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Risk-Based Approach – Risk Reduction Basics

Basics of Prevention, Mitigation and Control of Loss of Containment Scenarios

An ioMosaic White Paper

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Abstract

This manuscript is intended to provide an overview of layers of protection capable of reducing the risk level of a given process facility, i.e., measures intended to prevent and/or mitigate the identified hazardous scenarios. Based on the development and results of a risk-based quantitative assessment, regions, zones, or more detailed locations (e.g., occupied buildings, critical process equipment) with an intolerable risk level can be identified and the associated hazardous scenarios that most contribute to the risk of these zones. Sensitivity analysis and cost-benefit analysis can be conducted with the goal to find which safeguards achieve reducing risk to an acceptable level while ensuring that the investment is not in gross disproportion.

Table of Contents

List of Tables

List of Figures

Introduction

ISO 17776 **[1]** defines the concept of risk as the combination of the frequency of occurrence of an event and the consequences of that event. Its estimation is used to take decisions, usually supported by using graphical tools (e.g., F-N curve, risk profile, risk contour, exceedance curves) to show risk and the relationship between frequencies and consequences. Taking into account most of the factors that contribute to the total risk of a process facility, the risk values will highlight the major sources of risk and will give the decision-maker objectives for re-design or other loss prevention efforts. Techniques to achieve these goals are, for example, the risk-based quantitative assessment (see **Figure 01**).

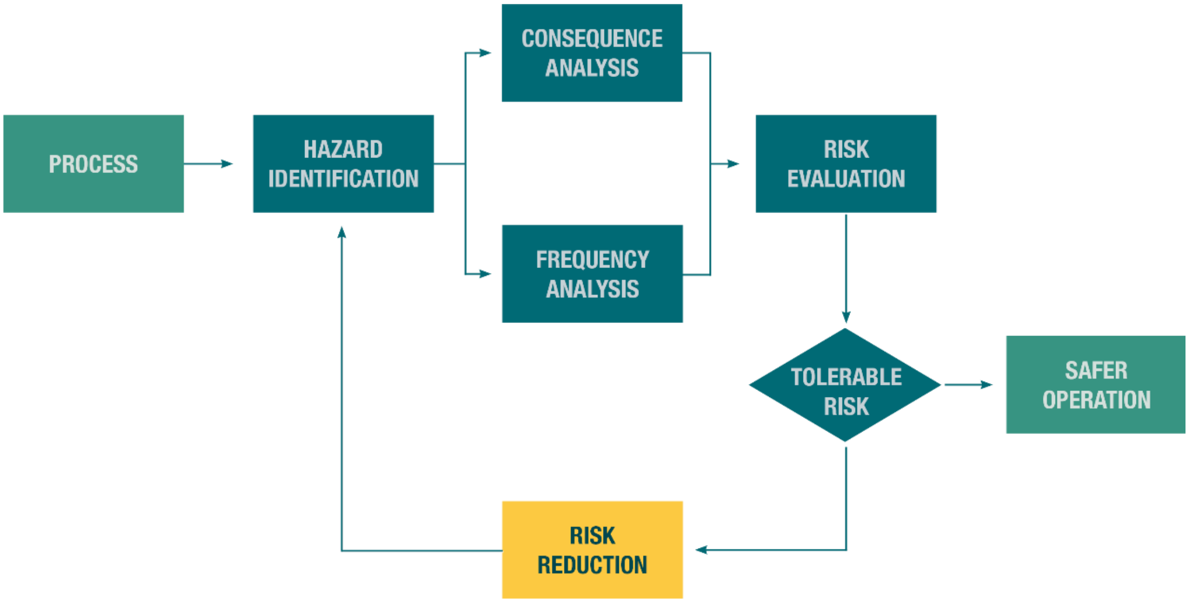


Figure 01: Risk Management Program Simplified Flowchart

However, actual risk results are not very useful if there are no criteria for comparison. The decision-making process should be based on internationally recognized tolerability criteria with the aim to compare the actual risk level and therefore, take the appropriate actions. This paper provides criteria on risk reduction measures for the Chemical Process Industry (CPI) and provides guidance for answering the following question: “***Which are the most appropriate safeguards for reducing risk to a tolerable level?***”

Detailed information on risk-based quantitative assessment development can be found in references **[2]**, **[3]**, **[4]**, **[5]**, **[6]**, **[7]** and **[8]**.

