

► SPECIAL REPORT

Mind the Gap: Analyzing the Legal Framework for Chemical Accident Prevention

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Abstract The increased use of highly hazardous chemicals poses significant risks to public and environmental health. Historical incidents, such as the Flixborough explosion in 1974 and the Bhopal disaster in 1984, highlight the lethal consequences of chemical accidents. The Process Safety Management standard, published in 1992, aimed to prevent accidental releases of hazardous chemicals via comprehensive requirements for hazard management. The U.S. Environmental Protection Agency implemented the Risk Management Program rule to protect public health and the environment by requiring facilities to take proactive measures to manage chemical hazards and prepare for potential incidents. The Chemical Facility Anti-Terrorism Standards (CFATS) program, established by the U.S. Department of Homeland Security, aims to enhance the security of high-risk chemical facilities. Although its statutory authority expired in July 2023, CFATS remains an interim rule. The regulatory frameworks for these three standards are critical for ensuring chemical safety and security.

Despite these efforts, gaps and overlaps between the programs necessitate ongoing evaluation and improvement, particularly regarding safer technologies and clarified risk assessment practices. Enhanced interagency coordination, partner engagement, and adoption of best practices are essential to advancing chemical safety and mitigating risks associated with the use of hazardous chemicals. This article provides an overview of key U.S. chemical safety and security regulations designed to prevent hazardous chemical incidents and protect public health, the environment, and critical infrastructure. It also highlights opportunities to strengthen these programs through improved coordination, risk management practices, and adoption of safer technologies.

Keywords: process safety management, risk management program, chemical facility antiterrorism standards, hazardous chemicals, chemical safety, chemical security, risk assessment, regulatory review, industrial safety, accidental chemical release

Introduction

Chemical production has grown significantly in the last decade, with the global chemical industry expected to double by 2030. Techno-

logical improvements can depend on chemical usage, with many new technologies relying on hazardous substances. Over the last several decades, the use of hazardous chemicals

has been tied to lethal or severely damaging accidents. Recovery from industrial chemical disasters can take decades, with consequences still negatively affecting communities years later (McCann, 2021).

Section 112(r) of the Clean Air Act Amendments of 1990 required the creation of programs to mitigate the impact of highly hazardous chemical release through appropriate design, monitoring, and control. Multiple agencies—Occupational Safety and Health Administration (OSHA), U.S. Environmental Protection Agency (U.S. EPA), and U.S. Department of Homeland Security (DHS)—have promulgated multiple programs focused on chemical accident prevention, such as OSHA's Process Safety Management (PSM) standard, the U.S. EPA's Risk Management Plan (RMP) regulation, and the Chemical Facility Anti-Terrorism Standards (CFATS) program. While each program is separately maintained and enforced, a facility could be subject to anywhere from one to three of these programs. Due to this overlap, there could be duplication of efforts but also gaps leading to hazardous circumstances falling through the cracks.

A History of Chemical Public Safety Regulation

Process Safety Management and OSHA

Following a growing concern for the risks of serious and long-lasting impacts on employee and public health, OSHA concluded that the safety standards of the 1980s–1990s had significant gaps in coverage for protection against exposure to large releases of hazardous chemicals. Although OSHA had by this time promulgated the Hazard Communication Standard (29 C.F.R. 1910.1200), and the Hazardous Material Standard (29 C.F.R. 1910 Subpart H), neither standard addressed hazardous chemical releases that are uncommon, large in

volume, or catastrophic. In 1990, OSHA first published a proposed standard covering requirements for hazard management associated with highly hazardous chemicals, which integrated technologies, procedures, and management practices. The final rule, the PSM Standard (29 C.F.R. 1910.119), was published in 1992 after multiple years and iterations of public comments, including several industries providing supporting comments (Process Safety Management of Highly Hazardous Chemicals, 2026).

There have been no amendments since 2012 for the PSM Standard (29 C.F.R. 1910.119), a gap of 24 years. Since 2012, the U.S. Chemical Safety Board (2024) has investigated 50 incidents. In 2022, OSHA—in response to Executive Order 13650, which required multiple facilities to update their chemical safety and security standards—announced a meeting for interested parties to review proposed changes to the rule, including clarification of exemptions, expanding reactive chemical coverage, updating applicable chemical listings, and defining “recognized and generally accepted good engineering practices” (RAGAGEP).

