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TECHNICAL REPORT

ISA-TR84.00.07-2018

Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness

Approved August 10, 2018

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ISA-TR84.00.07-2018, Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness

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Contents

Foreword	- 9 -
Introduction.....	- 11 -
1 Scope	- 15 -
2 References	- 15 -
3 Definition of terms and acronyms.....	- 17 -
4 Risk concepts in FGS design	- 19 -
5 FGS engineering activities in a project workflow.....	- 40 -
Annex A – Sample semi-quantitative performance target selection technique	- 43 -
Annex B – Detector coverage assessment techniques	- 53 -
Annex C – Mitigation action effectiveness concept	- 63 -
Annex D – Application examples	- 67 -
Annex E – Evaluation of computational fluid dynamics vs. target gas cloud for indoor gas detection design (reference 2.17)	- 97 -

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Foreword

The work to develop this edition of ISA-TR84.00.07 began in 2014 and was completed in 2018. At the same time, the functional safety standard ANSI/ISA 84.00.01-2004 was undergoing updates in parallel with IEC 61511. The ISA84 Fire and Gas Working Group maintained awareness of committee activities associated with modifying the governing standards. The scope of updates to the 2nd Edition of this technical report was limited by the ISA84 committee, and it was not in the working group's charter to align this edition of the technical report with the subsequent issuance of ISA's functional safety standard.

This technical report describes how the underlying principles of the functional safety standards can be applied to fire and gas systems. Those same underlying principles that were used to develop the guidance in the technical report remain consistent in the new issuance of IEC 61511-2016 and ANSI/ISA-61511-2018 (replacing ANSI/ISA-84.00.01-2004). Because of the timing associated with approval and publication, this technical report retains the references to ANSI/ISA-84.00.01-2004. At the time of publication, the working group provides this acknowledgment that the recent publication of ANSI/ISA-61511-2018 retains the same scope, application and underlying principles associated with fire and gas systems.

ISA-TR84.00.07-2018 is intended for use in evaluating the effectiveness of fire and gas systems (FGSs) in process industry applications. It addresses the implementation of FGSs to reduce the risk of hazardous releases involving safety impact.

NOTE Users can choose to apply the concepts in this technical report to environmental and/or operational loss scenarios.

ISA-TR84.00.07-2018 is provided for information purposes only and is not part of ANSI/ISA-84.00.01-2004 (IEC 61511 Modified) (reference 2.1).

ANSI/ISA-84.00.01-2004 and IEC 61511 (reference 2.9) are performance-based standards that provide the minimum requirements for designing and managing a safety instrumented system (SIS). As part of the safety lifecycle, the functional and integrity requirements are established for safety functions that reduce the risk of hazardous events identified using a hazard and risk analysis. Guidance is provided in Part 3 of either ANSI/ISA-84.00.01-2004 or IEC 61511 on the various methods used to evaluate risk and allocate risk reduction to identified safety functions. An underlying assumption in all of the methods is that the identified safety functions are capable of achieving the allocated risk reduction in the operating environment.

The scope of ANSI/ISA-84.00.01-2004 covers electrical / electronic / programmable electronic systems for use in safety applications. Accordingly, the ISA84 committee develops standards and technical reports to provide guidelines for the implementation of automated (or instrumented) systems in safety applications. The purpose of ISA-TR84.00.07-2018 is to provide guidance on how to evaluate the effectiveness of identified FGS functions in a manner that is consistent with the underlying principles of ANSI/ISA-84.00.01-2004. FGS functions that are identified as safety controls, alarms, or interlocks should be implemented according to the applicable requirements of ANSI/ISA-84.91.01-2012 (reference 2.10) and ANSI/ISA-84.00.01-2004, based on the degree of risk reduction being claimed for the FGS function, in addition to relevant application specific practices. For example, FGS functions should be implemented per applicable requirements in the following standards, based on the risk reduction needed:

- General fire and gas system safeguards with no specific risk reduction claimed should be implemented per application-specific standards from local jurisdiction having authority.
- FGS functions with claimed FGS risk reduction factor (RRF) less than or equal to 10 should be implemented per applicable requirements of ANSI/ISA-84.91.01-2012, *Safety Controls, Alarms and Interlocks in the Process Industries*.
- FGS function with claimed FGS risk reduction factor (RRF) in excess of 10 should be implemented per the applicable requirements of ANSI/ISA-84.91.01-2012 and ANSI/ISA-

84.00.01-2004 (based on IEC 61511 compliance, which includes consideration for IEC 61508 compliance and/or end-user prior use approval of sensor, logic solver and final element sub-systems).

Prescriptive approaches for the design of some/all components of an FGS are provided in recognized and generally accepted good engineering practices (reference 2.2 and 2.3) for certain applications. In complex hazard scenarios, especially those involving high-risk exposure (e.g., offshore oil and gas installations), and in situations where no other prescriptive guidance is available, supplementing these practices with performance-based analysis can result in an improved design with more effective coverage and lower probability of FGS failure. It is ultimately the user's decision on when to apply performance-based approaches. Nothing in this technical report suggests the prescriptive practices are invalid or that they should not be followed as required by local jurisdictional authorities. The concepts underlying a performance-based approach are suitable to the analysis and design of FGSs in process industries, and these principles can be used effectively in conjunction with other good engineering practices.

THE EXAMPLE RISK ANALYSIS METHODS AND RISK CRITERIA CONTAINED IN THIS TECHNICAL REPORT HAVE BEEN PROVIDED SOLELY AS EXPLANATORY MATERIAL AND SHOULD NOT BE INTERPRETED AS RECOMMENDATIONS.

ALSO, THE EXAMPLE FGS ARCHITECTURES, DETECTOR COVERAGES, AND MITIGATION EFFECTIVENESS REPRESENT POSSIBLE SYSTEM CONFIGURATIONS AND SHOULD NOT BE INTERPRETED AS RECOMMENDATIONS. THE CONFIGURATIONS USED IN ACTUAL APPLICATIONS ARE SPECIFIC TO THE OPERATING ENVIRONMENT AND PROCESS CONDITIONS IN WHICH THEY ARE USED. AS SUCH, NO GENERAL RECOMMENDATIONS CAN BE PROVIDED THAT ARE APPLICABLE IN ALL SITUATIONS.

