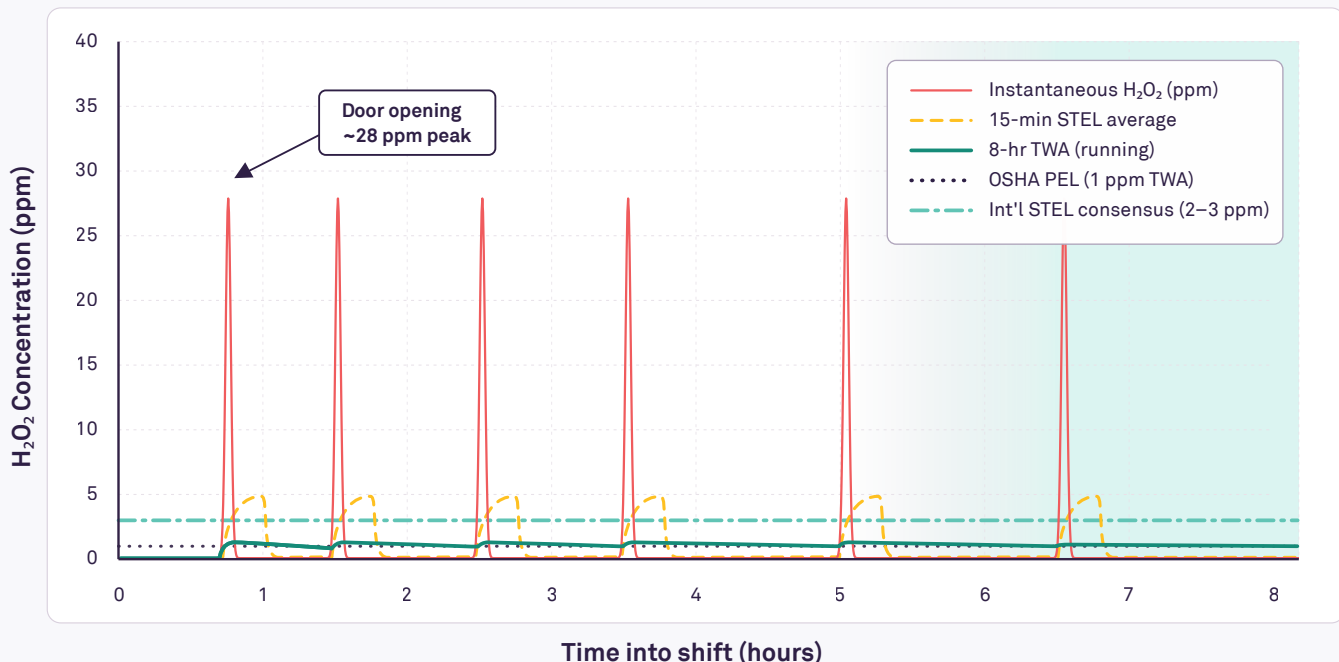


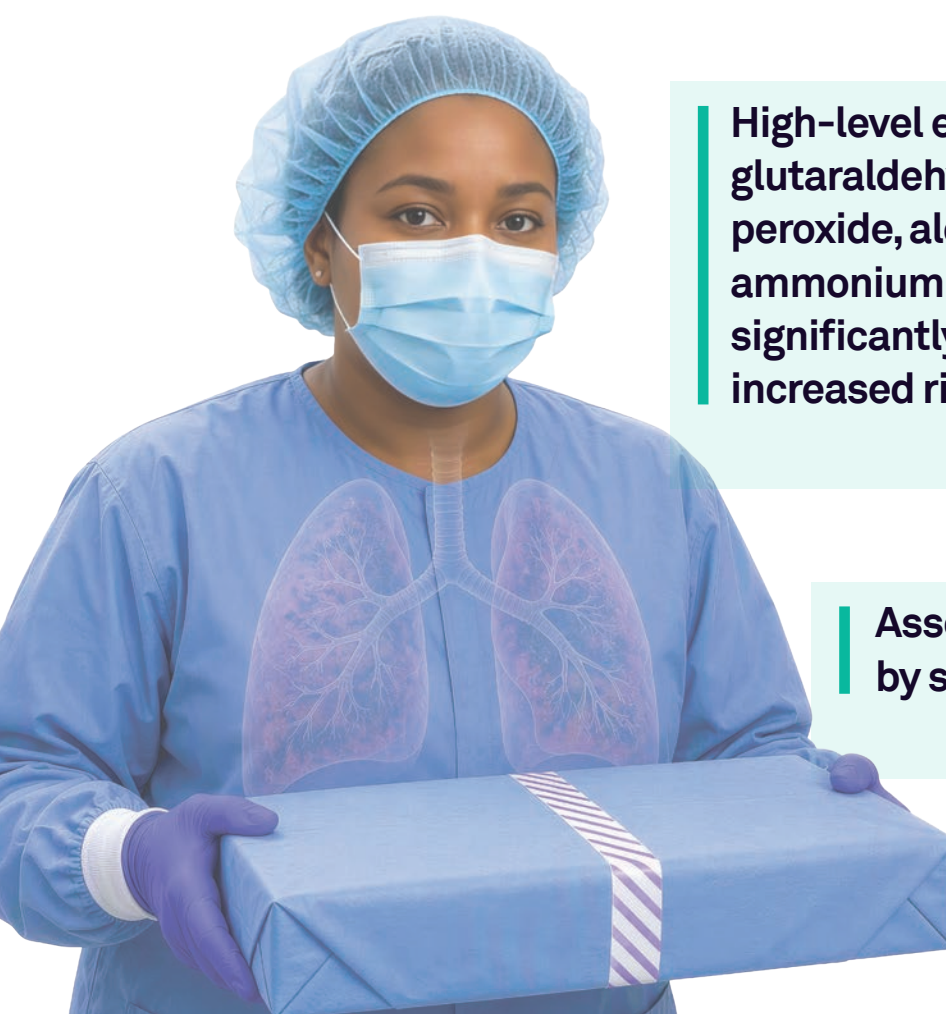
FIGURE 1. Illustrative simulation of six door-opening events across an 8-hour shift, modeled on the peak concentration range (25–40 ppm) reported by Cornelia & Warburton [2] for non-plasma sterilizers; actual values vary by sterilizer model, maintenance status, and room ventilation. The 15-minute STEL average (orange) briefly exceeds the international 2–3 ppm consensus. The 8-hour TWA (teal) remains below 1 ppm throughout—demonstrating how TWA-only monitoring is structurally blind to acute fugitive emission exposure.

The Clinical Evidence— What Hydrogen Peroxide Vapor Exposure Does to Healthcare Workers Over Time



A Landmark Prospective Study in JAMA Network Open

The safety case is supported by prospective epidemiological evidence. The key study, Dumas et al., followed 73,262 female nurses over 6 years. The findings may have important implications for occupational health and safety programs. Weekly occupational use of many germicidal chemicals was associated with a **35% increased risk** of developing physician-diagnosed Chronic Obstructive Pulmonary Disease (COPD) (adjusted hazard ratio [AHR] 1.35), independent of smoking status and asthma history. Hydrogen peroxide specifically was associated with a **29% increased COPD incidence risk** among nurses who have high-level exposure. The authors estimated that approximately **12% of COPD cases among female nurses were attributable to occupational disinfectant exposure** ^[3].



