

ChE 59700

Research Report

Comparison of Global PSM Regulations

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Team G2

McKenzie Temme, Aum Patel, Aishwarya Shetye

Executive Summary:

Over the last half century, countries around the world have passed process safety legislation to combat the loss of life and environmental damage caused by bulk chemical releases, fires, and explosions. Unsurprisingly, different countries and regions have adopted different approaches and focused on different aspects despite aiming for the same goal – the reduction of process safety incidents and a decrease in worker deaths due to these incidents.

This report reviews the process safety regulations for six chemical-producing regions: the United States, the European Union, India, China, Japan, and South Korea. Two main approaches to process safety are apparent in this group. The first is the safety case approach championed by the European Union. This approach requires the facility to create a detailed analysis of the process hazards and propose safeguards to reduce the risk to a tolerable level. There are few requirements, but the operational and design choices must be justified by the facility and approved by the regulator.

The second approach is championed by the US and is a blend of prescriptive and performance-based requirements organized into specific programs, frequently called “elements”. This approach is very popular around the globe, with most other countries reviewed having a similar set of process safety elements. Regulators do not proactively review and approve in this approach (with the exception of South Korea), so most regulatory contact is in the form of compliance audits.

A review of global process safety incident data showed two main conclusions. First, process safety regulation does indeed significantly decrease deaths due to serious accidents. This result was most pronounced in countries/regions with strong enforcement and good process safety awareness among industry, further indicating that regulation, when known and followed, is effective.

The second conclusion is that despite process safety regulation driving down deaths, serious process safety incidents continue to occur at an alarming rate around the world. The process safety community should continue to work together to share best practices, increase safety awareness, and promote reasonable government oversight to drive down the rate of process safety incidents in industry.

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Introduction:

Industrial safety regulations are critical for protecting workers, the environment, and public health, especially in high-risk industries like chemical manufacturing. These regulations are designed to reduce risks related to hazardous materials, accidents, and technological failures, ensuring that industries operate in a safe and responsible manner. However, the approach to industrial safety varies across countries, shaped by their legal systems, industrial policies, historical context, and level of economic development. This report provides a comparison of safety regulations for chemical plants and industrial operations in six key regions: the United States, the European Union, India, China, Japan, and South Korea. This report also reviews available process safety incident data to assess whether the regulations are effective and if one method is preferable to another.

Literature Review

Besserman et al (2017) provides an overview of regulations for the US, EU, UK, China and India including history, major incidents, exceptions, and subsectors like critical infrastructure and offshore operations.

Jain, Prerna et al. (2017) compares the main process safety regulatory approaches – the US system vs the safety case. He compares data from the US, UK, Norway, and Australia and concludes that there is no clear winner.

Nakagawa (2019) contrasts the Japanese PSM approach with that of the US and EU. He compares Japanese safety activities to the US CCPS's Risk Based Process Safety elements and makes recommendations for improvements to Mitsubishi's process safety management system.

Yoo, B-T. et al (2023) reviews 130 South Korean process safety incidents and their causes to determine how the PSM program can be improved. He concludes that small and medium sized companies are significantly more likely to have serious accidents and that nearly 70% of process safety reports receive a low rating.

Zhao, Jinsong et al. (2013) reviews the challenges faced by small and medium sized Chinese chemical companies in complying with the relatively new PSM regulations.

Definition of the Problem

As processes become ever more complex and public awareness of industry accidents becomes ever more critical, there is a strong interest in managing and improving process safety legislation. This paper summarizes the main process safety legislation of the United States, the European Union, India, China, Japan, and South Korea. It also contrasts the two main PSM approaches – the European safety case against the US 14 PSM elements. Finally, this paper reviews available process safety incidents data to determine if the US would be best served by switching to the safety case approach.

Analysis

The United States

In the United States, the Occupational Safety and Health Administration (OSHA) is the main process safety regulation. CFR 1910.119 became effective in 1992 and focuses on 14 elements to protect workers while on the company's property. This regulation applies only to facilities exceeding the threshold quantity of listed materials or handling more than 10,000lbs of flammable liquids. The legislation is a blend of prescriptive and performance-based requirements, and it allows the facility a wide degree of choice and self-determination in terms of risk tolerance, risk assessment methodology, and management systems (1, 15).

Compliance to CFR 1910.119 is driven by audits, incident investigations, and fines from OSHA. Notably, OSHA does not review or approve any PSM requirements before operations may start, and existing equipment, processes, etc. are typically considered to be "grandfathered – in" (not required to be updated to new or updated design codes and standards). PSM documentation and records are not submitted to OSHA in any form unless explicitly requested. Therefore, the main interaction with regulators is typically in the form of audits and potentially fines, which can create an adversarial relationship between industry and regulation (15, 19).

The Environmental Protection Agency also plays a role in PSM regulation. The Risk Management Program (RMP) was created in 1996 with the intention of protecting the environment and communities surrounding chemical processing operations. Like OSHA's PSM program, it only applies to facilities exceeding the threshold quantity of listed materials (notably similar to but not identical to OSHA's PSM list). The RMP categorizes processes into three tiers, and most of its requirements (e.g. process hazard analysis) are met by complying with OSHA PSM. Differences from OSHA PSM include defining a worst-case scenario with dispersion modeling and filing this information on the EPA's Central Data Exchange along with risk assessment and maintenance dates prior to receiving the hazardous material onsite. Despite the requirement to file, the EPA does not review or provide feedback on the information; like OSHA PSM, compliance activities are done in the form of audits and incident investigations (1, 14, 17).

The European Union (EU) and United Kingdom (UK)

Europe was an early adopter of process safety legislation with the Seveso Directive enacted in 1982. This legislation saw major updates in 1996, 2003, and 2012 with the most current version referred to as the Seveso Directive III. In addition to following the EU legislation, the UK has its own agency for process safety management - Control of Major

Accidents Hazards (COMAH). Similar to the US, the Seveso Directive legislation covers most hazardous chemicals above a certain quantity but exempts specific industries such as nuclear energy and explosives. Also similar to the US EPA RMP approach, the Seveso Directive categorizes covered processes into “upper tier” (more hazardous) and “low tier” (less hazardous) ratings with different requirements by level (1).

Europe’s process safety management philosophy is based on the idea of the “safety case”, which was developed in Norway in the 1980s and embraced by the UK in the aftermath of the Piper Alpha disaster (2). A safety case is a detailed analysis of the hazards presented by a process and the safeguards identified to reduce or mitigate the risk. The safety case provides less structure than the US approach, but it requires the facility to explain and justify their operational and design choices in detail. Safety cases are reviewed by a regulator and must be accepted. In addition, they draw audit focus to whether or not specified controls are functioning as described in the safety case as opposed to documentation and procedures (a main focus of US audits) (2).