THE USER OF THIS TECHNICAL REPORT IS CAUTIONED TO CLEARLY UNDERSTAND THE ASSUMPTIONS AND DATA ASSOCIATED WITH THE METHODOLOGIES IN THIS DOCUMENT BEFORE ATTEMPTING TO UTILIZE THE METHODS PRESENTED HEREIN.

Users of ISA-TR84.00.07-2018 will include:

- Vendors, end-users, and consultants who are applying the performance-based concepts to FGS functions, in addition to other applicable good engineering practices.
- Hazard and risk analysis teams that are allocating risk reduction to FGS functions.
- FGS designers who want to understand the impact of detector coverage and mitigation effectiveness on the integrity of FGS functions.
- Any additional entities who wish to gain further insight into performance based FGS design concepts.

Introduction

The ISA84 standards committee formed a working group to study the analysis and design processes that are commonly used in the process industry for fire and gas systems (FGSs) and to provide guidance on how these processes can be adapted to incorporate performance-based concepts.

FGSs, as they are considered in this report, are a subset of industrial automation and control systems that are employed in the process industries for the purpose of detecting loss of containment of hazardous materials from the process and initiating a response to mitigate the release impact. Loss of containment can be a small leak or a catastrophic release. It can be detected by measuring the presence of the released materials (e.g., gas concentration) or inferred from the effects of the release (e.g., thermal radiation from a fire).

Detection methods considered in this technical report can include detection of combustible gas, toxic gas, smoke, flame, acoustic emission, or rapid heat rise in areas adjacent to the process itself and in critical areas, such as occupied buildings or buildings with unrated electrical equipment. Detector coverage and associated detection capability vary substantially depending on the hazard scenario and the characteristics of the detector.

Actions taken by the FGS can be manually or automatically initiated and can affect a wide variety of systems, such as sheltering in place or evacuation in response to audible and visual alarm indications; water deluge; fire suppressant initiation; manipulation of heating, ventilation, and air conditioning (HVAC) system equipment; process isolation; or process depressurization. Similar to detection capability, the effectiveness of these mitigative actions is highly scenario dependent.

Use of performance-based design is not widely adopted for FGSs within the process industries. However, ANSI/ISA-84.00.01-2004 or IEC 61511 can be employed as a design basis for mitigative fire and gas safety functions by considering the following definitions from ANSI/ISA-84.00.01-2004 or IEC 61511:

mitigation

action that reduces the consequence(s) of a hazardous event

NOTE 1 Examples include emergency depressurization on detection of a confirmed fire or gas leak.

prevention

action that reduces the likelihood of occurrence of a hazardous event

protection layer

any independent mechanism that reduces risk by control, prevention, or mitigation

NOTE 1 It can be a process engineering mechanism such as the size of vessels containing hazardous chemicals, a mechanical mechanism such as a relief valve, a SIS, or an administrative procedure such as an emergency plan against an imminent hazard. These responses may be automated or initiated by human actions.

[SOURCE: IEC 61511-1:2016, Definition 3.2.61, modified – reference to Figure 9 removed from Note 1]

safety function

function to be implemented by one or more protection layers, which is intended to achieve or maintain a safe state for the process, with respect to a specific hazardous event

NOTE 1 The safe state of the process for each identified safety function is defined such that a stable state has been achieved and the specified hazardous event has been avoided or sufficiently mitigated.

[SOURCE: IEC 61511-1:2016, Definition 3.2.69, added Note 1, derived from 10.3.1.d]

safety instrumented function (SIF)

safety function to be implemented by a safety instrumented system (SIS)

NOTE 1 A SIF is designed to achieve a required SIL, which is determined in relationship with the other protection layers participating in the reduction of the same risk.

There are two broadly different philosophical approaches used in the process industries for establishing design requirements to ensure the availability and effectiveness of FGSs: prescriptive and performance-based. The choice of design method is an owner/operator decision. FGSs have traditionally been designed and implemented according to various good engineering practices, such as NFPA 72 (reference 2.2) and EN 54 (reference 2.3). These prescriptive practices do not require evaluation of the risk reduction capability of the FGS as measured by its safety integrity and probability of failure on demand (PFD), nor do they consider quantitative measures for detector coverage.

A performance-based approach consistent with the ANSI/ISA-84.00.01-2004 or IEC 61511 is attractive because it builds on the strength of the existing standard. However, without guidance, a performance-based approach has historically been challenging to apply to FGS design due to several factors.

Traditional hazard and risk analysis techniques are suited for hazards related to process deviations from normal operation. These process hazards have known initiating causes and consequences, allowing the safety function to be specifically designed to detect the event and to respond by achieving or maintaining a safe state of the process. FGSs are typically implemented to reduce the risk of general loss of containment, such as leaks from equipment seals, flanges, and piping, and are often not associated with a specific hazardous scenario. These hazards can be difficult to define and analyze and often require the use of advanced risk analysis techniques, such as gas dispersion, fire, and explosion modeling.

Most often FGSs do not prevent hazardous consequences from occurring, but rather mitigate the effects of an event that has already occurred. FGSs typically reduce the magnitude and severity of the consequence instead of eliminating it. Typical hazard and risk analysis assumes that the identified safety function eliminates the consequence. Therefore, it is important to understand and evaluate the hazard scenario resulting from FGS operation to ensure that the residual risk is acceptable.

An FGS can provide poor risk reduction due to an inadequate detection rate. An analysis by Health and Safety Executive (HSE) of eight years of hydrocarbon release data (reference 2.4) showed that the effective detection rate was about 60%. The detection of many releases was significantly delayed, leading to higher consequences than expected. Even if very high integrity can be achieved by the hardware design and testing (e.g., low average probability of failure on demand), sufficient reduction in risk will not occur unless the detector coverage is also very high. For FGS functions, detector coverage should be analyzed with the same (if not more) quantitative rigor as the verification of the average probability of failure on demand for the hardware design.