Overview of Layers of Protection for Risk Reduction

It is common during a risk-based quantitative assessment to have things go wrong. Normally, in a well-designed process, many layers of protection, conditional modifiers and enabling conditions are present which are intended to prevent a hazardous scenario from occurring. Typical risk reduction measures found in the Chemical Process Industry (CPI) are illustrated in **Figure 02**. Note that conditional modifiers and enabling conditions can be defined as follows:

- Enabling Conditions: conditions that must be present to allow the initiating event (i.e., Loss of Containment scenario, LOC) to cause the consequence of concern
- Conditional Modifiers: conditions that must be present for the hazardous scenario to develop in to the consequence of concern

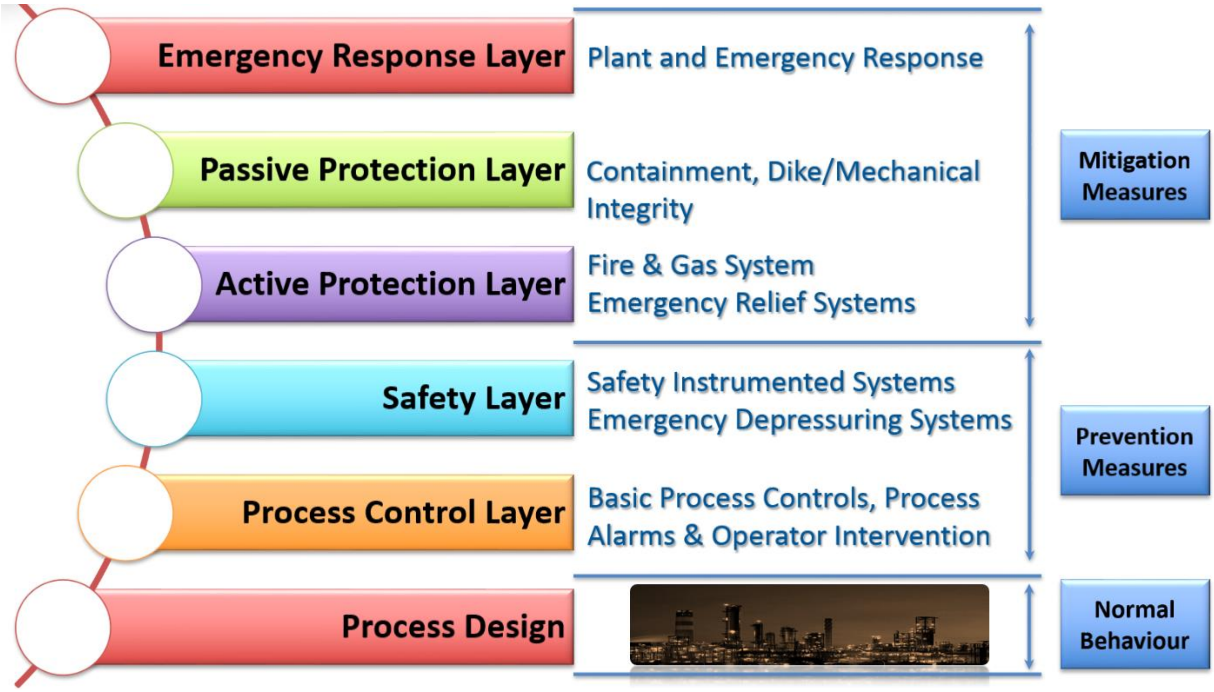
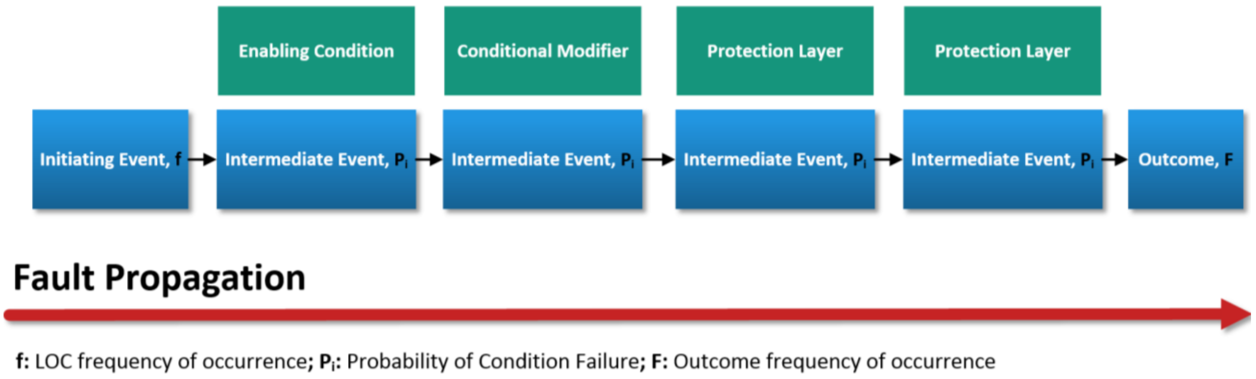