Table 1 below compares the United States’ and the European Union’s approach to process safety regulation.

Table 1 Comparison of the EU's Safety Case vs US's PSM Regulation (2)

Safety Case	US PSM regulations
A risk – or – hazard management framework - Identifying controls to deal with identified hazards and measures taken to ensure continual working of the controls function. A requirement to make the case to the regulator - Company demonstrates process of hazard analysis, and why certain controls are chosen over other. Safety case acceptance provides license to operate. - Regulator can impose higher standard on operators to respond to hazards. A competent and independent regulator - Safety case jurisdiction cannot be enacted. High level of expertise is necessary to accept/reject safety case. - Safety case changes what auditors do on the site visits. Rather than ensuring updated documents/working hardware, they need to ensure if specified control is functioning as intended. Workforce involvement - Employee participation is necessary for development of the case to the regulator. A general duty of care imposed on the operator to reduce risk to 'as low as reasonably practicable' (ALARP) - Provides leverage for regulators. o This is why fire protection standards on rigs in UK waters are higher than those in Gulf of Mexico. - Duty of operator to do whatever practicable to identify and control all hazards. o Operator cannot claim to be in compliance just because it has gone through hazard identification process. - If there is no directly applicable rule, operators still have a duty to manage risk. o They should maintain some reasonable level of risk awareness that goes beyond mere compliance.	Analogous to requirement of PHA by PSM standard - 1910.119 states PHA 'should be appropriate to the complexity of the process and shall identify, evaluate, and control the hazards involved in the process.' - US regulators do not evaluate and pass judgment of hazard management plans before allowing an operation to commence. - Misconception that safety case regulation is abandonment of prescription. - Comments of US offshore safety regulator, James Watson, suggests that the agency does not intend to engage companies in the way that is necessary to impose safety case. - PSM also requires employee participation. SEMS II, which became active in 2013 also requires employee consulting. OSHA requires inspectors to consult employee representatives on site, but no such regulation for offshore. - Blind compliance mentality characterized by Minerals Management Service (MMS) regime. - US OSH Act. Section 5(a)(1) of the Act specifies that employers must provide a workplace that is “free from recognized hazards that are causing or are likely to cause death or serious physical harm.” o Impose a duty on employers only when the hazard is actually causing or likely to cause harm. o There is no rule that unequivocally requires adopting a performance standard.

India

In India, multiple agencies are involved in overseeing process safety requirements: The Ministry of Environment, Forest and Climate Change, the Ministry of Labor and

Employment, and the Directorate General of Factory Advice Service and Labour Institutes (DGFASLI) (11).

Similarly, there are multiple laws governing PSM. The Factories Act of 1948 sets the fundamental standards for protecting the employee's welfare, health, and safety. Chapter IVA addresses hazardous procedures and makes it compulsory for factories to have safety committees and conduct regular health exams. (11). The Environment Protection Act (EPA) of 1986 gives the Indian government the authority to pursue environmental protection actions, such as preventing and lessening chemical mishaps (12). The Manufacture, Storage, and Import of Hazardous Chemicals (MSIHC) Rules of 1989 requires that industries create safety reports, do risk assessments, and make emergency plans for hazardous chemicals both on and off-site (11). The Chemical Accidents (Emergency Planning, Preparedness, and Response) Rules of 1996 requires that Crisis Groups be established for emergency response at the local, district, and state levels (13).

India has a thorough regulatory framework structured for chemical process safety, but its efficiency is hampered by a lack of industry understanding and awareness, especially in smaller facilities. PSM regulation enforcement is limited due to resource constraints and is decentralized, so there is significant variation from state to state (17). India's regulatory structure can be strengthened even more by cooperation with foreign authorities and the sharing of best practices.

China

Of all the countries reviewed, China was the last to enact process safety regulations. The State Administration of Work Safety (SAWS), the main health and safety agency in China, was created in 2005 and its process safety requirements AQ/T 3034-2010 were passed in 2010. SAWS' PSM regulation is heavily modeled on the US's approach, although the Chinese legislation only uses 12 of 14 US elements (Employee Participation and Trade Secrets are excluded) (10). Refer to Figure 1 below for an overview of the Chinese PSM elements.

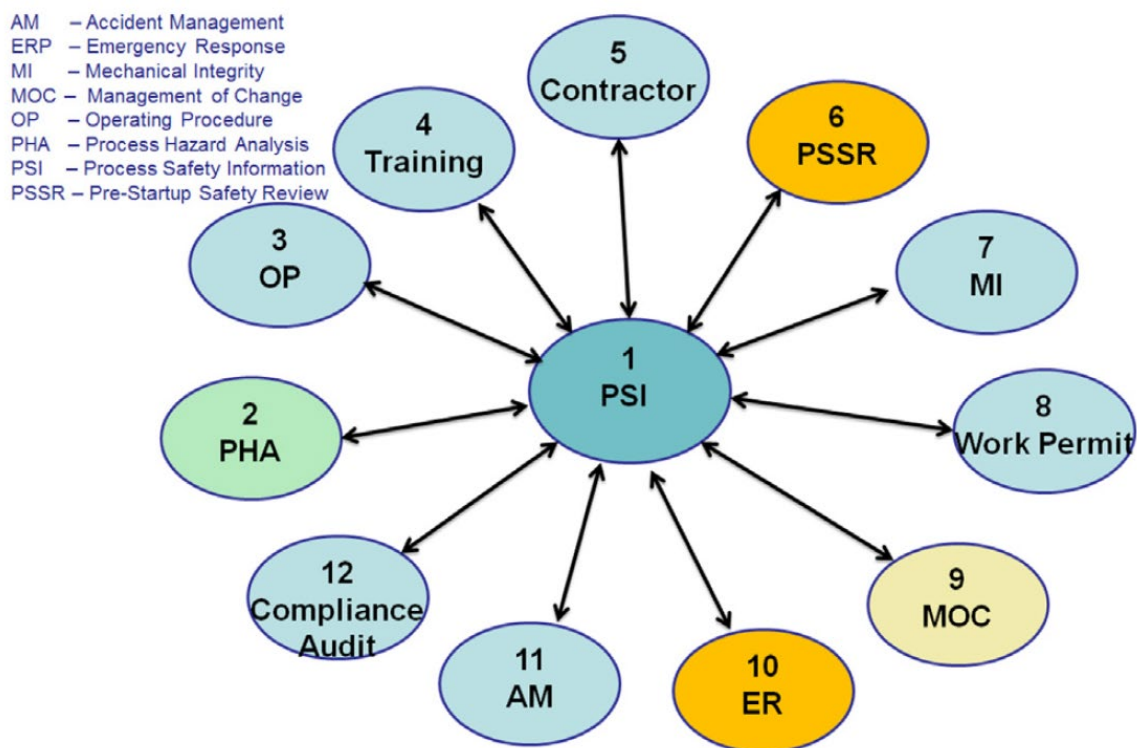


Figure 0-1 The Twelve Elements of the Chinese PSM Regulations (10)