FGS effectiveness is also related to the ability of the mitigation elements (e.g., fire water system, ventilation system, process isolation) to function in a way that reduces hazardous consequences predictably. Mitigation can include

- stopping the process
- diverting the hazardous material
- applying fire water with the appropriate flow and spray characteristics
- activating alarms notifying personnel to shelter in place or evacuate

As in the case of detector coverage, the effectiveness of the mitigative actions is dependent on many situational or scenario-specific factors. As a result of these complexities, initiating an FGS's action might not necessarily mean that the consequence can be fully mitigated.

As a result of these factors, a comprehensive approach to the hazard and risk analysis is indicated, as it is often difficult to develop a sound technical justification for allocating risk reduction to FGS functions using a simplified risk assessment process, such as layer of protection analysis (LOPA)

(reference 2.5 and 2.6). The identification of FGS functions and allocation of performance targets to them requires hazard and risk considerations that are beyond typical LOPA implementation. Furthermore, FGS performance verification should include evaluation of the detector coverage and consider the effectiveness of the mitigative actions and the safety availability of FGS hardware and software design.

This ISA technical report describes the analysis that should be undertaken and the effectiveness criteria that should be specified when an FGS is implemented in a safety application. The report integrates performance-based fire and gas system design techniques into the applicable portions of the safety life cycle described in either ANSI/ISA-84.00.01-2004 or IEC 61511. The report also discusses the development of detector-coverage criteria applicable to each FGS function and includes a series of application examples (Annex D) that illustrate the techniques used to develop and verify the detector coverage and mitigation effectiveness.

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1 Scope

This technical report is informative and does not contain any mandatory requirements.

This technical report is intended to be used in conjunction with other good engineering practices applicable to FGS installations. It is not intended to stand alone or be a replacement for application-specific practices.

ISA-TR84.00.07 is a derivative of the ANSI/ISA-84.00.01-2004 (IEC 61511 Mod) standard with application to process industries. This technical report is intended to address detection and mitigation of fire, combustible gas, and toxic gas hazards in process areas. Fire detection and mitigation within nonprocess areas is outside the scope of this document.

This technical report is intended to:

- Be used by those with a thorough understanding of ANSI/ISA-84.00.01-2004.
- Clarify the additional information that should be considered when developing a performance-based FGS design. This includes integrating the design activities into relevant portions of the safety life-cycle model.
- Clarify how to define FGS functions within typical FGS designs where automatic action is taken as a result of detection of a fire or gas event.
- Provide example scenario assessments to demonstrate the application of performance-based concepts to the analysis and design of FGSs.
- Demonstrate that any coverage or effectiveness factor below 90% results in an FGS risk reduction factor of less than 10 of the FGS design.
- Offer a performance-based methodology—for facilities using a prescriptive methodology (e.g., API-14C or API 14G) (reference 2.20 and 2.21) to allocate fire and gas detection. The methodology provides considerations for how to improve fire and gas effectiveness. The performance-based design process described in this TR can provide more effective hazard detection and detector placement in cases where fusible plugs (fire) may be needed.
- Define a methodology that addresses the design and effectiveness of FGS mitigative functions that is consistent with the underlying principles used to design and assess the effectiveness of preventative functions.

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3 Definition of terms and acronyms

3.1 Definitions

This section contains definitions of terms that have been introduced or clarified with respect to performance-based FGS applications and included in this technical report.

detector (geographic) coverage

The fraction of the geometric area or volume of a defined monitored process area that, if a hazard were to occur in a given geographic location, would be detected considering the defined voting arrangement.

detector (scenario) coverage

The fraction of the hazard scenarios from process equipment within a defined and monitored process area that can be detected considering the frequency and magnitude of the hazard scenarios and the defined voting arrangement.

fire and gas mapping

The analysis of detector coverage to examine a proposed or existing FGS detector layout/voting arrangement and verify FGS performance targets are achieved by the design.

FGS effectiveness

The ability of the FGS function to detect and mitigate a design-basis hazard under a demand condition.

NOTE 1 FGS effectiveness is dependent on a number of factors associated with design, installation, site-specific operating conditions, and maintenance. FGS effectiveness is a function of the selected FGS performance metrics, including detector coverage, FGS safety availability, and mitigation action effectiveness, accounting for common cause, common mode, and systematic failures.

FGS risk reduction factor

The ability of the FGS function to reduce the frequency of occurrence or the severity of harm.

NOTE 1 FGS risk reduction factor is analyzed quantitatively for FGS functions that prevent or completely mitigate the hazard as a factor equal to the reciprocal of one (1) minus FGS effectiveness.

NOTE 2 For FGS safety functions that do not completely mitigate the hazard, the residual risk is included in the analysis of FGS risk reduction. See Annex C for example.

FGS safety availability

The availability of the fire and gas function designed to automatically mitigate the consequences of hazards.

NOTE 1 FGS availability is equal to one minus the probability of failure on demand (PFDavg) for the FGS safety function (sensor, logic solver, and/or final element).

mitigation action effectiveness

The confidence that the final element(s) actions will successfully mitigate the consequence of the hazard defined in the FGS basis of design.

NOTE 1 Refer to Annex D for additional guidance on mitigation effectiveness.

1ooN voting arrangement

Implementation of 1ooN (where $N > 1$) voting in an FGS is such that upon activation of any single detector in a monitored area with multiple detectors, the logic solver commands specified safety action(s) to occur.

NOTE 1 This arrangement tends to provide a higher level of safety in that a dangerous undetected failure of a single detector will not inhibit the required safety action once the hazard is detected by any second nonfailed detector. This arrangement also provides a relatively higher level of exposure to spurious activation of the FGS, because a false alarm signal generated by any single detector will cause safety action(s) to occur when no hazard is present.

MooN voting arrangement

Implementation of MooN (where $N > 1$) voting in an FGS is such that the logic solver commands specified safety action(s) to occur only upon activation of any M or more detectors in a monitored area.

