A Review of the 2012 Reynosa Gas Plant Explosion

An ioMosaic White Paper

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Introduction

On September 18, 2012, a major fire and explosion ripped through a gas plant in Reynosa, Mexico resulting in 31 fatalities and many injuries. The incident was caught on Closed Circuit Television (CCTV) and has been viewed millions of times on social media sites such as YouTube. The video clip is particularly useful to process safety practitioners as it demonstrates the various hazardous outcomes that can result from one individual loss of containment event. In the case of this incident, it is possible to see the initial pressure wave, followed by turbulent momentum jet dispersion, then a flash fire and jet fire, as well as shrapnel projectiles.

This paper reviews the potential causes leading to the incident, as well as summarizing the lessons that can be learned from the video clip. Additionally, it emphasizes the need for a complete and thorough Process Safety Management program.

One motivating factor in writing this paper is the apparent lack of publicly available information and reports addressing this incident. Further research still confirmed the lack of readily available information, from either English or Spanish language sources. This paper therefore presents the opinions of the authors, based on the limited information and conclusions we were able to derive.

Incident Description

The major fire and explosion occurred at a gas plant near the city of Reynosa, Tamaulipas, which is located very near the US-Mexico border. The incident is regarded as one of the worst industrial accidents in Mexico's history, and left catastrophic damages and thirty-one fatalities.

Figure 1 – Still Footage From The Video Clip

Facility Description

The incident occurred in a natural gas processing unit section of the Central de Medicion KM-19 (Central Metering Station KM-19), located in the Reynosa suburb of Providencias. Natural gas metering stations are typically designed for simultaneous, continuous analysis of the quality and quantity of natural gas being transferred through a pipeline, by measuring properties such as upper calorific value, concentration of sulfur compounds, hydrocarbon dew point, and water dew point. Additionally, the processing unit typically separates natural gas from impurities, condensate, non-condensable fluids, acid gases and water while controlling the delivery pressure.

The unit, which distributed extracted natural gas from the Burgos Basin, handled about 900 MM ft^3 of natural gas per day. The processed natural gas from this plant is the main supply for many states in Mexico. The treatment process interstage pressure of a natural gas compressor such as may be found in this facility normally operates in the range of 300 psig - 400 psig.

Figure 2 shows the facility main entrance, while Figure 3 shows an aerial view of the affected area, including the locations of the cameras which recorded the incident (labelled here as Camera 1 and Camera 2).