As with other countries' regulations, China's PSM requirements are based on a threshold of quantities of chemicals onsite, meaning that many small and medium sized enterprises (SMEs), especially non-petrochemical facilities like pharmaceuticals, are not officially covered by this legislation. Recognizing that most chemical companies in China are SMEs and therefore likely lack the staffing and financial resources to meet the PSM legislation, the Chinese government encourages SMEs to move into Chemical Industrial Parks (CIPs) to share costs for process safety and environmental management (1).

Japan

The key regulatory framework in Japan is the Industrial Safety and Health Law (ISHL) which intends to control the risks produced by hazardous materials in order to guarantee health and safety in the workplace. This legislation was originally passed in 1972 and identifies chemicals that need safety data sheets and labeling, substances that are not allowed to be produced or imported into the country, and substances that need authorization prior to manufacturing or import. Japan also implemented the Poisonous and Deleterious Substances Control Law (PDSCL) in 1950 to protect the public from a list of specific chemicals. Similar to other process safety regulation, companies must comply with prescribed requirements to store or produce these materials (6).

While most other countries focus on a “top-down” approach to process safety, Japan’s management system is the opposite; refer to Figure 2 below. The EU and US list requirements that must be fulfilled by covered sites. Japan, however, takes a “bottom- up” approach that focuses heavily on small group safety activities at the site level.

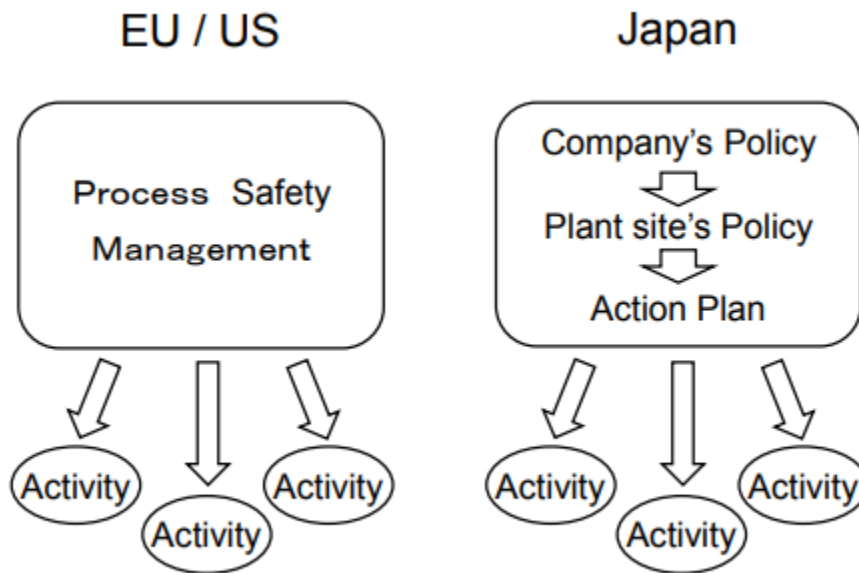


Figure 0-2 Differences in PSM Management Systems (5)

Company and site policy have a major influence on which process safety elements are perceived to be required, and the quality of the program is heavily dependent on the local employees. In theory, internal audits are intended to identify and address any gaps but without a standard program, risks may be missed. Also, Japan’s Kaizen philosophy focused on incremental change may overlook or delay the need for large-scale improvements or innovations (17). Table 2 lists common Japanese safety activities, many of which are similar to OSHA’s PSM elements.

Table 2 Common Japanese “Safety Activities” similar to US PSM Elements (5)

Category	Safety Activity
- Activities directly related to incident prevention	- Education/Training - Hiyari Hatt (HH)Activity - Kiken Yochi (KY) Activity - Patrol - Audit - Safety Assessment - Safety Analysis Procedure - Contractor Management - 5S Activity - Emergency Management - Utilization of Incident Information - Small Group Activity - Operational management - Equipment Management
- Activities to activate individual activities	- Award System - Achievement Presentation - Small Group Activity
- Activities to activate multiple activities	- Recreation

South Korea

South Korea created a PSM system in 1996 as an update to its Industrial Safety and Health Act (ISHA) (9). Supporting legislation includes the Chemicals Control Act (CCA) which mandates chemical accident prevention and lifecycle management. This program is similar to the US approach in that it is organized into 12 “factors”. Similar to the Chinese approach, the US elements of “Trade Secrets” and “Employee Participation” are dropped from the South Korean program (9). Oversight is provided by authorities such as the Ministry of Environment (MOE) and the Ministry of Employment and Labor (MOEL), with support from the National Institute of Chemical Safety (NICS). The system prioritizes emergency preparedness and imposes strict penalties for non-compliance (7).

Preparing and submitting a process safety report is a main requirement of the South Korean PSM program; refer to Figure 3 below for the report components.