3.2 Abbreviations and acronyms

1ooN: one out of N voting

1oo2: one out of two voting

3D: three dimensional

AIChE: American Institute of Chemical Engineers

ALARP: as low as reasonably practicable

ANSI: American National Standards Institute

API: American Petroleum Institute

CCPS: Center for Chemical Process Safety

CCTV: closed-circuit television

CFD: computational fluid dynamics

ERPG: emergency response planning guideline

ESD: emergency shutdown

FEED: front-end engineering design

H₂S: hydrogen sulfide

HSE: Health and Safety Executive

HVAC: heating ventilation air conditioning

IDLH: immediately dangerous to life and health

IEC: International Electrotechnical Commission

IR: infrared

ISA: International Society of Automation

FGS: fire and gas system

λ_{DU} : dangerous undetected failure rate

LEL/LFL: lower explosive limit/lower flammability limit

LOPA: layers of protection analysis

MOS: metal oxide semiconductor

NFPA: National Fire Protection Association

OSHA: Occupational Safety and Health Administration

PEL: permissible exposure limit

PFD_{avg}: probability of failure on demand average

PHA: process hazards analysis

PPM: parts per million

QRA: quantitative risk assessment

RHO: radiant heat output

RRF: risk reduction factor

SIF: safety instrumented function

SIL: safety integrity level

SIS: safety instrumented system

STEL: short-term exposure limit

TI: test interval

TLV: threshold limit value

TWA: time weighted average

UV: ultraviolet

VCE: vapor cloud explosion

4 Risk concepts in FGS design

This technical report provides an overview of some hazard and risk analysis methods applicable to fire and gas system design, including qualitative, semi-quantitative, and fully quantitative methods to estimate risk. Hazard and risk analyses are often used to identify loss-of-containment events due to a process deviation from normal operation. In contrast, most FGS functions are specified to address the risk of loss of containment due to problems with equipment mechanical integrity or other general causes of loss of containment not related to process hazard analysis (PHA) scenarios. Regardless of how the need for these functions is identified, an FGS can be important to an overall risk management strategy.

A performance-based design of safety functions is proceeded by analyzing the hazard and risk of credible scenarios and allocating risk reduction to safety functions that will be specifically designed to address these events. Although a variety of methods are used in the process industries, an increasingly common method is layer of protection analysis (LOPA) (reference 2.5 and 2.6). LOPA is an established method for evaluating hazardous event propagation and assessing the capability of safety functions in reducing event risk. An important objective of LOPA is to ensure adequate independence and separation of the initiating causes from independent protection layers to minimize common cause, common mode, and systematic failures.

However, LOPA does have limitations, which become clear when examining FGS functions. LOPA typically considers only two possible states for a candidate protection layer: success or failure. If the protection layer fails, there is a consequence. If the protection layer succeeds, the propagation of the hazardous event is halted and there is no consequence. While this is an appropriate assumption for many independent protection layers, it is not suitable for FGSs, since they typically do not stop the loss of containment event from occurring. Instead, a successful FGS function prevents an already bad situation from getting worse. It is crucial to ensure that common cause and dependent mode failures are evaluated between the FGS and the initiating source. If the end-user risk criteria are based on preventing the hazardous event (i.e., preventing the release of

materials), no risk reduction will be claimed for the FGS. Nevertheless, the principles in this TR may be used to provide guidance for improved FGS safeguard design.

This technical report presents a risk model to illustrate the concepts of how mitigative system risk can be analyzed. It addresses the detector coverage, safety availability, and mitigation effectiveness, and thereby allows these factors to be explicitly considered in the hazard and risk assessment. This model uses a simplified event tree to illustrate the risk analysis of identified initiating events from the initiating cause(s) to the final outcome(s). For FGSs, the simplified event tree (Figure 1) considers three aspects of FGS effectiveness: detector coverage, FGS safety availability, and mitigation effectiveness. While this simplified event tree shows mitigation effectiveness as a single probabilistic value, this is only to illustrate the risk concepts. In reality, the effectiveness of mitigation actions is often a more complex collection of factors. The event tree branches represent the probability of success and the probability of failure of these aspects—the mathematical complements.

The event tree begins with a hazard arising from loss of containment within an area of concern and follows the propagation of the scenario through the success (yes)/failure (no) of each aspect contributing to effectiveness. Quantitative analysis can be used to report the relative likelihood and magnitude of the consequence of each potential outcome. Risk assessment determines the tolerability of the potential outcomes based on the consequence severity and likelihood by comparing the outcome frequency and consequence severity to the end-user risk criteria.

	FGS Detector Coverage	FGS Safety Availability	FGS Mitigation Effectiveness	Relative Likelihood	Outcome
		Yes	0.90	0.70	Mitigated
	Yes	0.97			
	0.8		0.10	0.08	Unmitigated
Design Basis Hazard		No			
1.0		0.03		0.02	Unmitigated
	No				
	0.2			0.20	Unmitigated
			FGS Effectiveness	0.70	

Figure 1 – FGS effectiveness model

The first aspect of FGS effectiveness is the probability that the hazard is detectable given the detector layout and chosen voting arrangement. For example, if action is taken upon activation of two or more gas detectors, the hazard is detectable only if the scenario involves a gas cloud that covers at least two detectors in the array. Loss of containment places a demand on the FGS, requiring its sensor array to detect the hazardous condition and to initiate required action. Failed detection allows the incipient condition to escalate to a larger magnitude event. This escalated hazard might not be detectable by other detectors in the FGS; and if detectable, the FGS might not be effective in mitigating the larger hazard. This complexity has not been incorporated into the risk model in this technical report. For the sake of simplicity, it is assumed that an incipient condition that is not detected due to inadequate detector coverage results in an unmitigated hazard that is beyond the capability of the FGS to effectively mitigate.

The second branch of the event tree (FGS safety availability) represents the probability of successful FGS activation upon a detected hazard. FGS functions comprise sensor(s), logic solver(s), and final element(s). Failure of the FGS function to operate on demand results in

escalation of the consequence. Quantification of the probability of failure on demand can be performed using the techniques presented in ISA-TR84.00.02 (reference 2.8).