Figure 2 – Facility Entrance

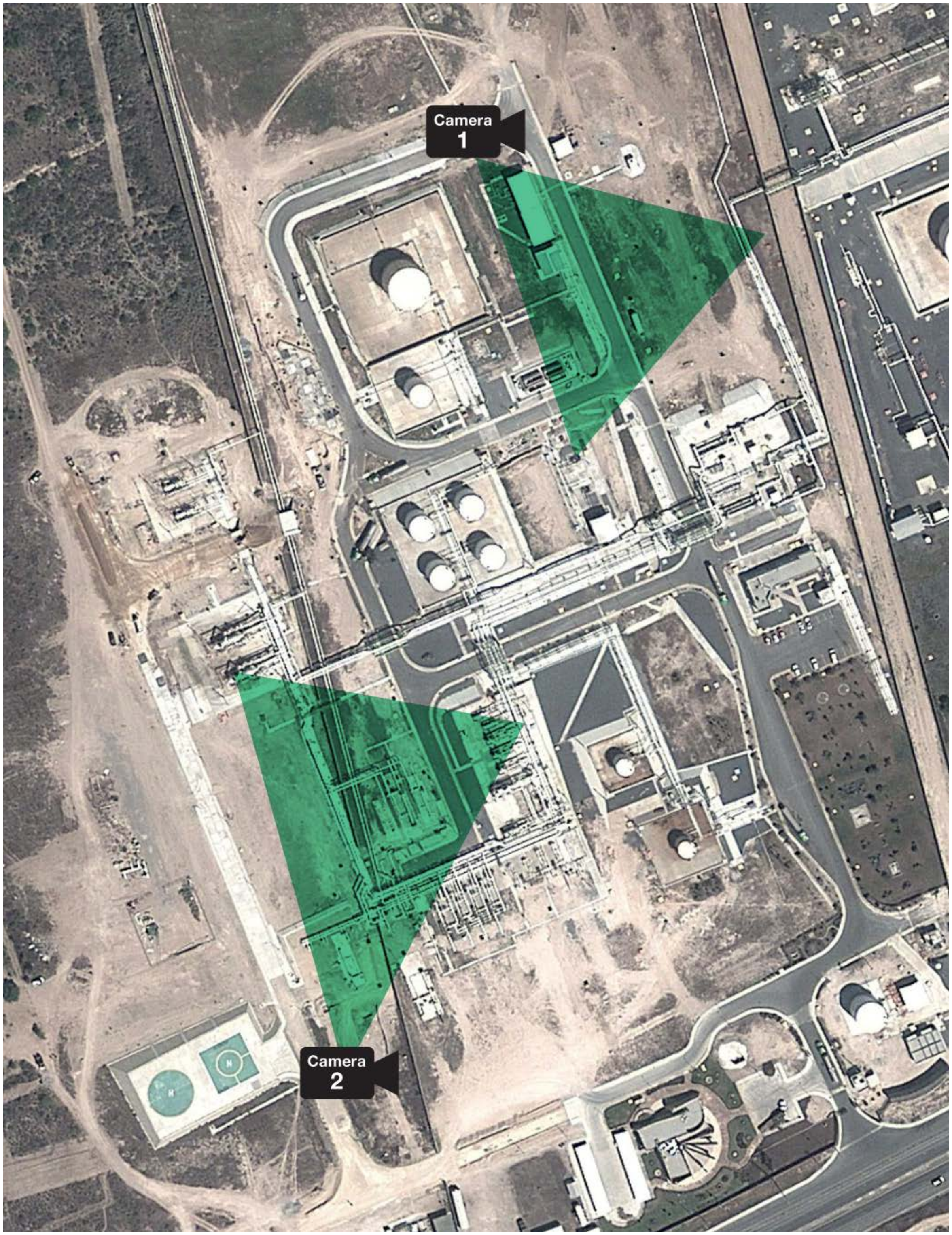

Figure 3 – Aerial View of Affected Area, with Location and Direction of Cameras Which Recorded the Incident.

Incident Description

The incident was caused by a pipeline rupture that turned into a flash fire and jet fire. As shown in the video, the incident escalated extremely rapidly leaving no chance for those caught in the vapor cloud and subsequent flash fire, which extended approximately 500 feet (150 meters).

Pipeline ruptures are typically attributed due to factors such as physical damage, age, condensation, temperature-related stress, and material failure.

Incident Investigation

A large majority of the victims were not direct employees of the operating company and were working for contractor companies. Immediately after the incident, this raised questions of whether the personnel were truly qualified to perform the technical duties required for the facility.

Shortly after the explosion, Carlos Morales Gil, the then General Director of the refinery, expressed that there were two major concerns regarding the explosion. The first concern was the possibility of a “sabotage or a botched attempt at fuel theft.” The second concern was the potential pipe rupture as cause of the explosion. Carlos Morales Gil later determined that “The primary cause is the rupture of a duct [pipeline] that carries gas from our site. This is where we measure the fuel before turning it over to our clients.”

During the investigation, questions arose regarding the integrity of the tanks and instruments. However, these issues weren’t directly addressed by refinery representatives and they redirected any instrumentation or safeguard questions to the rupture of the duct [pipeline].

The investigation was solely being conducted by the Attorney General of the Republic (PGR). Additionally, the Secretary of Energy (SENER), Secretary of Labor and Social Security (STPS), the Secretary of Public Function (SFP) and the Federal Attorney for Environmental Protection (PROFEPA) could conduct inspection visits to review the degree of compliance with the applicable regulations on the affected installations.