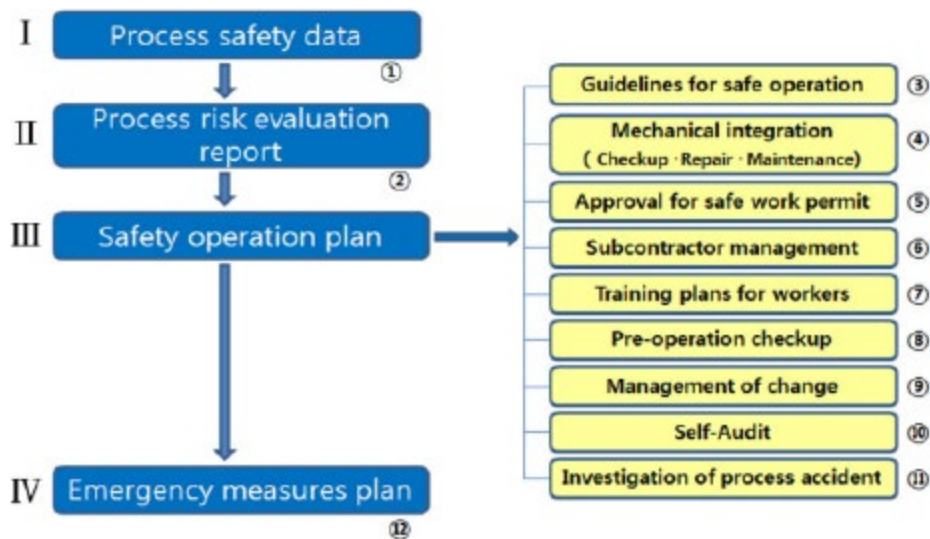


Figure 0-3 Required contents for a South Korean Process Safety Report

Similar to the EU system, this safety report is reviewed and approved by the regulatory agency, receiving one of four grades which determines inspection frequency (7,9). Improving safety report quality is a focus of the South Korean program as more than half of reports fail to receive an “S” or “P” grade. Table 3 shows the South Korean process safety grading system with corresponding inspection frequencies.

Table 3 South Korean Process Safety Report Grading System With Corresponding Inspection Frequency

Grade	Implementing Condition Assessment
P (Progressive) (Excellent)	Inspection once every four years after a rating evaluation
S (Stagnant) (Good)	Inspection once every two years
M+ (Mismanagement) (Normal)	Inspection and consulting once a year
M– (Mismanagement) (Bad)	Inspection twice a year, or inspection once a year

Refer to Table 4 on the next page for a tabulated comparison of the PSM programs for all six countries/regions discussed.

Table 4 Comparison of The PSM Programs Of All Six Countries

	Main Agency (or Agencies)	PSM Legislation and Year Passed	Focus	US model vs Safety Case	Limitations/issues
US	Occupational Safety and Health Administration (OSHA) Environmental Protection Agency (EPA)	CFR 1910.119 effective in 1992 Risk Management Program (RMP) in 1996	Paperwork and documentation Emergency preparedness Enforcement and penalties	Prescriptive and performance-based	Political climate leading to less certain funding Contentious relationship between industry and regulators
EU	Member states responsible for enforcement	Seveso Directive III (current) 1982 with updates in 1996, 2003, and 2012	Transparency/accountability Harmonization of standards to promote consistency across members states	Safety Case	Requires highly trained and specialized regulators to review/approve safety cases
China	State Administration of Work Safety (SAWS)	AQ/T 3034-2010 (SAWS PSM) in 2010	Large facilities Punishment rather than prevention	Very similar to US model, Has 12 elements but excludes Employee Participation and Trade Secrets	Small and medium facilities often not covered by the legislation but known to have high accident rates
India	Ministry of Labor and Employment The Ministry of Environment, Forest and Climate Change Directorate General of Factory Advice Service and Labor Institutes (DGFASLI)	Factories Act in 1948, updated in 1987 in response to Bhopal tragedy Environmental Protection Act (EPA) in 1986	Crisis management Environmental preservation Worker Safety	Incorporates elements of both but approach is closer to the US model	Limited resources for inspections and monitoring State-level implementation that is inconsistent Low awareness among small-scale industry
Japan	Japan Industrial Safety and Health Association (JISHA)	1972 Industrial Safety and Health Act (ISHL) 1950 Poisonous and Deleterious Substance Control Law (PDSCCL)	Employee participation Local control (bottom-down approach)	Safety Activities similar to US elements	Different aspects of chemical management are overseen by several government agencies resulting in overlaps and the potential for miss some risks
South Korea	Ministry of Employment and Labor (MOEL)	Industrial Safety and Health Act (ISHA) 1996 The PSM Standard	Emergency preparedness	Based on US model, has 12 "factors" Safety reports reviewed and approved like EU Safety Case	Many subcontractor deaths Only 5% of covered sites receive desired "passing" grade, half of sites are deemed low grade/high risk

Which Approach Is Best?

Looking over these programs, there are two main philosophies for process safety regulation. The US champions one style – the blend of prescription and performance-based requirements. This style typically details out “elements” for required programs like Mechanical Integrity, Process Hazard Analysis, and Process Safety Information. The US system has 14 elements, and routine enforcement focuses on documentation related to each of these requirements.

The second main approach is the safety case, championed by the European Union. This approach provides less structure and requires the operator to argue their case for why their operation is sufficiently safe. Regulators must have a high level of technical expertise as safety cases must be reviewed and approved, and they may require additional or modified safeguards. Enforcement focuses on verifying specific controls required by the safety case. Refer to Figure 2 below for a visual comparison of the two approaches.

While the approaches are different, both require a risk assessment, employee involvement, and have a general duty clause requiring employers to provide a workplace safe from reasonable risks.

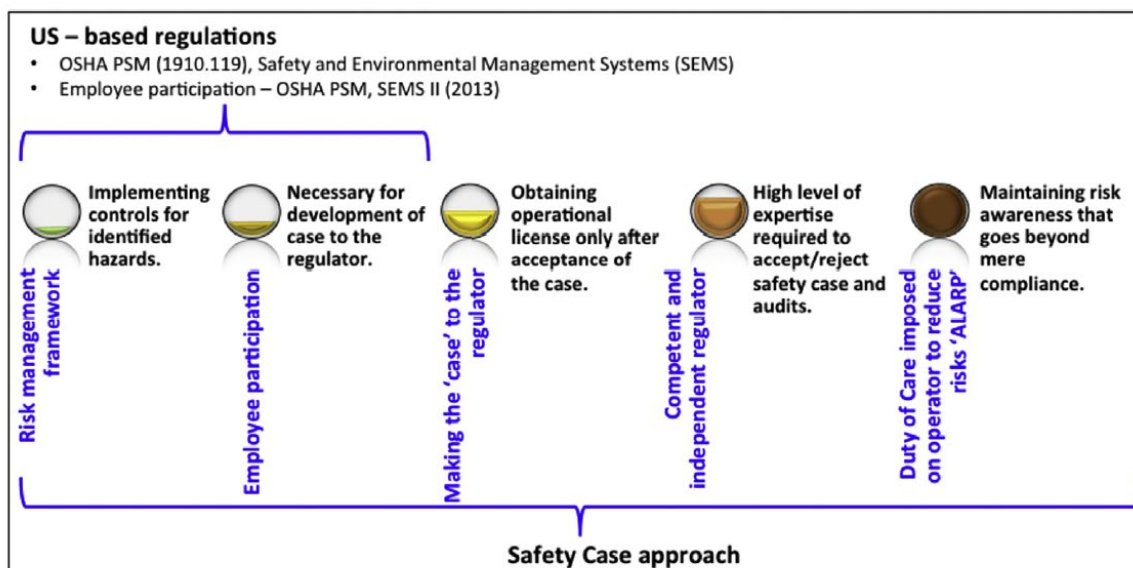


Figure 0-4 Visual Comparison of US vs Safety Case Approach (2)