Figure 02: Illustration of Typical Layers of Protection

Before defining each protection layer illustrated in **Figure 02**, it is important to introduce how an initiating event (LOC) can propagate throughout enabling conditions, conditional modifiers and protection layers to the final accident or incident, i.e., fault propagation.

Figure 03 illustrates an example of fault propagation starting from the initiating event and identifies specific circumstances and process properties and characteristics, conditions and protection mechanisms (i.e., intermediate events) intended to prevent the accident. Evaluating the frequency of the initiating event and the occurrence probabilities of the intermediate events, the final outcome can be identified and quantified. Note that this is the basis for Event Tree and Fault Tree Analyses. Both techniques together (i.e., Bow-Tie method) complete the identification of the complete sequence of events (including current protection layers present in the process) that have to be accounted for when defining the final outcome of interest. Detailed information of Fault and Event Trees Development can be found in references **[4]** and **[6]**.



f: LOC frequency of occurrence; **P_i:** Probability of Condition Failure; **F:** Outcome frequency of occurrence

Figure 03: Fault Propagation Illustration

The typical layers of protection that could be present in a typical CPI facility are categorized as follows:

Process Design Layer

- Process: The baseline design of process, if done properly, may provide some risk reduction for certain scenarios, i.e., inherent safety

Process Control Layer

- Basic Process Control System (BPCS): Process control which includes continuous control loops, on/off control loops and process control based interlocks. The BPCS may be considered a protection layer only under certain circumstances by ensuring that the BPCS is not the root of the accident

- Process Alarm and Operator Intervention: Layer of protection which requires operator's intervention to prevent the accident, i.e., operator surveillance-based and alarm-based operator intervention

Safety Layer

- Safety Instrumented System (SIS): A set of equipment, i.e., Safety Instrumented Functions (SIFs), specifically designed to prevent the hazardous scenario from proceeding by taking an industrial process to a safe state when specific conditions are violated. If the SIS complies with applicable standards **[9]**, **[10]**, **[11]**, it provides strong protection according to the design Safety Instrumented (SIL) level and associated Probability of Failure on Demand (PFD) per each SIF

- Emergency Depressuring Systems.

Active Protection Layer

- Emergency Relief Systems (ERS): A layer of protection which includes devices such as relief valves and rupture disks. It is still debatable if these layers of protection should be considered active or passive. In some situations, ERS are intended or capable to prevent the most severe consequence from occurring. But in other cases, the mentioned devices can eliminate or mitigate the consequence designed properly and tied in a well-designed flare system

- Fire and Gas Detectors (FGD): Modern fire and gas detectors pertain to this category as an active/passive protection layer as they can reduce or even eliminate a hazardous scenario. Specifically, FGD need to comply with criteria established in Standard ISA 84.00.TR.07 **[11]**

- Deluge Systems: The same FGD rationale is applicable to deluge systems, which are automatically activated by detection systems. Deluge systems provide protection against fires and they are normally composed of open sprinklers attached to a piping system that is connected to an extinguishing material supply (e.g., water, foam, dry powder, inert gas) through a heat responsive valve or activated by a selected detection system. When the system is activated, the discharge must occur rapidly and efficiently in response to a fire scenario

Passive Protection Layer

- Layers of protection that do not need to be physically activated to provide risk reduction, such as dikes, fire walls and blast walls. These layers are similar to process design protection layers such as material of construction and pressure rating, because they are a static characteristic of process equipment that provide risk reduction without involving sensors, logic solvers, or moving parts

Emergency Response Layer

- Emergency Response: last layer of protection category mainly intended for addressing catastrophic consequences such as releases of toxic materials, fires and explosions. Examples include plant and community evacuation plans

All these protection layers should be considered when identifying all applicable Loss of Containment scenarios (LOCs) and associated potential outcomes during the development of the risk-based quantitative assessment. It is imperative to ensure the probability of success or failure of enabling events, conditional modifiers and layers of protection considered for the final definition of hazardous outcomes; i.e., credibility. Furthermore, once the risk level of a facility has been evaluated and compared with a given risk tolerability criteria, risk reduction measures are required if the actual risk level is not in the tolerable risk region. When defining potential safeguards for risk reduction and decision-making, it is critical to ensure that these safeguards are completely independent and efficient, i.e., Independent Protection Layers (IPLs).