The third branch of the event tree is the FGS mitigation action effectiveness, which has an impact on the event outcomes and should be carefully considered when evaluating overall effectiveness of an FGS function. The design intent of an FGS is typically not to prevent a hazardous condition from initially occurring, but rather to reduce (or mitigate) the severity of consequences to a lower level. A small fire is prevented from becoming a large fire that can escalate into a larger or unacceptable consequence. A small gas release that presents a toxic and/or fire hazard is prevented from becoming a large gas accumulation that could result in a larger or unacceptable consequence. Therefore, the residual risk associated with a successful FGS operation should be considered in the overall determination of risk acceptability.

However, it would be technically incorrect to consider the FGS detector coverage, safety availability, and mitigation effectiveness in the same manner as one would consider independent protection layers. The separate depiction in the event tree of FGS detector coverage, safety availability, and mitigation effectiveness is simply intended to highlight the aspects of the FGS that make its evaluation different from the typical instrumented safeguard. Personnel involved in the design or modification of FGSs should consider that any change to the FGS or to the context in which it is installed will most likely result in changes to the values of all three of these parameters.

Different methods with different degrees of quantitative rigor are used in the process industries to implement the concepts discussed in the preceding paragraphs. These methods range from semi-quantitative techniques to full quantitative risk analysis (QRA) methods. A quantitative risk analysis can be used to make decisions about the risk reduction strategy (reference 2.7). The QRA should be based on a comprehensive risk analysis and consequence modeling for the hazardous event under consideration. Semi-quantitative methods utilize scoring methods that categorize the attributes that define risk and then select grades of FGS performance based on the results of the scoring process (see Annex A).

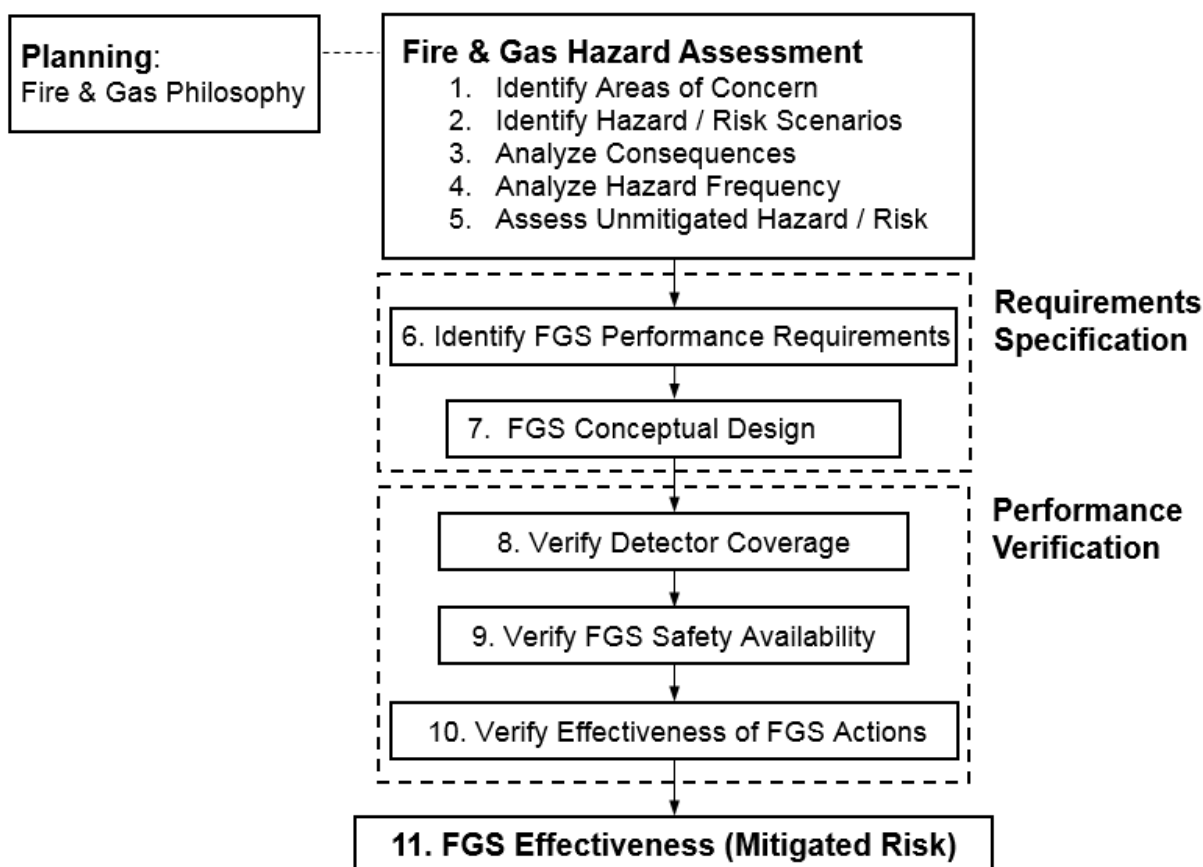
Where possible and practical, other instrumented safety systems, such as safety instrumented functions, should be designed to prevent loss of containment. The development of a methodology to allow the allocation and verification of the risk reduction capability of an FGS function should not be construed as an endorsement of the use of an FGS function in lieu of a properly designed preventive safety instrumented function. Thus, if risk analysis determines that two orders of magnitude of risk reduction is required to address a high-pressure scenario in a vessel, a safety instrumented function closing inlet feed to the vessel upon detection of high pressure with a risk reduction of two orders of magnitude is preferable. This technical report does not endorse addressing the above hazardous event with a safety instrumented function achieving one order of magnitude in combination with an FGS function providing the remaining one order of magnitude in risk reduction. This technical report focuses on the implementation of FGSs to protect people and the environment when the process is operating normally, but loss of containment has occurred due to such factors as corrosion, erosion, a leaking gasket, or tubing failure, or the process is operating abnormally, and preventative layers have failed. Thus, consider a different scenario where the pressure in the vessel is within tolerable limits (e.g., not high) and loss of containment has occurred. In this scenario, an FGS function is an appropriate choice for reducing the risk, because there is no potential for implementing a preventive safety instrumented function to prevent loss of containment.