But is the process safety legislation effective? And is one approach more effective than the other? This team reviewed data compiled from CHE 597 Process Safety Incident Investigations and the Marsh 100 Largest Losses report in an attempt to address these two questions. Despite the benefit of this large data set, it should be noted that the data set shows a clear preference for American and European incidents with far fewer investigations done outside of these regions. It is believed that while the data is not exhaustive, general trends are apparent. Note that multi-year chemical releases, nuclear events, and airplane crashes were excluded from the data set as these were difficult to assign a year or have additional specific regulation. As the data set did not include any pre-regulation incidents in Japan and only one incident total in South Korea, additional assessment of these countries was done separately. The summarized data is shown below in Table 5. Refer to the appendix for the complete dataset.

Table 5 Process Safety Incident Data By Country/Region

		Incident Count	Fatalities	Fatalities / Incident	Average Cost	Public Impact
United States	Pre-reg	30	1,864	62.13	\$701 million	100%
	Post-reg (1992)	97	136	1.40	\$185 million	40%
EU	Pre-reg	10	797	79.70	\$148 million	100%
	Post-reg (1982)	42	183	4.36	\$595 million	60%
India	Pre-reg	1	3787	3787	\$60 million	100%
	Post-reg (1982)	4	102	25.50	\$121 million	75%
China	Pre-reg	4	271	67.75	\$1.96 billion	100%
	Post-reg (2010)	8	541	67.63	\$1.17 billion	100%
Japan	Pre-reg	-	-	-	-	-
	Post-reg (2010)	7	10	1.43	\$282 million	86%
South Korea	Pre-reg	-	-	-	-	-
	Post-reg (2010)	1	5	5	\$33.4 million	100%

The data from these global incidents does appear to show that fatalities per incident goes down after process safety regulation is in place for all countries with available data. There is also some indication that process safety regulation is successful at reducing the number of incidents with off-site impact. These improvements are least obvious in China, where process safety regulation has been in place for less than 15 years.

While lethality of incidents does appear to go down, the economic impact of process safety incidents does not appear to be decreasing, nor does the number of process safety incidents. Process safety regulation appears to be most effective at reducing human deaths and offsite impact, but less effective at reducing the number of process safety incidents or their financial impact.

As to which methodology is best, it is hard to draw any kind of conclusive winner. The US data shows a lower fatality rate, lower cost, and lower likelihood of off-site impact,

but given that the US dataset contains more than twice as many incidents, it likely includes a significant number of lower-severity events than the European dataset. As the US and EU values are the same order of magnitude, they will be treated the same as within reasonable error. Additionally, the Japanese and South Korea values appear to be in line, indicating similarly effective regulation despite their differences in approach. China and India do stand out for higher fatalities/incident, possibly indicating that their regulation is less effective overall. This may not be due to the laws in themselves but to additional factors such as a higher rate of non-compliance (possibly due to lack of resources in smaller-sized operations) and/or corruption.

As the main dataset contained few incidents for Japan and South Korea, additional data was sought to assess the effectiveness of their regulations. Per Figure 5 below, Japan's 1972 legislation does appear to be effective at reducing on-the-job injuries and deaths, although it is not clear what fraction of these incidents are process safety related as opposed to personal safety. It is also notable that manufacturing injury and death rates in Japan did not decrease as much as general industry during this time period (8).

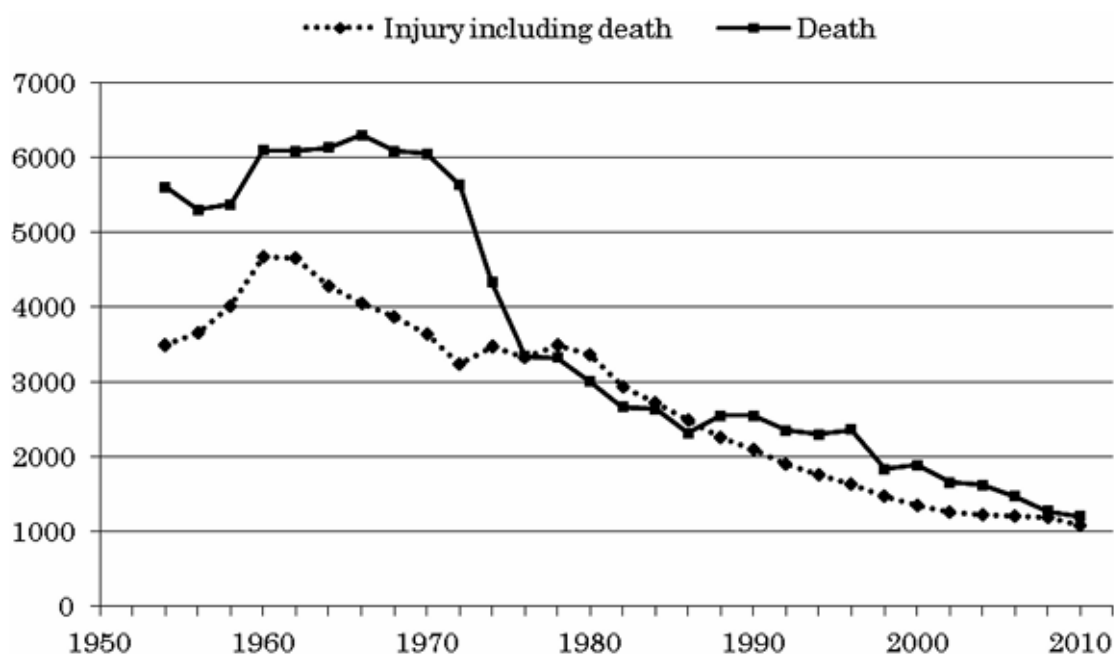


Figure 0-5 Number of Workplace Deaths and Injuries in Japan (8)

Of all six countries reviewed, South Korea was the only one without an incident on the Marsh 100 Largest Losses List (Mentzer), and recent chemical industry death rates are inline with those for the US and EU. Similar to the aggregate data, South Korea's process safety regulation does not appear to be driving down the total number of process safety

incidents, and South Korea sees a disproportionately high incidence of subcontractor deaths (Jung). Refer to Table 6 for a count of recent South Korean process safety incidents and contractor deaths.