High-level exposure to
glutaraldehyde, bleach, hydrogen
peroxide, alcohol, and quaternary
ammonium compounds was
significantly associated with
increased risk of COPD incidence.

— Dumas et al. ^[3]

Associations were not modified
by smoking or asthma status.

— Dumas et al. ^[3]

The Regulatory Imperative— AAMI ST58:2024 and Accreditation 360

Part 1 reviewed the health effects associated with hydrogen peroxide vapor exposure, including respiratory, eye, and skin irritation during short-duration peak exposure events ^[3,4,5]. Recognition of these acute exposure risks has contributed to the growing adoption of Short-Term Exposure Limits (STELs) and increasing emphasis on engineering controls and exposure monitoring within healthcare environments ^[6].

AAMI ST58: 2024: Engineering Controls Over Dilution Ventilation

ANSI/AAMI ST58: 2024—Chemical Sterilization and High-Level Disinfection in Health Care Facilities, is the profession's current consensus standard for low-temperature sterilization. Its approach to hydrogen peroxide vapor fugitive emission control has become markedly more explicit with each revision, and two provisions are particularly consequential ^[7]:



AAMI ST58: 2024 | Selecting Vapor Monitoring Equipment or Services (Annex P, Section P.4):

“All managers of locations where chemicals are used have clearly defined responsibilities to monitor and minimize worker exposure to chemical vapors.”