Additionally, to mitigate the impact on the supply of natural gas to the National Gas Pipeline System (SNG), a Coordination Commission for the Natural Gas Supply was formed. The Coordination Commission for Natural Gas Supply consisted of the Secretary of Energy (SENER), Exploration and Production (PEP), Gas and Basic Petrochemicals (PGPB), the Corporate Management of the Refinery, the Federal Electricity Commission (CFE), the Energy Regulatory Commission (CRE) and the National Hydrocarbons Commission (CNH). This interinstitutional groups' main objective was to maintain the conditions of the Natural Gas Supply, applying actions to maintain the natural gas supply, such as maximizing the use of the import infrastructure, as well as the increase in natural gas injection by the Exploration and Production refinery to different parts of the country.

While the initial investigation efforts and thoughts were well-publicized, the conclusions derived were not so well broadcast. A literature and internet document search has not revealed any publicly available incident investigation reports and conclusions.

Consequence Analysis

The video footage of the incident in Reynosa dramatically showed how multiple consequences can arise from one loss of containment scenario.

The video shows how the release transitions through the following consequences:

- Vessel / Pipe Burst (Shrapnel)
- Pressure Wave
- Dispersion Cloud (Turbulent Jet)
- Flash Fire
- Jet Fire

In the case of a flammable gas release such as the one in Reynosa, if immediate ignition does not occur and the high-pressure releases are not confined, the jet will continue to disperse until delayed ignition occurs or the release ends. Under these circumstances the lower flammability limit is usually reached while the jet momentum is still higher than ambient turbulence. When delayed ignition occurs, and depending on the sensitivity of the fuel and the strength of the ignition source, a small fireball/explosion may be experienced followed by a flame jet that will continue until the release ends. The amount of material involved in the fireball/explosion is limited and typically equivalent to no more than 10 seconds of flow. This can be readily in the Reynosa incident video clip.

If immediate ignition does not occur and the high-pressure jet is confined and/or obstructed (such as jets pointing vertically downwards or striking other nearby objects) the jet loses its momentum and will continue to disperse until delayed ignition occurs or the release ends. When delayed ignition occurs a flash fire will occur. Depending on the sensitivity of the fuel, the degree of confinement, and the strength of the ignition source, the flash can accelerate and lead to an explosion. The amount of material involved in the flash fire/explosion can be substantial.

Flash fires typically proceed at flame speeds ranging from 10 to 20 m/s. In general, indoor populations are expected to survive a flash fire, but outdoor populations are not. In flash fire exposure, a building is expected to burn from the outside to the inside. This often provides sufficient time for the occupants to escape.

Jet fires occur because of high pressure gas and/or two-phase releases, such as the case in Reynosa. Flame jets produce intense heating with flame emissive powers ranging up to 350 kW/m2. Flame jets impinging on nearby structures and/or vessels can lead to catastrophic failures in less than 10 minutes, such as with the portacabin which happened to be in the path of the jet fire.

Event tree analysis can be used to determine the probability and transition of each outcome. An example of an event tree, mapping out a Continuous Gas/Vapor Release is shown below in Figure 4.