Table 6 South Korean Contract Worker Deaths (Jung)

Analysis of deaths from chemical accidents from January 2008 to June 2018.

Year	Number of accidents	Deaths of principal contract workers	Deaths of subcontract workers
2008	6	3	0
2009	4	1	0
2010	5	0	6
2011	3	9	0
2012	5	12	3
2013	5	1	6
2014	11	1	2
2015	11	2	6
2016	11	3	3
2017	4	0	0
2018.6	6	5	0

Conclusions

In conclusion, process safety regulation saves lives. The rate of fatalities per incident has gone down in countries that have process safety regulation, especially in countries with effective enforcement. While it does save lives, process safety legislation does not appear to be significantly effective at eliminating process safety incidents from occurring.

Reviewing the data between these six countries/regions, it does not appear that any one method is superior to the other. Training and awareness programs, especially for smaller facilities with limited resources, and consistent enforcement anecdotally appear to be better predictors of effective process safety regulation than whether a safety case or PSM elements are required.

Recommendations

There is no hard evidence that switching to the safety case approach would be beneficial to the United States, and such a change would require significant financial and political effort. The United States should focus any improvement efforts on reasonable updates to its existing 14 PSM element program, which has been effective at reducing the impact of process safety events in the United States.

On a global level, the process safety community should work together to share best practices and promote reasonable regulatory oversight to continue to save lives and decrease the rate of serious process safety incidents.

Appendix

Mentzer, Prof. Ray. (2024). Selected dataset

United States Incidents (page 1 of 2)

Name of Incident	Year	Type of Operation	Fatalities	Country	RC#1	RC#2	Economic Loss (\$M)	Public Impact	Source	After PSM Regulation (1992)
*Accra Pac - N. Plant	1997	Manufacturing	1	US	Design	PM		Y	Mentzer Students	YES
*CITGO Lake Charles Refinery	2006	Refinery	0	US	OP	ER	\$20	Y	Mentzer Students	YES
*El Dorado Chem Plant, tx	2009	Chem	0	US	WP	Contr		Y	Mentzer Students	YES
*Honolulu molasses spill	2013	Manufacturing	0	US	MI	PM	\$20	Y	Mentzer Students	YES
*Liquid Transport Terminals	2015	Chem	1	US	WP	PHA		Y	Mentzer Students	YES
*Trinseco	2023	Manufacturing	0	US	PM	SC	\$2.70	Y	Mentzer Students	YES
*Washburn Mill Explosion	1878	Agriculture	18	US	SC	Regs	\$27	Y	Mentzer Students	No
*Westlake Chemical	2022	Chemical	0	US	HW	SC	\$10	Y	Mentzer Students	YES
Advanced Laboratories	1988	Chemical		0 US	PHA	ER	\$3.20	Y	Mentzer Students	No
Alon Refinery	2008	Refinery	0	US	PM	MI	\$380	Y	Mentzer Students	YES
Angus Chemical Plant - Sterlington, LA	1991	Chemical		8 US	MI	PM	\$120	Y	Mentzer Students	No
ARCO Chemicals	1990	Chemical		17 US	PM	SC	\$100	Y	Mentzer Students	No
Bartlett Grain Elevator	2011	Agriculture	6	US	SC	PT		Y	Mentzer Students	YES
Belpre, Ohio, US	1994	Petrochemicals	3	US	OP	PHA	\$182	Y	Marsh Report	YES
Big Benton Fireworks	1983	Manufacturing		11 US	Regs	SC		Y	Mentzer Students	No
Big Spring, Texas, US	2008	Refining		US	Natural Disaster	ER	\$380	Y	Marsh Report	YES
Boeing 737	2018	Aerospace	173	US	Design	PT		Y	Mentzer Students	DROP
Boeing 737	2019	Aerospace	173	US	Design	PT		Y	Mentzer Students	DROP
BPS Fire W. Helena, AR	2022	Storage	3	US	OP	Design		Y	Mentzer Students	YES
Buffalo Creek Slurry Dam	1972	Mining		125 US	SC	Design		Y	Mentzer Students	No
Caribbean Petr	2009	Refinery	0	US	HF	PM		Y	Mentzer Students	YES
Cedar Bayou, Texas, US`	1994	Petrochemicals	2	US	Siting	Natural Disaster	\$130	Y	Marsh Report	YES
Celanese Butane VCE, Pampa, Texas	1987	Chemical		3 US	HF	Design	\$215	Y	Mentzer Students	No
Challenger space shuttle disaster	1986	Aerospace		7 US	SC	MI	\$3,200	Y	Mentzer Students	No
Colonial Pipeline Leak	2016	Pipeline	0	US	SC	MI	\$3.30	Y	Mentzer Students	YES
Columbia Space Shuttle	2003	Aerospace	7	US	SC	MI	\$6	Y	Mentzer Students	YES
Desert Whale Jojoba Co	2017	Chemical	0	US	MOC	SC		Y	Mentzer Students	YES
Diamond Bar - Air Products	2018	Oil and Gas/Upstream	0	US	MI	OP	\$175	Y	Mentzer Students	YES
Dow, Freeport Inc	1966	Chemical		3 US	PHA	MOC	\$300	Y	Mentzer Students	No
DuPont PFOA	1951-2004	Chemical		US	SC	PHA	>\$1B	Y	Mentzer Students	DROP
East Ohio Gas Co	1944	Storage		130 US	Siting	MI	\$105	Y	Mentzer Students	No
Eastman Chemical	2017	Chemical	0	US	PM	OP	\$75	Y	Mentzer Students	YES
Eastman Chemical, Kingsport	1960	Chemical		16 US	MOC	PHA	\$46	Y	Mentzer Students	No
Exxon Valdez	1989	Shipping/Boat		0 US	SC	OP	\$4,300	Y	Mentzer Students	No
Falk Corp explosion, Milwaukee	2006	Manufacturing	3	US	PM	MI	\$72	Y	Mentzer Students	YES
Freedom Industries	2014	Storage	0	US	PM	ER	\$151	Y	Mentzer Students	YES
Gold King Mine	2015	Mining	0	US	PHA	MOC	\$18	Y	Mentzer Students	YES
Great Molasses Flood	1919	Storage		21 US	MI	PHA	\$100	Y	Mentzer Students	No
Hurricane Creek Mine Disaster	1970	Mining		38 US	SC	OP		Y	Mentzer Students	No
JCG Farms Feed Mill Explosion & Fire	2016	Agriculture	1	US	SC	OP	\$3	Y	Mentzer Students	YES
Kingston, Fossil Plant	2008	Power plant (Non Nuclear)	40	US	SC	OP	\$1,200	Y	Mentzer Students	YES
Lemont, Illinois, US	2001	Refining	1	US	MI	Design	\$285	Y	Marsh Report	YES
Limetree Bay Refinery	2021	Refinery	0	US	SC	PHA	\$813	Y	Mentzer Students	YES
Love Canal	1970	Chemical		725 US	Regs	OP	\$400	Y	Mentzer Students	No
Marcus Hook, Pennsylvania, US	1975	Terminals	29	US	Work Permit	OP	\$50	Y	Marsh Report	No
Medford, Oklahoma, US (July 2022)	2022	Gas Processing		US	OP	MI	\$425	Y	Marsh Report	YES
Natchitoches Pipeline Expl	1965	Pipeline		17 US	PM	MI		Y	Mentzer Students	No
Pascagoula, Mississippi, US	2007	Refining	1	US	PM	MI	\$200	Y	Marsh Report	YES
Peak Shaving LNG Explosion	2014	Oil and Gas/Upstream	0	US	OP	PM	\$69	Y	Mentzer Students	YES
Pepcon, Henderson, Nevada	1988	Chemical		2 US	OP	ER	\$300	Y	Mentzer Students	No