AAMI ST58: 2024 | Vapor Monitoring (Annex I, Section I.7):

“Vapor monitoring is recommended if there is the potential for the hydrogen peroxide vapor concentration to exceed the OSHA recommended permissible exposure limits. Emissions from properly operated and maintained chemical vapor sterilizers should be well below the OSHA PEL, but sterilizers and exhaust systems, as with any other complex equipment, can and sometimes do fail. If monitoring is deemed necessary, continuous personal and area monitors for hydrogen peroxide are commercially available. Gas and vapor emissions can occur from even the best made equipment and odor is an unreliable indicator of the presence and concentration of hydrogen peroxide gas below hazardous concentrations. Continuous gas monitoring systems are available to help employers satisfy the requirement to provide a safe work environment by providing alerts in case of potentially hazardous concentrations, informing workers when it is safe to return after a release and provide record keeping.”



As outlined in Part 1, occupational exposure limits are largely derived from historical Threshold Limit Values (TLVs) and remain primarily based on 8-hour time-weighted averages (TWAs), many of which date back to the late 1960s and early 1970s. While effective for controlling cumulative exposure, TWAs do not fully account for short-duration concentration peaks that may result in acute effects. Toxicological data for hydrogen peroxide highlight this limitation. Although exposures to 2.1 ppm (2.9 mg/m³) have not been associated with adverse effects in animal models, higher concentrations (≥ 10.5 ppm [14.6 mg/m³]) have been linked to respiratory irritation and tissue damage ^[8], underscoring the importance of transient peak exposures. To address this, many countries and professional organizations have incorporated Short-Term Exposure Limits (STELs) to better reflect real-world exposure scenarios. However, some regulatory frameworks continue to rely on legacy limits established more than 50 years ago. Occupational Safety and Health Administration (OSHA), for example, acknowledges that many Permissible Exposure Limits (PELs), largely adopted in the early 1970s and not substantially updated since, are outdated and not sufficiently protective of worker health ^[9,10].

Accreditation 360: Outcome-Based Governance and Data-Driven Continuous Improvement

In 2025, The Joint Commission launched Accreditation 360, shifting evaluation from episodic audits to continuous, measurable performance improvement ^[11]. For hydrogen peroxide vapor fugitive emission management, this has a key implication:

Longitudinal sensor data, closed-loop corrective action, and measurable emission reduction support implementation of environmental safety engineering controls.

Further, Accreditation 360 emphasizes the importance of daily processes and practice, rooted in data and metrics, that create compliance and high reliability as opposed to an endless cycle of reaction to audit findings and recommendations ^[11].



“Wait-to-Vent”—Why the Most Common Response Is Counterproductive

The Workaround and Its Unintended Consequences

When a non-plasma vH_2O_2 sterilizer cycle ends and staff perceive a hydrogen peroxide vapor fugitive emission risk, a commonly reported informal response is to open the sterilizer door, step back, wait, and let the hydrogen peroxide vapor fugitive emissions dissipate into the room before retrieving the load. Some people have moved the sensor back to avoid detecting the plumes of H_2O_2 rising up the front of the sterilizer door, but doing so only masks the problem, like putting tape over a smoke alarm.

Minor delays at the individual level can escalate into major disruptions at the institutional scale. Even short venting delays across multiple cycles, compounded across multiple sterilizers running near-continuous cycles throughout a workday can potentially translate into a quantifiable loss of productive workflow hours (see Figure 2 on pg. 10) and many SPD/CSSD institutions may not account for this.

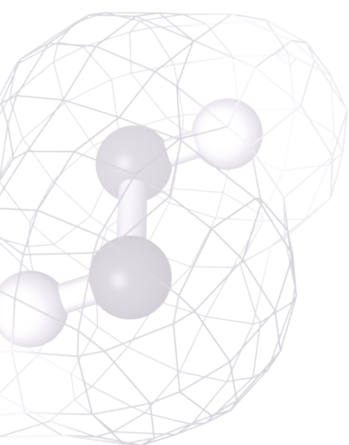
The wait-to-vent approach creates uncertainty in exposure levels. The consequences compound over time:

Vigilance stress.

Without sensor data, staff face a recurring judgment—

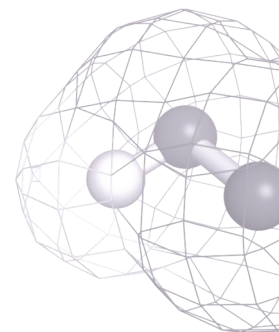
“Have I waited long enough?”