The Risk Management Plan and U.S. EPA

In 1985, the U.S. EPA initiated a program called the Chemical Emergency Preparedness Program (CEPP) to encourage community planning and preparation for serious hazardous releases. In 1986, the U.S. Congress took many of the elements of this program and integrated them into the Emergency Planning and Community Right-to-Know Act (EPCRA). Following the 1990 addition of subsection 112(r) to the Clean Air Act Amendments of 1990, U.S. EPA was required to promulgate an initial list of regulated substances that can or could cause harm to public and environmental health, as well as to develop reasonable regulations and guidance for chemical accident prevention. In 1996, the final rule was published for the Risk Management Program (Accidental Release Prevention Requirements: Risk Management Programs Under the Clean Air Act Section 112(r)(7), 2025).

In 2024, following agency review pursuant to Executive Orders 13650 and 13990, the PSM Standard rule was modified again. This most recent modification (i.e., RMP Safer

Communities by Chemical Accident Prevention rule, March 11, 2024) changed the U.S. EPA’s approach to “prevention-focused rather than . . . compliance-driven” (Accidental Release Prevention Requirements: Risk Management Programs Under the Clean Air Act; Safer Communities by Chemical Accident Prevention, 2025).

The Chemical Facility Anti-Terrorism Standards and DHS

In 2007, the U.S. Congress established the CFATS program via the DHS Appropriations Act (6 U.S.C. § 622). These standards were published as an interim final rule (Chemical Facility Anti-Terrorism Standards, 2021) and focused on establishing risk-based performance standards for chemical facility security, including identifying vulnerabilities, developing site security plans (SSPs), auditing, recordkeeping, and protecting information. The Act authorizing the CFATS program, however, has required reauthorization, the last of which occurred in January 2024. As of June 2024, this rule is still an interim rule—and the statutory authority for the CFATS program expired in July 2023.

Gaps and Recommendations

U.S. Chemical Safety Board Historical Recommendations and Actions

Within the Clean Air Act Amendments of 1990, the U.S. Chemical Safety and Hazard Investigation Board, more generally referred to as the U.S. Chemical Safety Board (CSB), was also authorized. This independent federal agency investigates significant chemical accidents and makes recommendations for improvements, both to regulatory agencies and to industry and industry groups. Due to CSB’s independence, one of the primary outputs is finding regulatory gaps not addressed by agency regulations. CSB publishes all investigation reports and keeps a database of recommendations, along with closure actions. As of June 30, 2024, there are 154 open recommendations; 11 requiring action by U.S. EPA and 21 requiring action by OSHA. Some recommendations have been open since 2002.

Examples of open recommendations include:

- Additional compliance assistance for RMP.
- More specificity in standards to address missed hazards.

- Addition of safer technology and alternatives analysis (STAA) and hierarchy of controls for process hazards.
- Additional evaluation for hazardous chemicals to expand the high-priority substance list.
- Push to conform to RAGAGEP provisions.
- Update of available tools, including reactivity assessment and coordination of simultaneous operations tools and guidance documents.
- Improve outreach to industry.

Multiple exemptions within PSM and RMP have left holes within the applicability of either standard, allowing facilities to escape implementation of a risk and hazard management system, leading to hazard releases, injuries, and fatalities. The recommendations to fill this gap have been submitted consistently by CSB since 2013, along with Executive Order 13650 that directed OSHA and U.S. EPA to review and expand the PSM and RPM standards to address these missed risks.

Changes, however, have been slow. After an investigation of an incident in 2019 involving atmospheric flammable tanks, CSB concluded that the “OSHA PSM standard continues to allow for catastrophic incidents to occur because necessary safeguards are not being implemented for equipment that should otherwise be covered under the PSM standard” (Johnson, 2024). Moreover, PSM, RMP, and CFATS address the same types of facilities, but they do not completely overlap to sufficiently address the myriad of high-risk processes (Johnson, 2024).

Discussion and Conclusion

Regulatory Framework

Within section 112(r) of the Clean Air Act, the U.S. EPA and OSHA are directed to reduce any remaining risk associated with hazardous air pollutant emissions to within an “ample margin of safety to protect public health.” This scientific uncertainty and lack of direction within risk assessment have hampered any effort to restrict the agency’s discretion in setting risk levels. The ambiguity of “safety margin” is both a pro and a con—it allows for unknown unknowns to be included within a field that is often fraught with missing data, but it also does not push toward setting thresholds and guidelines.