United States Incidents (page 2 of 2)

Name of Incident	Year	Type of Operation	Fatalities	Country	RC #1	RC #2	Economic Loss (\$M)	Public Impact	Source	After PSM Regulation (1992)
PG&E San Bruno Pipeline Explosion	2010	Pipeline	8	US	MI	ER	\$220	Y	Mentzer Students	YES
Phillips 66, Pasadena, TX	1989	Chemical	23	US	PHA	CONT	\$750	Y	Mentzer Students	No
Plain All-Amer P/L (Refugio leak)	2015	Pipeline	0	US	MI	PM	\$335	Y	Mentzer Students	YES
Plaquemine C12 Leak	2022	Chemical	0	US	OP	SC		Y	Mentzer Students	YES
Port Arthur, Texas, US	2006	Petrochemicals		US	PHA	PM	\$200	Y	Marsh Report	YES
Port Neches, Texas, US (November 2019)	2019	Petrochemicals		US	PHA	Regs	\$380	Y	Marsh Report	YES
Ray Compressor Station Fire	2019	Other	0	US	OP	Design	\$26	Y	Mentzer Students	YES
Richmond, California, US	1989	Refining		US	MI	PM	\$90	Y	Marsh Report	No
Santa Barbara spill	1969	Oil and Gas/Upstream	0	US	PHA	ER	\$51	Y	Mentzer Students	No
Shell Deer Park	1997	Refinery	0	US	MI	OP	\$135	Y	Mentzer Students	YES
Shell Martinez	2018	Refinery	0	US	PM	MI		Y	Mentzer Students	YES
Shell Norco refinery, LA	1988	Refinery	7	US	MI	PM	\$665	Y	Mentzer Students	No
Terra Industries - Port Neal	1994	Fertilizer	4	US	OP	PHA	\$203	Y	Mentzer Students	YES
Texas City, Texas, US	1978	Refining		US	MI	PM	\$55	Y	Marsh Report	No
Thiokol Woodbine explosion	1971	Manufacturing	29	US	PHA	OP	\$718	Y	Mentzer Students	No
Three Mile Island	1979	Power Plant (Nuclear)	0	US	PT	Design	\$6,000	Y	Mentzer Students	No
Times Beach	1971	Chemical	0	US	SC	PHA	\$110	Y	Mentzer Students	No
Titon II explosion	1980	Other	1	US	HF	ER	\$245	Y	Mentzer Students	No
TX City disaster	1947	Shipping/Boat	581	US	PHA	SC	\$33	Y	Mentzer Students	No
Union Oil Explosion in Romeoville	1984	Refinery	17	US	MI	PM	\$191	Y	Mentzer Students	No
Westwego, LA grain elevator expl	1977	Agriculture	36	US	SC	Design	\$55	Y	Mentzer Students	No
Winstom Salem Fertilizer Fire	2020	Manufacturing	0	US	SC	Design	\$2	Y	Mentzer Students	YES

Indian Incidents

Name of Incident	Year	Type of Operation	Fatalities	Country	RC #1	RC #2	Economic Loss	Public Impact	Source	After Factories Act updated (1987)
Bhopal Gas Tragedy	1984	Chemical	3787	India	PM	ER	\$60M	Y	Mentzer Students	No
Visakh refinery	1997	Refinery	56	India	SC	MI	\$15	Y	Mentzer Students	YES
IOCL Storage Explosion	2009	Storage	12	India	MI	SC	\$93	Y	Mentzer Students	YES
Viskhapatnam LG Polymers	2020	Chemical	12	India	SC	PHA	\$6.30	Y	Mentzer Students	YES
Mumbai High North Field, India	2005	Upstream	22	India	OP	PHA	\$370	N	Marsh Report	YES

Chinese Incidents

Name of Incident	Year	Type of Operation	Fatalities	Country	RC #1	RC #2	Economic Loss	Public Impact	Source	After PSM regulation (2010)
South China Sea	2009	Upstream		China	Natural Disaster	MI	\$191	N	Marsh Report	No
*Chuandongbei Oil Field	2003	Oil & Gas / Upstream	233	China	SC	OP		Y	Mentzer Students	No
Jilin Chemical Plant	2005	Chemical	6	China	SC	ER	\$3,700	Y	Mentzer Students	No
Qinghe Special Steel Corp	2007	Manufacturing	32	China	Design	SC		N	Mentzer Students	No
Chengdu Plant Explosion	2011	Manufacturing	3	China	Regs	SC	\$5,000	Y	Mentzer Students	YES
Qingdao, China pipeline	2013	Pipeline	62	China	PM	PHA	\$100	Y	Mentzer Students	YES
Zhongrong Metal Production Dis	2014	Manufacturing	146	China	PT	Regs		Y	Mentzer Students	YES
Tianjin explosion	2015	Storage	173	China	SC	Regs	\$1,100	Y	Mentzer Students	YES
Tenglong Aromatics Explosion	2015	Chemical	50	China	PT	PM		Y	Mentzer Students	YES
Jin YU Petrochemical	2017	Chemical	10	China	OP	PHA	\$6.50	Y	Mentzer Students	YES
Yibin Hengda	2018	Chemical	19	China	SC	OP	\$6.20	Y	Mentzer Students	YES
Jiangsu Plant Expl	2019	Chemical	78	China	SC	Regs	\$800	Y	Mentzer Students	YES