Independent Protection Layers (IPLs)

Independent Protection Layers can be defined as protection layers which are demonstrated to be specific, effective, independent and auditable. An IPL is a device, system, or action which is capable of preventing or mitigating a hazardous scenario from proceeding to its undesired outcome that is independent of the initiating event or the action of any other protection layer associated with the scenario. The categorization of a protection to be considered as an IPL is based on four (4) key characteristics (i.e., **SIDA**): (1) **S**pecific, (2) **I**ndependent, (3) **D**ependable and (4) **A**uditable.

- **Specific**: The IPL must have capacity of preventing or mitigating the specific consequence from occurring by ensuring the following two criteria are met: (1) rapid response to prevent or mitigate the specific outcome and (2) action will always prevent or mitigate the specific outcome
- **Independent**: All components of the IPL must be independent from the initiating event and other safeguards in place, including any SIFs
- **Dependable**: The IPL must provide a known level of risk reduction, which can be defined by a Probability of Failure on Demand (PFD), by reducing the outcome frequency of occurrence or reducing the impacted area of the associated consequences. Note that based on a risk-based quantitative approach, the new impact distances after considering a potential IPL can be quantitatively evaluated by a sensitivity analysis. This procedure provides quantitative

evidence that the installation of a specific IPL will reduce the actual risk level to a tolerable region when compared to applicable risk tolerability criteria

- **Auditable**: The effectiveness of the IPL must be validated through an audit process, which should verify the design, installation, maintenance and testing of the IPL ensuring its effectiveness

As a simplified approach, risk reduction measures such as layers of protection can be classified as safeguards intended to reduce the likelihood and impacts of the hazardous scenarios. They both prevent scenarios from occurring and mitigate the effects of a scenario. The following contents provide guidance on how to identify and address risk reduction measures.

Measures Intended to Prevent Hazardous Scenarios

Protection layers intended to prevent hazardous LOCs are designed for avoiding or eliminating the release of hazardous materials. Based on **Figure 02**, three different layers of protection could be considered for preventing hazardous LOCs: (1) Process Design, (2) Process Control and (3) Safety Layer.

Process Design

A proper process design is the first layer of protection to be considered and normally is developed following the key principles of what is called "inherent safety." Based on the definition from Kletz and Amyotte, **[12]**, the concept of inherent safety can be defined as follows:

Intensification, substitution, attenuation and limitation of effects produce inherently safer design because they avoid hazards instead of controlling them by adding protective equipment. The term inherently safer implies that the process is safer because of its very nature and not because equipment has been added to make it safer. Note that we talk of inherently safer plants, not inherently safe ones, for we cannot remove all hazards.

The Chemical Center for Process Safety (CCPS) **[13]** uses somewhat different terminology and identifies four (4) strategies to consider when designing or modifying a process:

- Substitute: Use materials, chemistry and processes that are less hazardous
- Minimize: Use the smallest quantity of hazardous materials feasible for the process, reduce the size of equipment operating under hazardous conditions, such as high temperatures or pressures
- Moderate: Reduce hazards by dilution, refrigeration, or process alternatives that operate at less-hazardous conditions. reduce potential impact of an accident by siting hazardous facilities remotely from people and other property
- Simplify: Eliminate unnecessary complexity by designing "user-friendly" plants

Process Control and Procedural

The BPCS, alarm management and operator intervention are some of the prevention measures that can be considered. It is obvious that a robust BPCS design could be considered as part of the inherent safety of the process and for this reason, it is not easy to classify prevention measures into the same category. The key concept that is the important role of the operator intervention, which requires procedural safety systems to control hazards through personnel education and management (i.e., standard operating procedures, safety rules and procedures, operator training, emergency response procedures and Management systems).

Safety Layer

The safety layer can be considered as the first line of defense, which entails safety systems only intend to act when a process deviation is detected to avoid hazardous scenarios. The key safety systems that fall into this category are called Safety Instrumented Systems (SIS). A SIS is based on functional safety standards **[9]**, **[10]** and **[11]**, that enable them to work correctly and with a high probability of success. Accordingly, functional safety is the primary objective when designing a SIS. To achieve an acceptable level of functional safety, several issues must be considered that may not be part of the normal design process for automation systems. These issues are provided as requirements in the cited international standards.