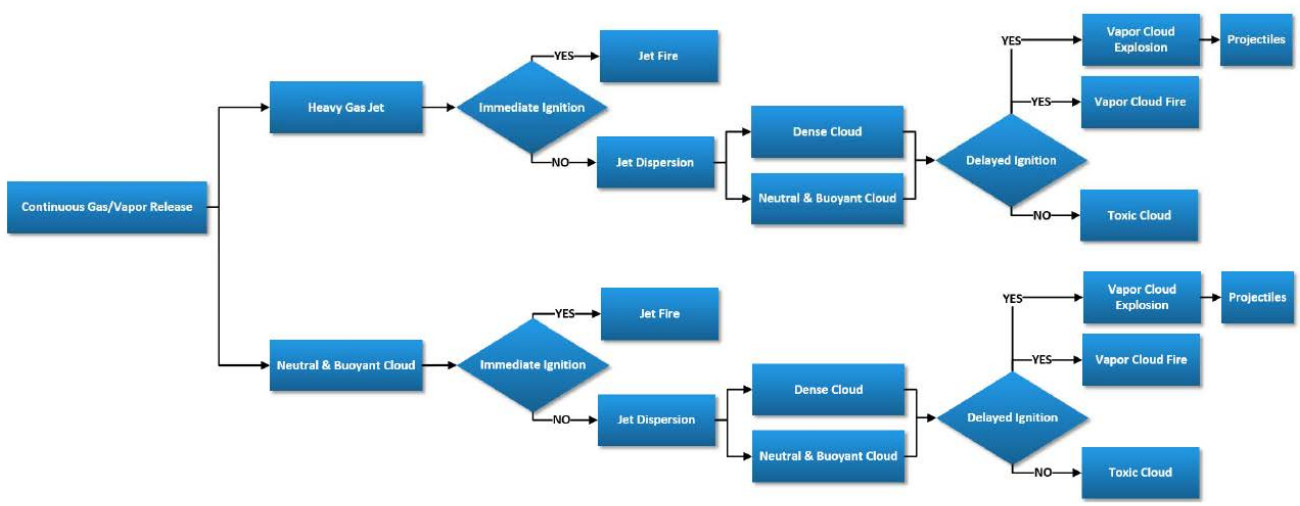

Figure 4 – Continuous Gas/Vapor Release Event Tree

Using consequence modeling software tools, it is possible to develop a simulation aimed to recreate the event.

To accurately define such an event, the following consequence modeling inputs would be required:

- Fluid Conditions (Temperature, Pressure, Phase, Composition, Explosion Reactivity, Toxicity)
- Release Flowrate or Hole Size
- Release Coordinates
- Equipment Type and Size
- Hole Diameter(s)
- Piping Length (if applicable)
- Release Duration
- Release Geometry (1D, 2D, 2.5D, 3D)
- Degree of confinement
- Meteorological conditions
    - Ambient Temperature, Ambient Pressure, Wind Speed, Humidity
    - Surface Roughness (Topography)

The more accurate these inputs can be defined, then the more accurate the output consequence results will be.

A simulation was modeled in SuperChems Expert, based on the following key inputs, with the aim to recreate the incident:

- Mixture composition: Natural gas (methane, ethane, propane)
- Source pressure and temperature: 400 psig, ambient temperature
- Release size: 24” pipe failure (assumed)
- Meteorological conditions: 30°C, D stability, 5 meters per second wind speed, surface roughness 1 meter

Additional inputs were also required, but are not listed here.

Based on the release conditions described, this yields the following outputs:

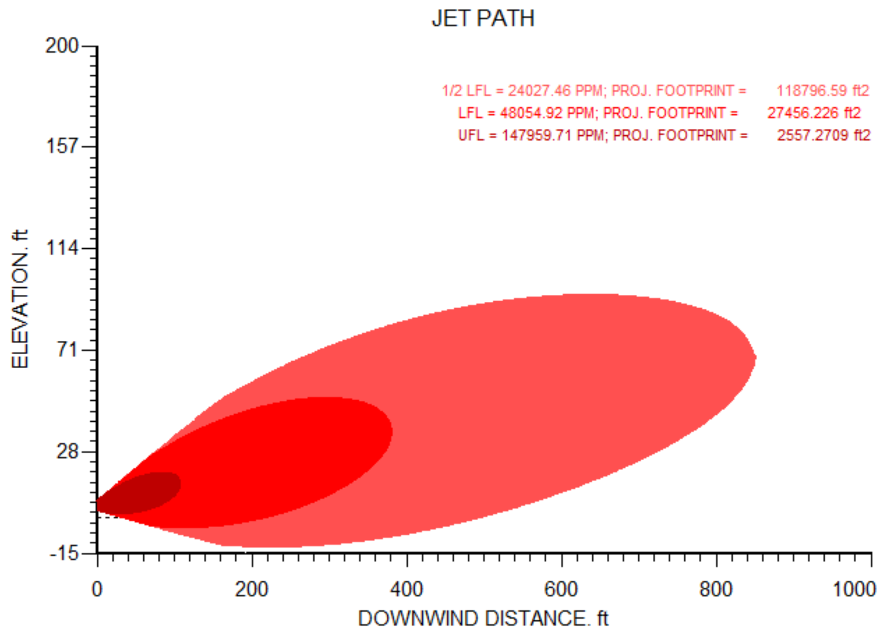

Figure 5 – Vapor Cloud Dispersion (Side View)