—with no objective answer.



The Potential Operational and Economic Cost of Hydrogen Peroxide Vapor Fugitive Emissions

A Quantifiable Impact Assessment



The workflow cost of hydrogen peroxide vapor fugitive emission venting delays is straightforward to estimate and transparent to audit. For example, if personnel spend an additional 15 minutes per cycle waiting to clear the sterilizer, the following formula can be used:

$$\text{Lost hours/year} = (\# \text{ sterilizers}) \times (\text{cycles/day/sterilizer}) \times (\text{days/week}) \times (\text{weeks/year}) \times (\text{delay min/cycle}) \div 60$$

The two mid-range examples below show this scale:

SCENARIO	PARAMETERS	LOST HOURS/YEAR
Mid-size SPD/CSSD	4 sterilizers × 3 cycles/day × 5 days/week × 50 weeks/year × 15 min/cycle ÷ 60	750 hours
Larger, higher-throughput SPD/CSSD	5 sterilizers × 5 cycles/day × 6 days week × 52 weeks/year × 15 min/cycle ÷ 60	1,950 hours

TABLE 1. Illustrative hydrogen peroxide vapor fugitive emission venting delay calculations using the leader-ready formula. Parameters are representative; each facility should apply its own values.

These point estimates are consistent with the Monte Carlo simulation conducted for Part 1 of this series, which modeled a full probability distribution across low, mid, and high parameter ranges. That simulation yielded a 90% confidence interval of approximately 465 to 1,812 annual hours lost, with a central estimate near 1,100 hours lost. If staff multitask to gain back efficiency, they risk potentially increasing error rate with unnecessary multitasking.



465 hrs

Annual venting delay (5th percentile)



~1,100 hrs

Annual venting delay (central estimate)



1,812 hrs

Annual venting delay (95th percentile)



Monte Carlo Simulation: Annual SPD Workflow Hours Lost to Hydrogen Peroxide Vapor Fugitive Emission Venting Delays

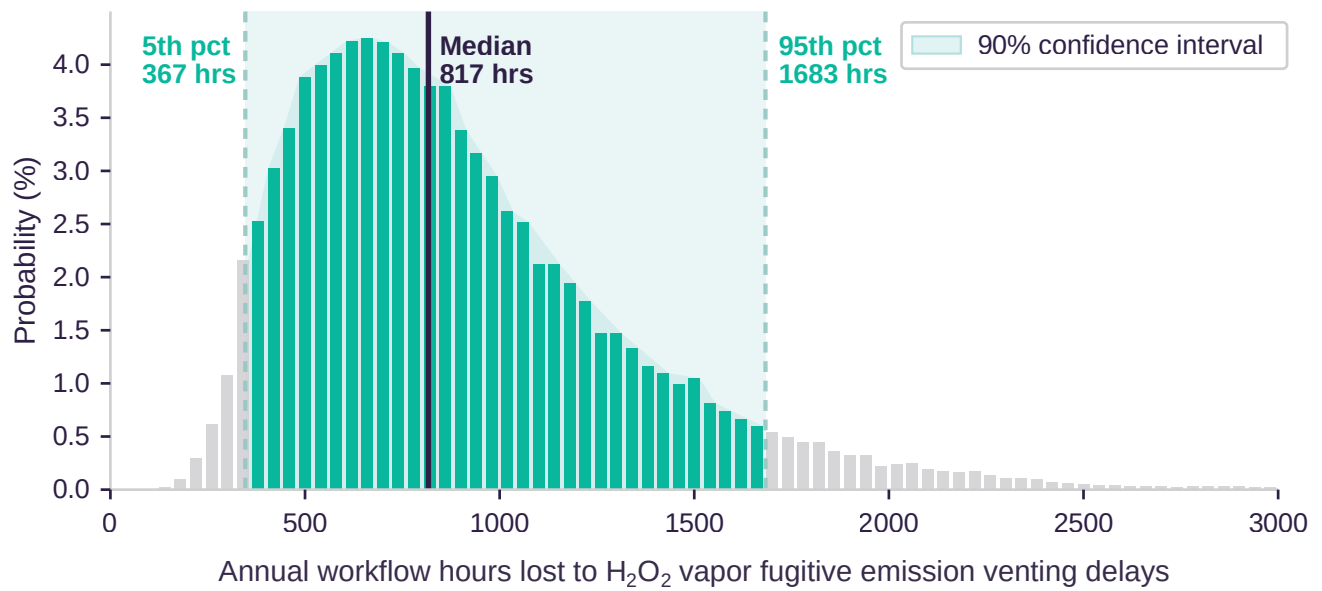


FIGURE 2. . Monte Carlo simulation result: annual SPD workflow hours lost to hydrogen peroxide vapor fugitive emission venting delays (90% confidence interval). Central estimate ~817 hours/year; 5th–95th percentile range 367–1,683 hours.