The definition and characterization of SIS is complex and is out of the scope of the present manuscript. Reference **[14]** is focused on providing guidance on how to identify the need of a SIS, how to define the associated Safety Instrumented Function (SIF) to be implemented and how to verify its reliability, i.e., Safety Integrity Level (SIL).

Measures intended to Mitigate Hazardous Scenarios

Protection layers intended to mitigate hazardous LOCs are designed for the control of a hazardous material once it has been released into the environment and can be critical parts of an emergency response plan. The protection layer can provide time for the response team to activate and for evacuation of personnel to a safe location. Mitigation measures can be classified into two categories:

- Containment or suppression, which involves limiting the amount of material that is released
- Countermeasures, which are applied once the released materials have formed a pool and/or a vapor cloud

Major areas mitigation measures include **[15]**: (1) Vaporization Reduction, (2) Secondary Containment, (3) Fluid Curtains, (4) Detection and Response and (5) Emergency Response.

Vapor Reduction

The basis for this mitigation technique is to minimize the amount of material released into the atmosphere to form a vapor cloud. Once the material is in the vapor cloud, it can travel and become hard to control. If the material is flammable it may find an ignition source. A toxic material may be airborne and result in a sensitive population receiving a significant dose either from the concentration of the material or the time of exposure.

The major factors that determine if a stream becomes a vapor upon release are the vapor pressure and boiling point of the compound. These data help indicate whether material will be a gas if released, if flashing is going to occur and provide energy for flash atomization, or if the material will be a liquid and form a pool which will vaporize. Determining what a released material will do if it is released from different parts of the process is essential in identifying appropriate mitigation measures, i.e., source term **[15]**. After release, the following factors will affect vaporization, especially if a liquid pool is formed:

- Surface area
- Wind Velocity: mass transfer coefficient for connective heat loss is proportional to the wind speed
- Ground temperature: due to heat conduction from the ground to the pool, a higher ground temperature will cause a higher initial vaporization rate
- Available energy for vaporization: Part of the energy for vaporization comes from the substance when it is released; the balance of the needed energy comes from the surroundings. How fast this energy will be transferred depends on the temperature of the material and surroundings and the amount of surface area available. The energy can come from either the ground on which the liquid pool lies, or in the case of an aerosol formed during an event, from the atmosphere.

Table 01 summarizes some of vaporization reduction measures capable of interfering with the mechanisms that cause the vaporization of a released material **[15]**.

Table 01: Example of Vaporization Risk Reduction Measures

Protection	Description
Shading	If the material is going to run out onto a concrete pad, providing a shade may prevent the pad from being warmed by the sun and reduce the amount of energy the material picks up from the ground.
Foam	The application of foam has been shown to be effective in the reduction of the amount of material that will evaporate. Reductions of 50 percent to 70 percent have been reported in the literature although it must be said that information is minimal. The manufacturers of the foams run proprietary tests for companies to determine which foam will be the most effective and give the best reduction in vaporization.
Dry Chemicals	Dry chemicals are available that can be blown onto a spill in the same manner as a dry chemical firefighting agent. However, in this case the materials are acidic for the neutralization of a basic material that has been spilled and basic for the neutralization of acids. When using one of these materials, one should expect a puff

Protection	Description
	during the initial application due to the heat of neutralization. After the spill has had time to react with the powder, it can be shoveled up and disposed of in an environmentally safe manner. Dry chemical equipment should be inspected and tested in the same manner as fire extinguishers.
Covers	Many covers can be applied to a spill, ranging from absorbent materials like corn cobs to sheets of plastic and ping pong balls. For substances that are denser than water and not highly soluble in water, such as bromine or carbon disulfide, water can be an effective cover as well.
Refrigeration	Refrigeration cannot be considered purely a post-release mitigation technique as it is usually required for process reasons. However, if a release of hazardous liquid does occur, much of the cold material will remain as a liquid that can then be recovered, or additional steps can be taken to retain control of the material.

Secondary Containment

If a material can be contained, it can be controlled and application of the vaporization reduction techniques discussed above will further minimize the impact of the release. In addition, other approaches can be applied such as dilution, recovery and destruction by chemical reaction. Examples of secondary containment **[15]** are listed in **Table 02**.