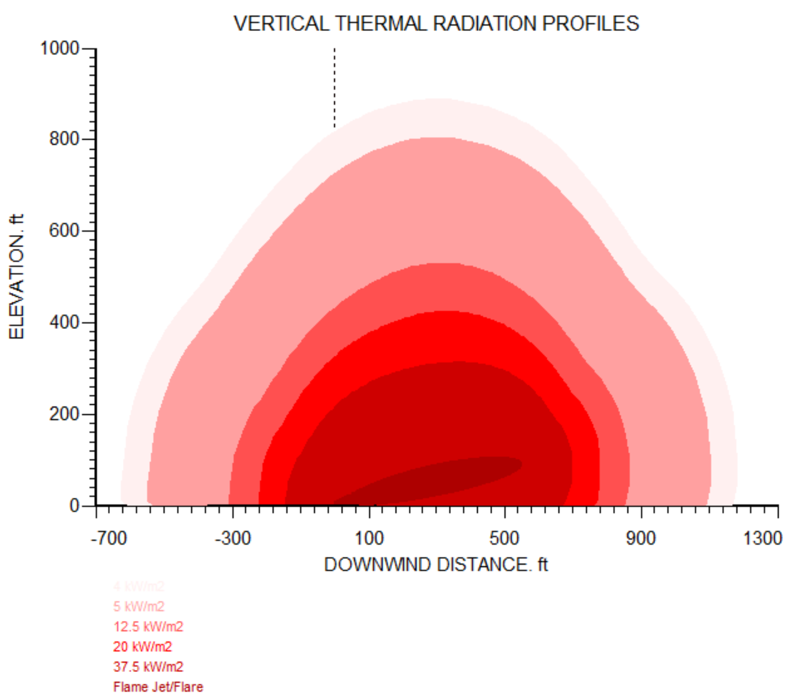

Figure 6 – Thermal Radiation Effects (Side View)

The results modeled here determined a release rate of approximately 900 kg/s; which resulted in a jet fire of over 500 feet and lower flammable limit of almost 400 feet. These results are very consistent with the jet fire results seen in the video clip.

Facility Siting

Given the proximity of the portacabin to the release point, this incident also highlighted the importance of facility siting considerations as part of a process safety management program.

In December 2009, API issued the Third Edition of the Recommended Practice 752, “Management of Hazards Associated with Location of Process Plant Permanent Buildings,” which incorporated much of what has been learned from catastrophic incidents since their Second Edition was published in 2003. In addition, API RP 753, “Management of Hazards Associated with Location of Process Plant Portable Buildings,” was developed and issued in June 2007.

API’s Recommended Practice 753 (Management of Hazards Associated with Location of Process Plant Portable Buildings) is relatively prescriptive in terms of requirements and methodologies when compared to API RP 752. A three-zone method is applied for locating portable buildings. Each zone is based on the size of the congested process area and the distance from the edge of this congested area to the portable building. These zones are shown in Figure 7, which comes directly from API 753.

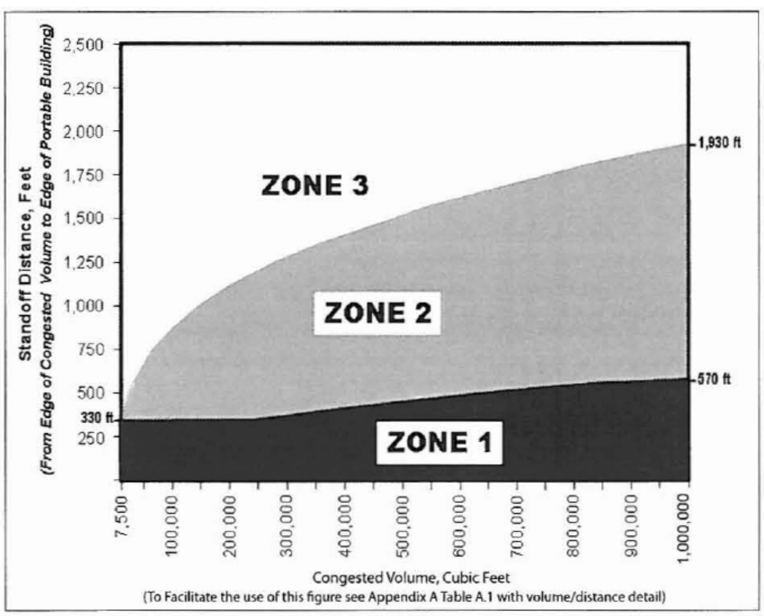

Figure 7 – Portable Buildings Location Guidance (from API RP 753)