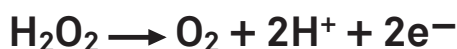
Continuous Monitoring— Making Hydrogen Peroxide Vapor Fugitive Emissions Visible

The Technology: Electrochemical Sensing in the SPD/CSSD

Direct-reading electrochemical sensors represent the validated, peer-reviewed standard for real-time vH_2O_2 monitoring in SPD/CSSD environments ^[6,7]. These instruments function as specialized monitoring devices that generate an electrical signal proportional to the hydrogen peroxide vapor concentration in the air. This signal is digitally processed to provide a quantitative reading of the hydrogen peroxide concentration in ppm; and if the concentration is above alarm threshold limits, a visual and auditory alert is generated, giving staff and managers a clear, real-time reading. Many continuous monitors also provide rolling 15-min and 8hr TWAs with data logging.

Electrochemical Reaction

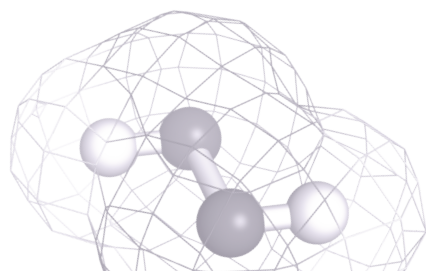
At the working electrode, hydrogen peroxide undergoes oxidation:



The resulting electron flow generates a measurable current proportional to H_2O_2 concentration.

Modern sensors achieve: ^[12]

- ▶ **Low Detection Limits** — enabling consistent, reliable accuracy below all established occupational exposure thresholds.
- ▶ **Fast Response Times** — capturing the full peak and decay profile of each hydrogen peroxide vapor fugitive emission event.
- ▶ **Appropriate Operating Range** — spanning peak emissions, TWA, and STEL monitoring needs across the full spectrum of SPD/CSSD sterilizer operation.
- ▶ **Minimal cross-sensitivity** — to alcohols, aldehydes, and other SPD/CSSD related vapors, ensuring selective detection of hydrogen peroxide. This helps minimize false alarms.





Deployment, Data, and the Real Time Feedback Loop

Fixed sensors at breathing-zone height (1.2–1.5 meters) adjacent to each sterilizer door, combined with simple to use monitors for task-based and maintenance assessments, create a robust hydrogen peroxide vapor fugitive emission surveillance network. The value of this network extends far beyond regulatory compliance:

- ▶ **Risk management.** Objective, timestamped documentation of hydrogen peroxide vapor fugitive emission events provides defensible evidence of exposure control effectiveness, and of timely corrective action when thresholds are exceeded.
- ▶ **Staff training.** Showing staff environmental conditions with objective measurement data creates a deep understanding of safety conditions. This reinforces the requirement to follow existing safety protocols.
- ▶ **Continuous Improvement.** Continuous logs of concentrations over time, peak frequency, STEL compliance rates, and corrective action correlations satisfy AAMI ST58:2024's environmental monitoring expectations and provide exactly the longitudinal outcome evidence that Accreditation 360 promotes.



Plasma Technology— Minimizing Hydrogen Peroxide Vapor Fugitive Emissions *Before the Door Opens*

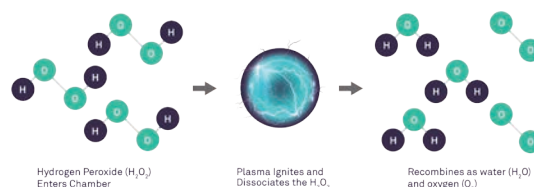
The Engineering Solution to Source Emissions

Monitoring makes hydrogen peroxide vapor fugitive emissions observable. Plasma technology enables rapid decomposition prior to chamber opening, minimizing staff exposure and eliminating the need for extended venting delays. The FDA recognizes plasma technology as “plasma is used to aid in removal of the sterilant [vH₂O₂] from the chamber”^[13], and the underlying mechanism explains why it is the most effective source-control approach available.