Additionally, what is U.S. EPA's role above thresholds that are set: elimination, or mitigation? Elimination would better follow the standardized safety hierarchy of controls and the setup of inherently safer design, but both OSHA and U.S. EPA have previously declined to enact those concepts within regulation. Moreover, what is an acceptable risk for public safety, who should be making that decision, is this decision best left to the U.S. Congress, or is it best left to these agencies? A fundamental tension exists between regulatory program design and target uncertainty, which can be lessened by increased transparency that improves the substance of agency decision-making with additional information and alternative routes (Jackson, 2009).

Stepping Stones to Improvement

Although U.S. EPA, OSHA, and DHS have all promulgated regulations to manage risk associated with extremely hazardous chemicals, the regulatory approach so far has been within the risk management paradigm. Therefore, industry efforts have also followed the risk management paradigm.

A competing approach to risk management is the risk prevention paradigm. This structure focuses more on the hierarchy of controls: elimination, substitution, and reduction of extremely hazardous chemicals within a process or system. Risk prevention follows the concept of inherently safer design. When a process or system is interactively complex (with nonlinear relationships within the various subsystems or subprocesses) and tightly coupled (wherein a change in status in one part of the process quickly affects associated processes), accidents are bound to occur and can be considered "normal."

Given the increasing risk of catastrophic failures due to extreme weather events, climate change also requires attention within the sphere of chemical release protection. These weather events can cause what are called "natmat" events, which could be liquid spills, air emissions, or fires and explosions (Malloy, 2008). During these events, damaged equipment, false alarms masking real alarms, lack of available emergency response, and power failures, for example, could combine into a series of catastrophic failures.

Historically, chemical terrorism—a real risk for industrial chemical facilities with toxic materials located near residential areas

because of high impact on both the population and the economy—has had diffuse regulation that has generally been within security management systems. Regulators are aware of these risks but have focused on management approaches rather than the engineering basis of prevention approaches. Neither PSM, RMP, nor CFATS have allowed for consideration of inherently safe design and often have cited as barriers affordability and feasibility of both review and implementation of new technologies—even though there have been multiple recommendations by CSB and industry groups for inherently safer technologies.

Additionally, there is the concern of shifted risk (i.e., to upstream suppliers when reducing the storage of chemicals on-site). In an ideal circumstance, the process or system would first address risk via risk prevention and inherently safe design and then include risk management strategies to control residual risk—thus following the health, safety, and environment (HSE) standard hierarchy of controls (Malloy, 2008).

Risk assessment works when the threat and consequences are well-known; however, when data are unavailable or there is ambiguity due to a complex system, conventional risk analysis works poorly. To address these concerns, comprehensive risk analysis and assessment can be expanded to include prevention and resilience.

Control strategies involve specifying the level of residual risk that is acceptable, which should consider these values of prevention and resilience as well. Furthermore, PSM and RMP are not risk analysis regulations but rather are management-based regulations, requiring a review of what can go wrong and what must be implemented to prevent the release of hazardous chemicals. Both PSM and RMP provide only minimum requirements for process hazard analysis and typically prompt a facility to use generally accepted industry practices.

Additionally, analysis requires data. Data availability, however, can be time- and resource-intensive or completely unavailable. Data gaps generate uncertainty. Some uncertainty can be resolved by collecting information, but this action presumes that the risk analyst understands the potential threats, interactions, and consequences.

Alarms, interlocks, and other engineering controls, while often mandated through

incident investigation or industry best practices, can lead to increased system complexity and therefore unexpected incidents. Prior research has noted that "redundancies and safety systems are the biggest single source of catastrophic failure in complex, tightly coupled systems" (Malloy, 2008). These complex systems also often have a great deal of indeterminacy; humans often act in ways that deviate from analysts' assumptions.

Although U.S. EPA, OSHA, and DHS promote preventive measures, often this guidance does not include substitution, minimization, moderation, or simplification within the regulation; rather, these preventive measures are promoted primarily within industrial best practices. Safety standards heavily promote the hierarchy of control to rank methods of prevention, but OSHA and U.S. EPA have been reluctant to mandate elimination or substitution. Prevention has been treated much more voluntarily.

Within safety and risk management and research, resilience has been pushed—avoiding or minimizing adverse effects by absorbing the event—but it has not been pushed within regulation. A resilient system, however, can bend without breaking and better adapt to a shock. System failures push a system past resiliency and into an incident; a facility or organization can learn from these failures and breaks to build up system resiliency and prevent that "break" from occurring in the same way again.