Congested volumes, regardless of the material handled, should be considered as potential explosion sources, as a released vapor cloud may drift from adjacent facilities. Additionally, the operating status of a process unit does not exempt it from assessment. As before, a vapor cloud may drift into an offline unit.

For the three zones identified in Figure 7, light wood trailers intended for occupancy should not be located in zone 1. Other portable buildings require a detailed analysis before being placed in zone 1. All portable buildings within zone 2 require a detailed analysis. Finally, any portable buildings may be located in zone 3 without a detailed analysis. A detailed analysis may either be a consequence analysis or quantitative risk analysis.

If a Facility Siting study were conducted for this facility, it is unlikely that that portacabin would be located in its present location.

Storage Tanks Venting Due to Fire Flux

In the video clip (and shown in Figure 8), it is possible to see vapors venting from the storage tanks which are being impinged upon by the major jet fire. Atmospheric storage tanks are protected for overpressure and underpressure scenarios as described in API Standard 2000.

Figure 8 – Venting See Coming From Storage Tanks

API Standard 2000 covers the normal and emergency vapor venting requirements for aboveground liquid petroleum or petroleum products storage tanks and aboveground and underground refrigerated storage tanks designed for operation at pressures from full vacuum through 103.4 kPa (ga) (15 psig). It also includes the causes of overpressure and vacuum; determination of venting requirements; means of venting; selection and installation of venting devices; and testing and marking of relief devices.

While the conservation vents protecting these tanks are seen to be venting, they would not be intended to protect against such a severe event as jet fire impingement, therefore the tanks would eventually be expected to fail as the tank metal wall temperatures increased.

The Importance of Flame Retardant Clothing

In the video clip, a person can be seen in the foreground having had his clothes burned off after being exposed to the flash fire. This is shown in Figure 9.

Figure 9 – Affected Person

Flame Retardant Clothing (FRC) is a well-known passive safeguard, commonly used in many facilities, and stipulated by organizations such as API, OSHA and NFPA. FRC is personal protective equipment (PPE), which is the last line of defense after engineering controls and administrative controls have failed. FRC are designed to protect against a flash fire that only lasts three to five seconds. It is not protective beyond that point except for the fact that it is self-extinguishing.

API RP 500, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division I and Division 2, identifies areas that present a fire hazard to employees and, therefore, require PPE. These areas include work in Class I, Division I areas and work where a process is opened to increase the likelihood of flammable gases or vapors to 10% of the lower flammable limit (LFL). If work is performed in a Class I Division I area or where a process that contains flammable vapors, then API RP 500 identifies the need for FRC. Many companies apply a sitewide FRC requirement, rather than designating specific areas.

API summarizes RP 500 as follows: this recommended practice provides guidelines for determining the degree and extent of Class I, Division 1 and Class I, Division 2 locations at petroleum facilities for the selection and installation of electrical equipment. Basic definitions provided in the National Electric Code (NEC) have been followed in developing this document, which applies to the classification of locations for both temporarily and permanently installed electrical equipment. RP 500 is intended to be applied where there may be a risk of ignition due to the presence of flammable gas or vapor, mixed with air under normal atmospheric conditions.

Wearing FRC is intended to reduce the potential for burns to personnel, and hence reduce the amount of skin surface area burned. This is especially important when considering that there is a direct relationship between age, percentage of burned area, and mortality. This relationship is shown in the Green Book (CPR-16E - Methods for the Determination of Possible Damage), and shown below in Figure 10.