It is advisable to use an approach that ensures:

- Loss of containment is minimized through implementation of preventive systems and an equipment mechanical integrity program.
- FGSs are designed and maintained to be effective in reducing the severity of loss-of-containment.

4.1 Performance-based FGS design process

Design and implementation of an FGS can be performed in a manner that is consistent with the underlying principles of both ANSI/ISA-84.00.01-2004 and IEC 61511. The fundamental approach is to examine the hazard and risk in order to establish required FGS performance, and then to specify a design that achieves that performance. This performance-based FGS design process is illustrated in Figure 2, and it integrates into the relevant portions of a safety life cycle for safety functions.



NOTE Steps 7, 8, 9, and 10 may require iteration to meet performance targets.

Figure 2 – Performance-based FGS design process

4.2 Planning: Fire and gas philosophy

Planning for performance-based FGS design should include determination of the end user's fire and gas system philosophy. This philosophy is a well-reasoned technical basis that establishes the overall goals for hazard detection and mitigation. It should be consistent with the end user's risk acceptance criteria that will be used in the allocation of safety functions to protection layers. It guides choices made by FGS designers. Appropriate choices for a given user facility are often best performed through standardized application of a fire and gas philosophy.

FGSs are beneficial in mitigating the severity of hazards typical to the process industries. Additional information about these hazards can be found in CCPS (reference 2.7). The description here is intended to aid in defining FGS performance objectives based on the chosen philosophy of the end user.

To understand performance requirements for FGS, it is important to have a definition of the end user's philosophy that is being applied to mitigate hazards. Mitigation systems usually need to have a philosophy developed before a designer can proceed. Different users of this TR will have different philosophical approaches toward detection and mitigation of fire and gas hazards. This section describes how the elements of the fire and gas philosophy translate to performance-based FGS design. Some elements of a mitigation philosophy are included in codes, industry recommended practices, or company standards. However, elements associated with detection and mitigation are usually established by the end user.

The primary questions to be addressed in defining the performance objectives for fire and gas mitigation:

- What magnitude of hazards should the FGS detection equipment be designed for?
- What FGS actions are required to successfully mitigate the hazard?

This TR provides guidance on how the chosen philosophy will impact performance-based FGS design.

4.3 Fire detection philosophy

When flammable or combustible hydrocarbon liquids are released from the process, accumulate, and are subsequently ignited, the result is a turbulent diffusion fire. The extent of a pool fire hazard is governed by the size of the pool, the burning intensity of the fuel, and to a lesser extent, meteorological conditions. When pressurized gas (or liquid/two-phase) is released and ignited immediately upon release, the result is a momentum-driven, turbulent jet fire. The extent of a jet fire hazard is governed by the rate of release, the shape of the flame, the flame orientation, and the burning intensity of the fuel.

Both pool fires and jet fires emit thermal radiation, which can be hazardous to people within seconds of exposure. Process equipment or structures can be damaged within minutes of intense fire exposure, especially if fireproofing is not provided or not effective. Fires can produce heavy smoke, which is hazardous if introduced in an occupied building. Personnel can be harmed either by the direct effect of the ignition of the hydrocarbon release or by exposure to an ongoing fire if the ability to safely evacuate is impaired. Fire detection can be beneficial in the latter case, by detecting an incipient fire in time before further exposure to personnel or impairment of evacuation routes can occur.

The actions that are most effective in the early (incipient) stage of a fire are:

- alarms and evacuation/sheltering of personnel
- automatic emergency shutdown (ESD) with isolation of fuel and depressurizing
- activation of deluge systems/foam systems to suppress burning, cool surrounding equipment, or, in some cases, extinguish the fire

If a fire is not detected early (incipient), the potential exists for the fire to escalate to a hazard that impacts more equipment, impacts evacuation/egress, and causes more severe harm to people and the process.

Fire detection philosophy statements are useful in determining the performance objectives of fire detection system. The performance objective will guide the designer on the magnitude of fire that should be detected and the safety actions to be automatically activated. With a specific philosophy statement, the FGS designer can identify the performance objectives, and this will guide the designer to choose the proper basis of design. Without a well-defined philosophy, the FGS designer can provide a system that is over-designed or under-designed and does not achieve end-user expectations. The following are two different philosophies for fire detection. Each is valid for a particular application.

Table 1 – Example fire detection philosophies

Fire Detection Philosophy	Elements of Philosophy Decision	Typical Application
Goal is to detect fire as early as practical to reduce the possibility of escalation, minimize impact to the asset, and allow personnel to take appropriate protective actions.	<i>Within a monitored process area:</i> Detection: Incipient fire Successful FGS mitigation - prompt evacuation or shelter-in-place response to alarm notification - isolate fuel source - depressurize the process - initiate fixed fire suppression of affected equipment and surrounding equipment	Occupied offshore facilities High-value assets Onshore process plants with significant occupancy
	<i>Migration beyond monitored process area:</i> Detection: Smoke at building air intakes Successful FGS mitigation: - prompt evacuation or shelter-in-place response to alarm notification - shutdown ventilation	Occupied offshore facilities
Goal is to detect fire that has the potential to produce major damage beyond the area of origin to mitigate against total asset loss.	<i>Within a monitored process area:</i> Detection: Fully developed fire Successful FGS mitigation isolate fuel source and allow to extinguish by depletion of fuel	Normally unmanned installations, onshore or offshore, with limited firefighting capability
	<i>Migration beyond monitored process area:</i> Detection: (none)	

It is impractical to detect all potential fire hazards. Detection can occur of an incipient hazard (early stage) or a fully developed hazard. Note that with larger fires, optical flame detector performance might be degraded. Safety actions can be as simple as containment and isolation of fuel, or as complicated as isolation, depressurizing, and suppression. The fire detection philosophy should specify if alarms and FGS actions will occur on a single detector in alarm state (100N) or require more than one detector in alarm state (e.g., 200N).