A strong culture of safety promotes resilience and awareness, allowing mitigation decisions to be made at the operational level. When data are relatively unavailable or unreliable, prevention through resilience mitigates risk by lessening the need for the data. If a safer alternative is available, there is less need for high-cost data.

Moreover, if there are related parameters that can be more easily and quickly monitored, critical points can be identified before a release occurs (using leading rather than lagging indicators). Additionally, restoration beyond immediate response should be addressed. Too often, emergency response ends at first response (e.g., containment, evacuation, shutdown) and does not go further to improve system adaptation and resilience. Adaptation promotes learning both at the system level and organizational level. This approach counters the unknown

unknowns generated by complexity, lack of facts, and indeterminacy.

Instead of “fail-safe” systems, the approach must shift toward a “safe-to-fail” system. Irregular events that are low probability and high consequence must not be excluded from review simply due to low likelihood of occurrence. A perfect storm of events could increase the likelihood of an irregular event through pathways that were previously unknown due to the complexity of the system.

Meaningful integration of these expansions to risk analysis requires significant attention to the promulgation of a new framework for regulatory risk assessment. U.S. EPA has some roots within the Design for the Environment certification program, which focuses on alternatives assessment (i.e., a method for identifying and comparing safer alternatives to materials, processes, or activities). This program, however, is not part of the PSM, RMP, or CFATS program network. Both U.S. EPA and OSHA provide some guidance, though, on risk assessment but virtually none on risk mitigation. Any guidance that does exist is focused on add-ons rather than prevention or resilience-based measures that would require additional attention on core operational strategies.

Even hazard assessment itself could focus more specifically on safer technologies. When designing facilities, the most critical design errors occur within construction materials, protection systems, utilities setup, and/or equipment sizing. Multiple methods have been used to catch these errors. The use of a singular most common method might not encapsulate enough potential risks for evaluation. Of note is the quantity and qual-

ity of data available. To perform a quality risk assessment, data must be available, which can be a sticking point for PSM for estimated risks and unknown unknowns. Risk acceptance is based on inherently safe design standards of minimization, substitution, moderation, and simplification. When a risk bypasses the benchmark action threshold using one of the above indices, safety measures must then be evaluated to determine acceptable residual risk (Husin et al., 2018).

Improved risk assessment and hazard analysis has long been a recommendation for updates to PSM, RMP, and CFATS but has not come into fruition for regulatory updates. Instead, industry groups have taken the lead in pushing for improvements. Assessments and following the hierarchy of control also need to take into consideration the impact of human behavior. Critical risks for PSM, RMP, and CFATS related to human factors often include maintenance integrity, equipment labeling, critical operational procedures, and incident reporting. Critical success factors for program maturity are organizational learning and continuous improvement supported by leadership. Blame, fear, and siloing of information all undermine leadership development and therefore safety management system maturity. Regular employee check-in and testing are recommended for improving maintenance priority and critical operational procedures (Behari, 2019).

Improvements to consider include the redundancy and interdependency of protection factors. Independent protection layers are selected to reduce these blind spots via multiple layers of prevention; however, undefined hazards and inadequate

or degraded independent protection layers could still allow an accident to occur. Human factors (e.g., schedule compression, incorrect timing of checks, stress) also contribute to hazard leak-through and can lead to undetected errors. A lack of expertise can lead to missed hazards or incorrectly assessed hazards, also.

Furthermore, new technology and new designs can also lead to unexpected problems with unknown risks. A well-designed system integrates humans into processes where they are known to perform well and avoids less reliable activities. With continual change, however—which organizations undergo whether or not change is desired—blind spots can continue to be generated in new and unforeseen ways. Similarly, tasks and procedures can exist outside of the known scope and therefore not be assessed for safety and risk (e.g., undocumented repairs and changes implemented from a problem during an unscheduled event or holiday weekend, spare parts not actually meeting “replacement-in-kind” standards, a failure to apply Management of Change or security review processes due to timing).

Time-sensitive decisions exacerbate stress and lead to failures. Red flags can arise from these situations: “We’ve always done it this way,” “I’ve never seen that happen,” or “We don’t have time for that.” These red flags are the “last chance” point to prevent a critical failure (Shephard, 2011) and allow a facility an intervention point before a disaster occurs. 🌸

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