The plasma phase occurs within the sealed chamber as the final step of the cycle. An electrode (antenna) within the sealed sterilizer chamber applies radiofrequency (RF) energy to the chamber volume. This electromagnetic field ionizes residual hydrogen peroxide vapor and water molecules, creating a non-thermal (cold) plasma. Once the electric field is turned off, the plasma ceases to exist and water vapor and oxygen gas remain from the hydrogen peroxide in the chamber.

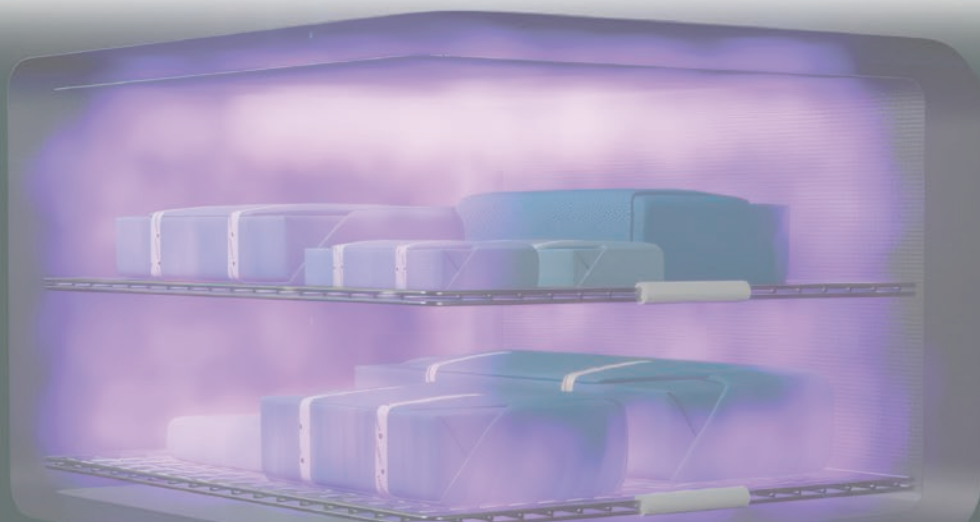
Decomposition Sequence

- ▶ **Primary dissociation (electron impact):** $e^- + \text{H}_2\text{O}_2 \rightarrow 2\cdot\text{OH} + e^-$
- ▶ **Radical recombination (gas-phase):** $2\cdot\text{OH} \rightarrow \text{H}_2\text{O} + \frac{1}{2}\text{O}_2$
- ▶ **Net result:** $\text{H}_2\text{O}_2 \rightarrow \text{H}_2\text{O} + \frac{1}{2}\text{O}_2$ (water vapor and oxygen—both harmless)



Chamber hydrogen peroxide concentration is reduced from the post-sterilization phase level to extremely low levels^[2], yielding door-plane hydrogen peroxide vapor fugitive emission concentrations that are very low.

Longitudinal occupational monitoring has confirmed approximately 19-fold lower peak exposures in plasma-equipped SPD/CSSDs compared with non-plasma systems, despite both meeting the OSHA 8-hour TWA PEL^[2].





Margin of Safety: Sterilization and Staff Protection Work in Sequence

The sterilization phase of a vH_2O_2 plasma cycle uses hydrogen peroxide concentrations well above the minimum needed to achieve the required Sterility Assurance Level. **This provides additional Margin of Safety^[14].** The plasma phase then converts the residual hydrogen peroxide—which has already done its job—into water and oxygen.



The higher vapor concentration increases the margin of safety of the sterilization process, supporting patient safety.

By utilizing the plasma phase, in-chamber plasma technology provides a dual benefit: supporting patient safety while minimizing staff exposure to fugitive emissions.



Higher organism microbiocidal activity +
Decreased Hazard to People, Environment, and Instruments
= Plasma is the Pivotal Enabler



The Closed-Loop System— Monitoring + Plasma as a Natural Evolution

The cornerstone of LEAN is continuous improvement which includes the PLAN-DO-CHECK-ACT cycle. This can be applied to Peak Emissions Management (PEM) and the following framework ^[15].