Table 02: Examples of Secondary Containment Risk Reduction Measures

Protection	Description
Diking	Dikes alleviate the potential hazards from an accidental release of the fluid by reducing the total vaporization rate through reducing the surface area available for vaporization and making it possible to employ some of the covering techniques described in "*Vapor Risk Reduction Measures*".
Double Wall Containment	Costly but effective way to provide spill containment by providing a second outer wall such as a pipe or vessel around the inner wall which is the primary carrier of the hazardous fluid. In case of inner wall failure, the outer wall will contain the material. The outer wall should be designed to withstand the temperatures, pressures and corrosivity of the process fluid and a detection system of inner wall failure should be in place with the aim to take an appropriate action.
Enclosure	Measure that prevents or delays a release from reaching the environment until proper action can be taken to stop, drain, or vent the material in a controlled manner. Use of enclosures is common where other containment systems would be impractical, as in the case of hazardous vapors or volatile liquids. Releases from enclosures are either scrubbed before being released to the atmosphere, vented to some safe location, or routed to a flare system.
Transfer Vessel	Measure intended to receive the contents of another vessel or the inventory of a process unit for emergency or non-emergency purposes. The transfer vessel can be a vacuum truck, or a hard-piped, dedicated system. For liquids, the transfer system usually consists of a container located below the vessel to be protected to allow gravity flow. In other circumstances, the transfer vessel may consist of a spare vessel capable of accepting the contents of a nearby vessel.

Fluid Curtains

Fluid curtains help mitigate explosions by absorbing energy into a fluid and creating droplets that increasing the total surface area. They reduce the potential or toxic hazard zones through dilution with air, by reaction with water, or by reactive materials contained in the fluid curtain.

Table 03 provides examples of fluid curtains reduction measures **[15]**.

Table 03: Examples of Fluid Curtains Risk Reduction Measures

Protection	Description
Water Curtains	Measure effective in dealing with vapor clouds of flammable materials because the concentration of the cloud can be reduced to below the Lower Flammable Limit by dilution with air. This dilution is accomplished by the entertainment of air into the vapor cloud by momentum transfer from the water droplets. Water curtains are not effective in diluting some toxic materials due to the very low level of concentration that must be achieved to reduce their hazardous effects. However, toxic materials that are highly soluble in water, such as ammonia, hydrogen fluoride and hydrogen chloride can be effectively removed from the vapor cloud by a water curtain because mass transfer controls the absorption of the material into the water spray.
Steam Curtains	Measure effective in providing dilution of flammable materials. Steam curtains hinder the absorption effects needed for toxic materials. Note that large quantities of steam are required to ensure an effective curtain.
Air Curtains	Compressed air can also be used for a fluid curtain, but it is only effective in providing dilution of flammable materials. Note that large quantities of air are required to ensure an effective curtain.

Detection and Response

When a release occurs, a detection system is needed to initiate an effective response, activate the emergency response team or automatic system and warn other personnel of the danger and need to evacuate or take shelter. Detection provides an early warning of a leak occurring in an area or at a specific piece of equipment. For this function, fixed point detectors are usually utilized. At the same time, many types of portable instruments can be used to detect leaks and warn personnel in areas where hazardous materials are concentrated. Fire and Gas Detectors (FGD) technology has exponentially evolved during the last years and dedicated standards have been developed for defining best practices, guidance and requirements for defining the associated performance-based approach. ISA 84.00.TR.07 **[11]** provides guidance for defining the tasks to be considered in the FGD “management system”:

- FGD Philosophy Considerations
- Fire and Gas Zone Definition and Categorization
- Fire and Gas Performance Targets
- Detector Coverage Verification
- FGS Safety Availability (SIL) Verification

The five (5) tasks mentioned above are required to be developed to comply with the performance-based requirements established in reference **[11]**. The performance-based quantitative assessment normally performed for a complete definition of FGD is called a “*Fire and Gas Mapping study,*” and it can take advantage of all results obtained from a risk-based quantitative assessment. Reference **[16]** illustrates the basics of a complete “Fire and Gas Mapping study” proposed approach.

Emergency Response

Emergency Response includes intervention from different parties. Therefore, the same criteria as used for operator intervention (i.e., procedural) should considered for emergency response.

Risk-Based Approach – Addressing Risk Reduction Measures

Once the risk-based quantitative assessment has been completed and the actual risk results have been compared with the applicable risk tolerability criteria, it is time to evaluate if a gap exists between the actual and the tolerable risk levels. For example, based on individual risk contours, it is easy to find if the actual results indicate that there are areas within the process facility analyzed that are considered to be in the intolerable risk region. In those cases, the installation of potential risk reduction measures should be analyzed with the aim to reduce the risk of the hazardous scenarios that lead to high individual risk contours. **Figure 04** illustrates an example of individual risk contours estimated for a facility handling hazardous materials. If an individual risk level greater than 1.00E-03 yr^{-1} (i.e., red contour) is considered intolerable, the individual risk contours confirm that the area within the red contour has to be considered an intolerable risk region.