European Incidents

Name of Incident	Year	Type of Operation	Fatalities	Country	RC #1	RC #2	Economic Loss	Public Impact	Source	After Seveso Directive (1982)
*Amoco Cadiz	1978	Shipping/Boat	0	France	MI	MOC	\$85	Y	Mentzer Students	No
*Brenntag GmbH	2007	Storage	1	Germany	HF	PHA	\$0.11	Y	Mentzer Students	YES
*Evangelos Florakis Naval Base	2011	Storage	13	Cyprus	SC	ER	\$3,000	Y	Mentzer Students	YES
*Lubrizol France	2019	Manufacturing	0	France	SC	OP	\$50	Y	Mentzer Students	YES
*M.V. Betelgrusa	1979	Shipping/Boat	50	Ireland	PM	ER	\$120	Y	Mentzer Students	No
Ajka Alimir spill	2010	Manufacturing	10	Hungary	OP	PM	\$456	Y	Mentzer Students	YES
Antwerp, Belgium (October 1975)	1975	Petrochemicals	6	Belgium	MI	Design	\$60	Y	Marsh Report	No
B&R Hauliers	1982	Storage	0	UK	HF	SC		Y	Mentzer Students	YES
Baia Mare Cyanide Spill	2000	Mining	0	Romania	PHA	Design	\$170	Y	Mentzer Students	YES
Bantry Bay, Ireland	1979	Terminals	50	Ireland	PM	OP	\$70	Y	Marsh Report	No
BASF, Oppau	1921	Fertilizer	561	Germany	MOC	PHA	\$26	Y	Mentzer Students	No
Buncefield	2005	Storage	0	UK	PM	SC	\$1,200	Y	Mentzer Students	YES
Chemical PARK Expl	2021	Chemical	7	Germany	PM	PHA		Y	Mentzer Students	YES
Chevron Pembroke	2011	Refinery	4	UK	SC	OP		Y	Mentzer Students	YES
Conoco Phillips Humber refinery	2001	Refinery	0	UK	MOC	MI		Y	Mentzer Students	YES
Dutch States Mines	1975	Refinery	14	Netherlands	Design	OP	\$50	Y	Mentzer Students	No
Enschede Fireworks, Netherlands	2000	Manufacturing	22	Netherlands	Design	Regs	\$428	Y	Mentzer Students	YES
Explosion at Grove Park Mills, Maryhill, G	2004	Manufacturing	9	UK	PHA	PM		Y	Mentzer Students	YES
Feyzin	1966	Refinery	18	France	PT	ER	\$70	Y	Mentzer Students	No
Flixborough, England	1974	Chemical	28	UK	MOC	SC	\$500	Y	Mentzer Students	No
Ghisleghein	2004	Pipeline	24	Belgium	ER	PM	\$130	Y	Mentzer Students	YES
Hickson @ Welch	1992	Chemical	5	UK	PHA	OP		Y	Mentzer Students	YES
ICL Plastics	2004	Manufacturing	9	Scotland	SC	PM		Y	Mentzer Students	YES
Instantbul fireworks explosion	2008	Manufacturing	22	Turkey	SC	OP		Y	Mentzer Students	YES
IQOXE	2020	Chemical	3	Spain	PHA	MOC	\$100	Y	Mentzer Students	YES
La Mède, France	1992	Refining	6	France	MI	ER	\$225	Y	Marsh Report	YES
Lune-Wyre S Chemicalo	1984	Other	16	UK	Design	OP		Y	Mentzer Students	YES
Poole Expl	1988	Chemical	0	UK	SC	PHA		Y	Mentzer Students	YES
RAF Fault Munitions Explosion	1944	Storage	70	UK	SC	OP		Y	Mentzer Students	No
Sandoz Chemical Spill, Switzerland - fire &	1986	Storage	0	Switzerland	OP	SC	\$55	Y	Mentzer Students	YES
Sannazzaro de Burgondi, Italy	2016	Refining		Italy	OP	PM	\$325	Y	Marsh Report	YES
Seest Fireworks Incident	2004	Manufacturing	1	Denmark	OP	ER	\$118	Y	Mentzer Students	YES
Seveso	1976	Chemical	0	Italy	PHA	ER	\$350	Y	Mentzer Students	No
Toulouse Fertilizer	2001	Chemical	31	France	PHA	SC	\$1,900	Y	Mentzer Students	YES
Vohburg, Germany (September 2018)	2018	Refining		Germany	MI	MI	\$770	Y	Marsh Report	YES
Windscale fire nuclear disaster, UK	1957	Power Plant (Nuclear)	240	UK	Design	ER	\$91,000	Y	Mentzer Students	DROP

Japanese Incidents

Name of Incident	Year	Type of Operation	Fatalities	Country	RC #1	RC #2	Economic Loss	Public Impact	Source	After PSM Regulation
Sodegaura, Japan	1992	Refining		Japan	MI	OP	\$161	Y	Marsh Report	Yes
Niigata, Japan (March 2007)	2007	Petrochemicals	1	Japan	PM	PHA	\$240	Y	Marsh Report	Yes
Sendai, Japan	2011	Refining		Japan	Natural Disaster	Design	\$590	N	Marsh Report	Yes
Tokaimura Criticality Incident	1999	Manufacturing	2	Japan	SC	OP	\$136	Y	Mentzer Students	Yes
Fukushima tsunami nuclear	2011	Power Plant (Nuclear)	574	Japan	PHA	ER	>\$100B	Y	Mentzer Students	DROP
Nippon Shokudai, Himeji plant	2012	Chemical	1	Japan	Design	PHA		Y	Mentzer Students	Yes
Mitsui Chemical Plant	2012	Chemical	1	Japan	PT	OP		Y	Mentzer Students	Yes
Mitsubishi Materials	2014	Chemical	5	Japan	PHA	SC		Y	Mentzer Students	Yes
Minamata Mercury Poisoning	1951-2011	Chemical	900	Japan	SC	Regs	\$2.83B	Y	Mentzer Students	DROP

South Korean Incidents

Name of Incident	Year	Type of Operation	Fatalities	Country	RC #1	RC #2	Economic Loss	Public Impact	Source	After PSM Regulation?
Hube Global; Gumi HF Leak	2012	Chemical	5	S Korea	SC	ER	\$33.4 M	Y	Menzter Students	YES

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