Detect, Analyze, Intervene, Verify

Monitoring alone quantifies the hydrogen peroxide vapor fugitive emission problem but does not solve it. Plasma alone solves the problem but cannot prove it. Together, they create a closed-loop Peak Emissions Management (PEM) system with four operating phases (see Figure 3 on pg. 16):

Detect. Continuous electrochemical sensors capture each hydrogen peroxide vapor fugitive emission event in real time—instantaneous peak, decay profile, STEL accumulation—which can be tagged to cycle, sterilizer, and shift.

Analyze. Longitudinal data identifies patterns: identify which sterilizers produce higher hydrogen peroxide vapor fugitive emission peaks, which load types or configurations correlate with exceedances, and whether maintenance events affect performance.

Intervene. Data-driven interventions—equipment selection favoring plasma technology, targeted maintenance, protocol adjustments, and ventilation optimization—are implemented with a clear before/after measurement design.

Verify. Post-intervention monitoring confirms that hydrogen peroxide vapor fugitive emission peaks have been reduced, STEL compliance has improved, and the intervention has delivered the expected benefit. This closed loop continuous improvement is what Accreditation 360 promotes. This cycle continuously repeats, ensuring the dual goals of patient and staff safety are met.





Proactive management beats reactive guessing.

Closed-Loop Peak Emissions Management (PEM) System
Detect → Analyze → Intervene → Verify

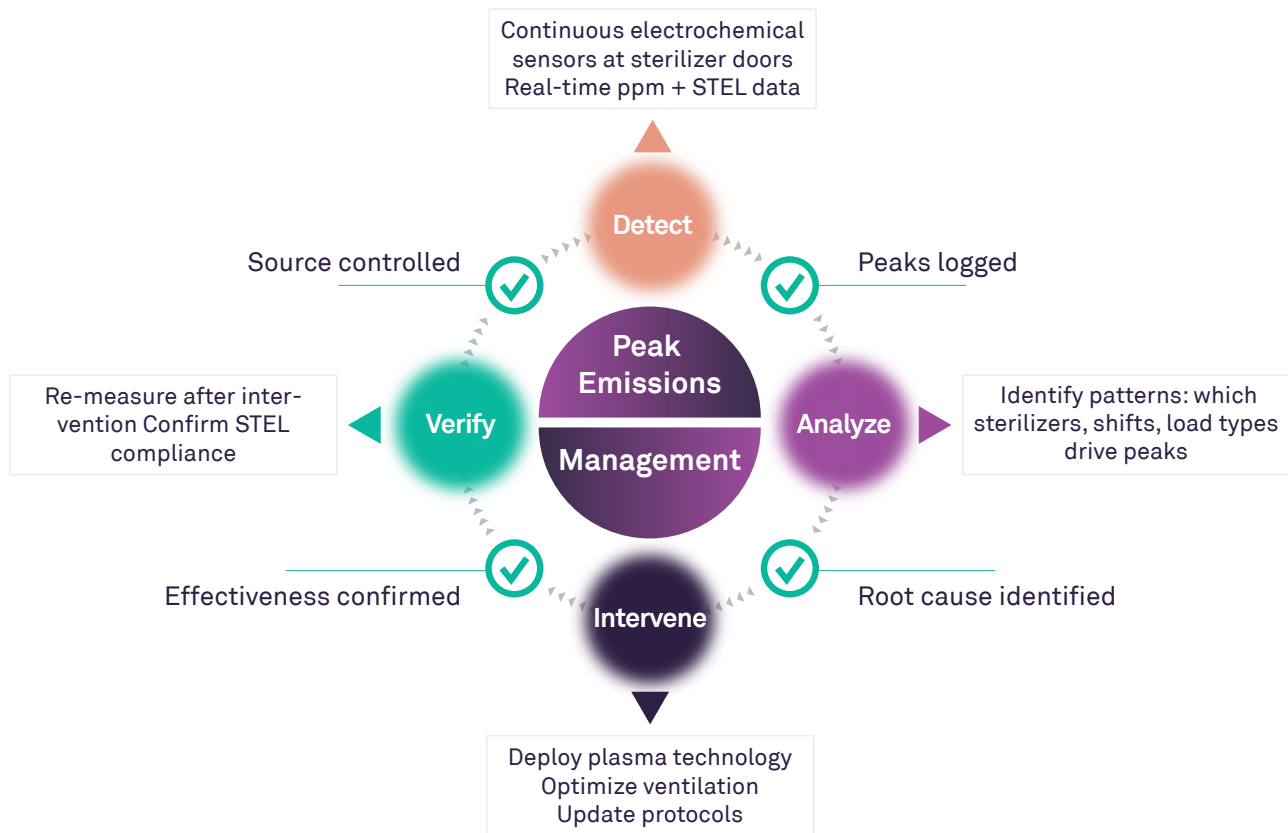


FIGURE 3. The closed-loop Peak Emissions Management (PEM) framework: Detect (continuous electrochemical monitoring) → Analyze (pattern identification) → Intervene (plasma technology, protocol changes) → Verify (post-intervention re-measurement). This cycle satisfies both AAMI ST58:2024 engineering control requirements and Accreditation 360 continuous improvement expectations.