As a result, it is important to focus on identifying which are the most contributing hazardous scenarios and associated outcomes that generate the red contour. However, this is not an easy task when the total number of LOCs defined in a risk-based quantitative assessment for a facility can entail hundreds of thousands of scenarios and even more when considering the multiple potential outcomes from one single LOC. In this sense, it is critical to identify the specific hazardous scenarios that effectively contribute to the risk level of the area of concern.

Figure 04: Example of Individual Risk Contours for a Given Process Facility

Identification of Most Significant LOCs

For a risk-based quantitative assessment, the challenge is to collect the specific LOCs with the greatest contribution to the zone or region identified with an intolerable risk level. Advanced tools analyze results from the risk-based quantitative assessment and very specific information can be extracted to be used for risk reduction purposes. Process Safety Office™ (PSO) SuperChems™ **[17]** includes advanced analysis tools capable of identifying individual hazardous scenarios that contribute to target locations or zones. The development of risk contours, risk indices, exceedance curves and other useful parameters intended for quantitative risk ranking (see references **[2]** and **[7]** for detailed information) help generate a list with the most significant LOCs. **Table 04** provides guidance on how useful and how to use these mentioned tools for LOCs identification. Once the key LOCs have been identified, the safety engineer and managers can discuss how these LOCs should be addressed. The detailed information that can be extracted from each LOC can be very detailed including:

- Piece of process equipment, which identifies the specific location and definition of the LOC, which identifies the cause-consequence pairs (i.e., hazardous scenarios) including the value of the initiating event

- Composition and phase of the hazardous material released, which identifies the type of hazard (i.e., toxicity, flammability) and which type of risk reduction can be analyzed. For example, diking for vaporization reduction due to a liquid spill

- Enabling conditions and conditional modifiers (e.g., location of ignition sources and associated probabilities of ignition, layers of protection in place) that contribute to the feasibility of the final outcomes. This includes knowledge on the outcome frequency and probability of intermediate events

- Impact distances of outcomes evaluated per each LOC

All this information is valuable for defining the risk reduction strategy, which would require a sensitivity or cost-benefit analysis for ensuring the most effective safeguard at the lowest possible economic investment.

Table 04: Tools and Results for LOCs Identification – Risk Reduction

Tool	Description
Individual Risk Contours	Identification of zones with intolerable risk levels (i.e., probability of fatality) impacted for all outcomes that contribute to hazardous effects, (toxicity, thermal radiation and overpressure). Note that it is relevant to evaluate more specific individual risk contours per type of hazard such as only considering toxic effects, thermal radiation effects, or overpressure effects, at certain thresholds of interest.
Toxic Risk Contours	Identification of zones with risk levels evaluated at a given toxic concentration or dose of interest. Reference **[5]** reviews the state-of-the-art damage criteria due to toxic dispersions.
Thermal Risk Contours	Identification of zones with risk levels evaluated at a thermal flux or doses of interest. Reference **[5]** reviews the state-of-the-art damage criteria due to fires.
Overpressure Risk Contours	Identification of zones with risk levels evaluated at an overpressure or impulse of interest. Reference **[5]** reviews the state-of-the-art damage criteria due to explosions.
Exceedance Curves	Exceedance curves for addressing toxicity, thermal radiation, or overpressure can be developed for dedicated target locations, such as occupied buildings, critical process equipment. SuperChems™ **[17]** provides a list of LOCs that impact the location under analysis.
Risk Indices	Risk indices quantitatively evaluate the contribution of a given number of selected LOCs to a specific zone with an intolerable risk level by using risk contours or exceedance curves. IR_{TOT} (Total Individual Risk) and PLL (Potential Loss of Life) are valuable indices for comparing risk contribution **[7]**.

Sensitivity Analysis and Cost Benefit Analysis

The effectiveness of the selected risk reduction measures can be determined using consequence analysis models by considering the probability of success of the proposed safeguards and finally calculating the new risk level. Different combinations of safeguards that reduce the risk from the actual risk to a tolerable risk are evaluated. Thereafter, once the iterative sensitivity analysis has been performed and several options have been identified that achieve the pursued goal, the cost-effective solution is naturally the one that achieves the reduction of risk to an acceptable level at the most reasonable cost.