% Body area burned	Age (yr)																
	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80
93+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
88-92	.9	.9	.9	.9	1	1	1	1	1	1	1	1	1	1	1	1	1
83-87	.9	.9	.9	.9	.9	.9	1	1	1	1	1	1	1	1	1	1	1
78-82	.8	.8	.8	.8	.9	.9	.9	.9	1	1	1	1	1	1	1	1	1
73-77	.7	.7	.8	.8	.8	.8	.9	.9	.9	1	1	1	1	1	1	1	1
68-72	.6	.6	.7	.7	.7	.8	.8	.8	.9	.9	.9	1	1	1	1	1	1
63-67	.5	.5	.6	.6	.6	.7	.7	.8	.8	.9	.9	.9	1	1	1	1	1
58-62	.4	.4	.4	.5	.5	.6	.6	.7	.7	.8	.9	.9	1	1	1	1	1
53-57	.3	.3	.3	.4	.4	.5	.5	.6	.7	.7	.8	.9	.9	1	1	1	1
48-52	.2	.2	.3	.3	.3	.3	.4	.5	.6	.6	.7	.8	.9	1	1	1	1
43-47	.2	.2	.2	.2	.2	.3	.3	.4	.4	.5	.6	.7	.8	1	1	1	1
38-42	.1	.1	.1	.1	.2	.2	.2	.3	.3	.4	.5	.6	.8	.9	1	1	1
33-37	.1	.1	.1	.1	.1	.1	.2	.2	.3	.3	.4	.5	.7	.8	.9	1	1
28-32	0	0	0	0	.1	.1	.1	.1	.2	.2	.3	.4	.6	.7	.9	1	1
23-27	0	0	0	0	0	0	.1	.1	.1	.2	.2	.3	.4	.6	.7	.9	1
18-22	0	0	0	0	0	0	0	.1	.1	.1	.1	.2	.3	.4	.6	.8	.9
13-17	0	0	0	0	0	0	0	0	0	.1	.1	.1	.2	.3	.5	.6	.7
8-12	0	0	0	0	0	0	0	0	0	0	.1	.1	.1	.2	.3	.5	.5
3-7	0	0	0	0	0	0	0	0	0	0	0	0	.1	.1	.2	.3	.4
0-2	0	0	1	0	0	0	0	0	0	0	0	0	0	.1	.1	.2	.2

Figure 10 – The Relationship Between Age, Percentage of Burned Area and Mortality (From The Lancet, 20 November 1971)

When considering this information, the wearing of FRC is common sense in any facility handling flammable materials, even when the operating company does not mandate it. An ounce of prevention is worth a pound of cure!

Emergency Planning

Considering the speed at which the incident developed, those people caught in the path of the jet fire would have little chance of escape. However, a well-developed emergency plan could prevent further escalation, and minimize further injuries and damage.

Operating companies, at a minimum, should have an emergency action plan that will facilitate the prompt evacuation of employees (and contractors) when there is an unwanted release of a highly hazardous chemical. The operating company's plan would be activated by an alarm system to alert employees when to evacuate, and should allow for employees who are physically impaired to ensure that they have the necessary support and assistance to get them to a safe zone.

The intent of the emergency plan would be to alert and move employees quickly to a safe zone. Delaying alarms or confusing alarms should be avoided. The use of process control centers or buildings as safe areas is discouraged, if these buildings are not known to be blast-resistant. Experience has shown that that lives can be lost in these structures because of their location and because they are not necessarily designed to withstand overpressures from shock waves resulting from explosions in the process area.

If there are unwanted incidental releases of highly hazardous chemicals in the process area, the operating company should inform employees of the actions/procedures to take. If the operating company wants employees to evacuate the area, then the emergency action plan will be activated. For outdoor processes, where wind direction is important for selecting the safe route to a refuge area, the employers should place a wind direction indicator, such as a wind sock or pennant, at the highest point visible throughout the process area. Employees can move upwind of the release to gain safe access to a refuge area by knowing the wind direction.

If the operating company wants specific employees in the release area to control or stop the minor emergency or incidental release, these actions must be planned in advance and procedures developed and implemented. Handling incidental releases for minor emergencies in the process area must include pre-planning, providing appropriate equipment for the hazards, and conducting training for those employees who will perform the emergency work before they respond to handle an actual release.