Conclusion

Hydrogen peroxide vapor fugitive emissions are a documented occupational hazard. Peak concentrations of 25–40 ppm ^[2] may occur with every non-plasma door opening, far exceeding widely accepted thresholds, with large-scale prospective data linking disinfectant exposure to COPD.

An integrated, comprehensive response is not just needed – it is readily available. Continuous electrochemical monitoring makes hydrogen peroxide vapor fugitive emissions visible—providing the real-time data, longitudinal trends, and closed-loop verification that AAMI ST58:2024 and Accreditation 360 require. vH_2O_2 with plasma technology significantly reduces fugitive vapor emission to well below globally adopted thresholds.

Lower hydrogen peroxide vapor fugitive emissions. Higher margin of sterilization safety. Measurable STEL compliance. Stable, data-driven workflow. Promoting a Culture of Safety for Staff.





Institutional Readiness Checklist

- ☐ Is your staff aware that **hydrogen peroxide vapor is odorless** at concentrations that may cause physiological harm? This makes sensor based monitoring of hydrogen peroxide vapor beneficial for safety.
- ☐ Do you **use continuous electrochemical sensor monitoring at a breathing-zone height** to help protect staff safety?
- ☐ Has your facility established **internal STEL targets of 2–3 ppm** (15-min time-weighted average) consistent with the international regulatory consensus?
- ☐ Is **monitoring data integrated with your EHS system** and available as longitudinal, outcome-focused evidence for Accreditation 360 survey presentation?
- ☐ Does your capital equipment evaluation process include **documented hydrogen peroxide vapor fugitive emission performance** relative to staff safety as a formal selection criterion?
- ☐ Does your SPD/CSSD operate **vH₂O₂ with plasma in-chamber sterilization technology**, eliminating hydrogen peroxide vapor fugitive emissions at the source rather than relying on a wait-to-vent workaround?
- ☐ Have you quantified the annual workflow hours lost to **hydrogen peroxide vapor fugitive emission venting delays** in your SPD/CSSD using the leader-ready formula in Section 4 (page 9)?
- ☐ Is there a defined **continuous improvement cycle**—detect, analyze, intervene, verify—for hydrogen peroxide vapor fugitive emission management, with regular data review and documented corrective actions?



Glossary

- ▶ **Chronic Obstructive Pulmonary Disease (COPD):**
Pre-existing lung condition that can be exacerbated by hydrogen-peroxide exposure.
- ▶ **Environmental, Health and Safety (EHS):** a discipline designed to protect healthcare workers, patients, and the community from workplace hazards while ensuring regulatory compliance.
- ▶ **U.S. Food & Drug Administration (FDA):**
Oversees medical device reports (MAUDE) and recognizes vH_2O_2 sterilization.
- ▶ **Occupational Safety & Health Administration (OSHA):** U.S. agency that enforces Permissible Exposure Limits (PELs).
- ▶ **Peak Emissions Management (PEM):** a framework built on continuous electrochemical monitoring and plasma decomposition technology.
- ▶ **Permissible Exposure Limit (PEL):** OSHA-enforceable eight-hour TWA exposure limit.
- ▶ **Short-Term Exposure Limit (STEL):** 15-minute exposure limit used to control peak irritant exposures.
- ▶ **Time-Weighted Average (TWA):** Eight-hour average exposure metric used in Occupational Exposure Limit (OEL).
- ▶ **Vaporized Hydrogen Peroxide (vH_2O_2):** Sterilization technology designated by FDA as Established Category A.



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► Protecting patients during their most critical moments.™



Advanced Sterilization Products is a leader in infection prevention, dedicated to creating the products, solutions, and processes needed by practitioners to protect patients during their most critical moments. Our ultimate responsibility is to the patient—it is our job to elevate the standard of care for patients everywhere, and we are committed to continuously advancing infection prevention technologies that healthcare depends upon.

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