Conclusions

The present paper provides an overview of layers of protection suitable to reduce the risk level of a process facility that handles hazardous materials, i.e., measures intended to prevent and/or mitigate the identified hazardous scenarios. For all layers of protection considered, the Safety Instrumented Systems (SIS) and performance-based Fire and Gas Detectors (FGD) were found as safeguards that should comply with very specific requirements stated in related standards. Using these systems provides a strong, quantifiable basis for risk reduction at CPI facilities. Both systems are not covered in the scope of the present paper and dedicated guidance is provided in references **[14]** and **[16]** respectively.

Based on the results of a risk-based quantitative assessment, zones or locations and their associated hazardous scenarios having the most significant intolerable risk level can be identified. Sensitivity analysis and cost-benefit analysis can be performed with the aim to find which safeguards achieve reducing risk to an acceptable level at the most reasonable cost.

References

[1] ISO 17776, 2000. “Petroleum and Natural Gas Industries - Offshore Production Installations - Guidelines on Tools and Techniques for Hazard Identification and Risk Assessment”.

[2] Amorós, M., Dunjó, J., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Quantitative Risk Assessment. Foundation of Process Safety and Loss Prevention”. An ioMosaic White Paper, ioMosaic Corporation.

[3] Dunjó, J., Amorós, M., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Hazard Identification. Guidance for Identifying Loss of Containment Scenarios”. An ioMosaic White Paper, ioMosaic Corporation.

[4] Dunjó, J., Amorós, M., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Frequency Analysis. Estimating Frequencies of Occurrence and Conditional Probabilities of Loss Containment Scenarios”. An ioMosaic White Paper, ioMosaic Corporation.

[5] Dunjó, J., Amorós, M., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Damage Criteria. An Overview of the State-of-the-Art Damage Criteria for People and Structures”. An ioMosaic White Paper, ioMosaic Corporation.

[6] Dunjó, J., Amorós, M., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Consequence Analysis. An Introduction to Consequence Modeling and Identification of Outcomes from Loss of Containment Scenarios”. An ioMosaic White Paper, ioMosaic Corporation.

[7] Amorós, M., Dunjó, J., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Risk Evaluation. Tools for Risk Characterization”. An ioMosaic White Paper, ioMosaic Corporation.

[8] Dunjó, J., Amorós, M., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Risk Tolerability Criteria. An Overview of Worldwide Risk Tolerability Criteria for Chemical Process Industries”. An ioMosaic White Paper, ioMosaic Corporation.

[9] IEC 61508, 2010. “Functional Safety of Electrical / Electronic / Programmable Electronic Safety-related Systems”. Parts 1-7 International Electrotechnical Commission (IEC).

[10] IEC 61511, 2016. “Functional Safety - Safety Instrumented Systems for the Process Industry Sector”. Parts 1, 2 and 3. International Electrotechnical Commission (IEC).

[11] ISA 84.00.TR.07, 2010. “Guidance on the Evaluation of Fire and Gas System Effectiveness”. International Society of Automation (ISA).

[12] Kletz, T. A., Amyotte, P., 2010. “Process Plants: A Handbook for Inherently Safer Design”. Second Edition. CRC Press, Boca Raton, FL.

[13] CCPS, 2010. “Definition for Inherently Safer Technology in Production, Transportation, Storage and Use. Prepared by Center for Chemical Process Safety”. The American Institute of Chemical Engineers Center for Chemical Process Safety, for U.S. Department of Homeland Security, Science and Technology, Chemical Security Analysis Center, Aberdeen Proving Ground, MD.

[14] Dunjó, J., Amorós, M., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Preventing Hazardous Scenarios. An Introduction to Safety Instrumented Systems (SIS)”. An ioMosaic White Paper, ioMosaic Corporation.

[15] Melhem, G.A., 2015. “Advanced Consequence Analysis; Fluid Flow, Emergency Relief Systems Design, Thermal Hazards Assessment, Emission, Dispersion, Fire and Explosion Dynamics”. ioMosaic Corporation.

[16] Dunjó, J., Amorós, M., Prophet, N., Gorski, G., 2016. “Risk-Based Approach – Mitigating Hazardous Scenarios. An Introduction to Fire and Gas Detectors Mapping”. An ioMosaic White Paper, ioMosaic Corporation.

[17] ioMosaic Corporation, SuperChems™ a component of Process Safety Office™, ioMosaic; http://www.iomosaic.com/software/process-safety-office-.