Preplanning for more serious releases is an important element in the operating company’s line of defense. When a serious release of a highly hazardous chemical occurs, the employer, through preplanning, will have determined in advance what actions employees are to take. The evacuation of the immediate release area and other areas, as necessary, would be accomplished under the emergency action plan.

Drills, training exercises, or simulations with the local community emergency response planners and responder organizations help to ensure better preparedness.

An effective way for medium to large facilities to enhance coordination and communication during emergencies within the plant and with local community organizations is by establishing and equipping an emergency control center. The emergency control center should be located in a safe zone so that it could be occupied throughout the duration of an emergency.

Lessons Learned

After an accident, some of the first thoughts that come to mind are safety-related. What does a company have to do to prevent this from happening again? What measures are needed to be safe in a preferably long extended term? How does a company train new employees and contractors?

Many of the victims were subcontractors during the accident, so the company began to ensure proper training of their contractors after the incident, including emergency preparedness drills.

This was the second accident to affect this company in the month of September. Earlier in the month, four workers were injured after a fire broke out at one of their other refineries in Tamaulipas. Another fire at the same location occurred less than a month before on August 13. With a series of incidents in a short time span, Gerardo Reza said that the company implemented inspections and evaluated their systems before restoring process activities. Companies included within the investigation were the following; the Energy Agency, Environmental Protection Agency and the Labor and Social Security. “Prior to the restoration of activities in the metering center, the company carried out a mechanical integrity inspection and evaluation program consisting of non-destructive testing, visual inspection, wall thickness measurement, ultrasound, metallography, hardness, verticality and roundness, which ended on September 30, 2012.”

The Burgos well administration stated that the investigation of the explosion was completed on December 2012 and officially sent to the PGR (Mexican government) in January 2013, though it is unclear if the findings have ever been made publicly available.

As with any incident, there are typically multiple contributing factors which need to line up before the incident can occur, illustrated with the Swiss Cheese Model (Figure 11). The Swiss cheese model of accident causation illustrates that, although many layers of defense lie between hazards and accidents, there are flaws in each layer that, if aligned, can allow the accident to occur.

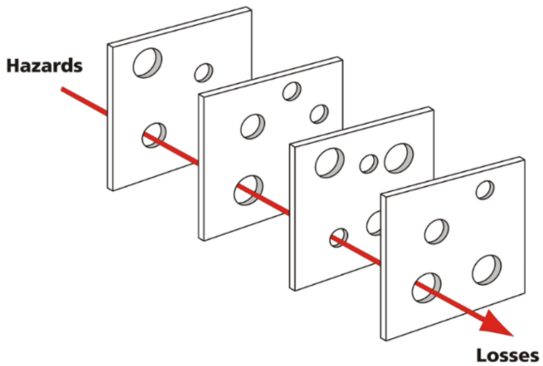

Figure 11 – Swiss Cheese Model

A review of the fourteen elements in OSHA's PSM Standard (Process Safety Management of Highly Hazardous Chemicals) shows that most, or all, of these elements could have played a part in preventing such a catastrophic incident such as the one in Reynosa.

The fourteen elements in OSHA's PSM standard are:

- Employee Participation
- **Process safety information (PSI)**
- **Process hazard analysis**
- Operating procedures
- Training
- **Contractors**
- Pre-startup safety review (PSSR)
- **Mechanical integrity**
- Hot work permit
- **Management of change**
- **Incident investigation**
- **Emergency planning and response**
- Compliance Audits
- Trade secrets

Elements which could have potentially contributed to, or prevented, the Reynosa incident have been highlighted in bold.

It is worth noting that the facility in Reynosa is located approximately twelve miles from the US border. Had this plant been located twelve miles to the north, on US soil, the incident investigation and aftermath would have been significantly different. The follow-up to an event of this scale in the US would include public enquiries, a public Chemical Safety Board investigation, industry-wide recommendations, and probable updates of affected standards and regulations.

This paper concludes with the following thoughts:

1. Operator intervention cannot always be relied upon, as some incidents escalate too quickly to allow for any immediate response. In which case, an automated, independent protection system would be much more effective.
2. The lessons learned from any major incident, regardless of location, should be shared and implemented on an industry-wide, and international basis.

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