4.4 Flammable gas detection philosophy

When flammable gas (or volatile liquid) is released but not immediately ignited, a flammable fuel-air mixture forms, which can accumulate and/or migrate away from the point of release. Safe dispersion occurs when the gas dilutes in air below the lower flammable limit (LFL) concentration.

If there is an absence of physical confinement of the flame front and absence of flame front interaction with turbulence-inducing obstacles, then the flame will not significantly accelerate. If ignited, the initial phenomenon is a short-duration, transient fire that burns from the point of ignition through the gas cloud in short duration. The flame front expands slowly near the point of ignition. In the event the flame front does not accelerate, the vapor cloud fire will not produce a significant pressure wave (blast). The fire is therefore called a flash fire. A flash fire is hazardous, but the extent is limited to the shape/size of the flame envelope itself.

However, gas can accumulate in confined and semi-confined areas of a process. Historically, a minimum gas cloud accumulation of 5 meters (reference 2.4 and 2.12) was demonstrated to be sufficient for enabling a flame front to accelerate to a velocity that has the potential to cause a significant pressure wave. This does not exclude the potential that under adverse conditions, an accumulation of less than 5 meters might result in similar hazards. This pressure wave is also called a blast, and the phenomenon is known as a vapor cloud explosion (VCE). The extent of the VCE hazard is governed by the amount of gas accumulation and the degree of confinement and congestion, and it can be measured as the pressure generated by the blast and its duration.

Personnel located outdoors are often not injured by the pressure wave itself but can be hurt by high-velocity fragments. Non-blast-resistant structures can be severely damaged or collapse, causing harm to building occupants. Blast effects can result in hazards at significant distance beyond the boundary of the flammable cloud.

It is desirable to detect flammable gas before ignition, especially if it is in a confined and congested area where the gas can accumulate. FGS can be beneficial in detecting the presence of a flammable fuel-air mixture (or detecting a release of high-pressure gas). Automatic actions can be taken by the FGS to minimize both the possibility of ignition and the severity of the vapor cloud fire hazard. Actions that are most effective in the early stage of a gas release or accumulation are:

- alarms and evacuation/sheltering of personnel
- automatic ESD with isolation and depressurizing equipment that can be leaking gas
- automatic control of ignition sources (electrical de-energization, etc.)
- activation of deluge systems to disperse gas and suppress burning of the gas

In this context, early detection means before a high probability of ignition or before a large accumulation occurs. If gas is not detected early, there is the potential for further accumulation resulting in escalation to a more severe hazard, including the potential for a VCE, or for gas to migrate beyond the process area to locations where there is either high personnel occupancy or strong ignition sources.

Within a few seconds or less, a vapor cloud fire will burn back to the point of ignition and cause the hazards described above; however, the aftereffects can include a residual jet fire (for a momentum-driven release) or pool fire (for a liquid release/pooling), or perhaps both. The residual fire will continue to burn until the source of the fuel is isolated and any accumulated fuel is consumed. While it is highly preferable to detect a flammable gas hazard before ignition to safeguard life, FGS can also be beneficial in detecting the residual fire and taking actions to limit its duration and intensity.

There are several different philosophies for flammable gas detection. Flammable gas detection can be applied to detecting either an accumulation of gas or a release of gas. Actions could be prompt evacuation, shelter in place in response to an alarm notification, or acting to limit the size/extent and ignition potential for a vapor cloud. The following are two different philosophies for flammable gas detection. Each is valid for a particular application.

Table 2 – Example combustible gas detection philosophies

Flammable Gas Detection Philosophy	Elements of Philosophy Decision	Typical Application
Detect credible gas releases by strategically placing detection equipment in proximity to release sources to minimize potential for extended duration gas release that could ignite with severe consequences.	<i>Within a monitored area:</i> Detection: Leak/release sources and size should be identified, and detectors located in proximity to leak sources to provide incipient (early) indication of a hazard before gas migrates to a location where ignition and escalation are likely. Successful FGS mitigation: alarm to evacuate personnel to safety and allow controlled operator shutdown (or automatic ESD)	Onshore process plants
	<i>Migration beyond a monitored area:</i> Detection: Variation in gas cloud size and direction makes it difficult to specify detector layout and spacing within a monitored area to address all possible leak scenarios. Because ignition sources and occupancy are well controlled within a process area, detection within a monitored area should be supplemented with perimeter gas detection to improve confidence that the release will be detected before migrating to a strong ignition source or area with higher occupancy and a more severe impact. Successful FGS mitigation: alarm to evacuate personnel to safety and allow controlled operator shutdown (or automatic ESD)	
Detect gas accumulations in hazardous quantities that, if ignited, could cause significant impairment to life, safety, and the asset.	<i>Within a monitored area:</i> Detection: Gas dispersion patterns might not be predictable, and gas hazards are most severe in areas where gas can accumulate within confined and congested process areas. Detectors should be placed in areas where gas can accumulate in order to mitigate a threshold accumulation volume that can result in a more severe blast, which could impair structural integrity or impair evacuation/egress. Successful FGS mitigation: - isolate fuel source and depressurize - de-energize electrical apparatus - evacuate personnel to safety	Offshore facilities
	<i>Migration beyond a monitored area:</i> Detection: Reliable detection cannot be assured in areas where gas does not accumulate (absence of confinement/congestion), nor is the severity of an ignited gas cloud of high concern due to the lower severity of a vapor cloud fire (no VCE). Credible leak scenarios should be identified, and detection of gas migration should be provided at receptors of concern (detection at HVAC air intakes, etc.). Successful FGS mitigation: - alarm to shelter/evacuate personnel - de-energize electrical apparatus	

It is impractical to detect all gas leaks, even all leaks that could be hazardous. Release sources and direction of dispersion cannot always be predicted with certainty. In some locations, where gas can be dispersed by wind or ventilation, a strategy of placing detectors only around likely release sources can have limited effectiveness. The gas detection philosophy should specify if alarms and FGS executive actions will occur on a single detector in alarm state (1ooN) or require more than one detector in alarm state (2ooN). A well-defined philosophy will guide the FGS user in determining the correct performance objectives.

4.5 Toxic gas detection philosophy

Toxic gas detection involves an analysis of a specific application, as general guidelines are difficult to set due to the widely varying hazards of different toxic materials, the variations in concentrations of toxic materials, and the high dependency of toxic hazards on site-specific factors, including

meteorology. Therefore, one approach is to select a hazard scenario and model the extent of the hazard (e.g., dispersion, computational fluid dynamics [CFD]). To model a toxic gas hazard, consider the smallest hazard scenario that would require detection; this can be based on either risk or a team-based review and should be likely to occur in the project lifetime. A second approach is to directly postulate the magnitude of a toxic gas volume that is of concern and then design using a geographic technique (e.g., 5 m H₂S cloud size, 8 m H₂S cloud size).

The objective of a toxic gas detection system is to detect concentrations of gas that could be hazardous to personnel in time for proper protective actions to be taken. Automatic actions can be taken by the FGS to minimize the severity of the hazard. Actions that are most effective in early-stage of gas release or accumulation are:

- alarms and evacuation/sheltering of personnel
- automatic ESD with isolation and depressurizing equipment that can be leaking gas

The following is an example philosophy for toxic gas detection.

Table 3 – Example toxic gas detection philosophies

Toxic Gas Detection Philosophy	Elements of Philosophy Decision	Typical Application
Detect credible gas releases by strategically placing detection equipment in proximity to release sources to minimize potential for extended duration gas hazard that could result in severe consequences.	<i>Within a monitored area:</i> Detection: Leak/release sources and size should be identified, and detectors should be located in proximity to leak sources to provide early indication of a hazard before gas migrates to a location where exposure is likely. Successful FGS mitigation: • alarm to evacuate personnel to safety or shelter and allow controlled operator shutdown (or automatic ESD)	Onshore process plants and offshore facilities
	<i>Migration beyond a monitored area:</i> Detection: Variation in gas cloud size and direction results in difficulty specifying the detector layout and spacing within a monitored area to address all possible leak scenarios. Because occupancy is well controlled within a process area, detection within a monitored area should be supplemented with perimeter gas detection or gas detection along egress paths to improve confidence that the release will be detected before migrating to an area with higher occupancy and more severe impact. Successful FGS mitigation: • alarm to evacuate personnel to safety or shelter and allow controlled operator shutdown (or automatic ESD)	

4.6 Fire and gas hazard assessment, requirements specification, and performance verification

Determining the target performance of an FGS function should be accomplished using hazard and risk analysis. In this context, performance includes: safety availability of the FGS equipment, the coverage of the FGS detectors, and the effectiveness of the mitigative actions. A design for FGS mitigation requires input from the end user's fire and gas philosophy in terms of establishing the performance objectives.

Techniques used to select target FGS performance should consider parameters that affect the hazard and risk. They are often applied on an equipment-item basis to determine if an FGS should be considered to protect each equipment item and, if protection is required, what degree of performance should be targeted in the design. The hazard and risk parameters that should be considered include the following:

- material flammability/toxicity
- process temperature
- process pressure
- hazard frequency
- source leak size
- ignition sources
- potential for gas accumulation
- environmental conditions

Two typical strategies for the hazard and risk assessment for the selection of FGS performance targets are used in industry. These two general approaches are referred to as semi-quantitative and fully quantitative risk analysis. While the fully quantitative risk analysis methodologies are more precise, the semi-quantitative methods are also acceptable.

- Semi-quantitative risk analysis has a level of effort similar to layer of protection analysis (reference 2.5 and 2.6). It uses lookup tables and “order of magnitude” selections to categorize various risk parameters and thereby establish the needed performance targets. These semi-quantitative techniques need to be calibrated to ensure that these coarse level-of-effort tools provide satisfactory results. See Annex A for an example of a semi-quantitative hazard and risk analysis.
- Fully quantitative risk analysis verifies that quantitative risk tolerances have been achieved using detailed quantification of the hazard and risk. While the fully quantitative analysis provides more accurate results, it is also more time consuming and can be resource intensive (see Annex D).

The following steps are broadly applicable to both strategies for hazard and risk analysis.

4.6.1 Step 1 – Identify areas of concern

FGS installations in the process industries are typically designed to address hazards associated with loss-of-containment events caused by leaks, corrosion, and erosion. In many cases, FGSS are only expected to provide general process area coverage. Under these circumstances, the FGS design can be based on simple prescriptive practices (e.g., references 2.2 and 2.3), if available for the application. In some process plants, their implementation is beneficial, while in others use of an FGS is unnecessary. Not all process plants will even undergo a formal analysis of FGS design requirements. The determination of whether formal assessment of FGS design requirements analysis is required will be the result of end-user policies/procedures and regulatory oversight, such as:

- process hazards analysis (PHA) recommendations
- QRA for FGS
- end-user standards and design practices
- regulatory requirements
- auditor recommendations
- FGS screening analysis
- previous incidents

An FGS screening analysis can be used to identify areas of concern where FGS installation can be beneficial in reducing risk. An FGS screening analysis should consider the flammability and toxicity of the materials being processed, which would identify process equipment that represents an area of concern for possible performance-based FGS design. The plot plans, process flow

diagrams, heat and material balance, and P&IDs should be analyzed to identify the process material(s) and normal operating conditions, and whether the materials processed contain fire hazards, combustible gas hazards, or toxic gas hazards.

4.6.2 Step 2 – Identify hazard/risk scenarios

Performance-based FGS design requires identification of hazard scenarios for which FGS functions are designed. Although the FGS is expected to perform on demand for a wide range of general hazards, a few specific hazards should be identified to establish target performance and allow measurement of achieved performance.

Major equipment items should be analyzed to identify the type of fire or gas hazard, and this should include storage tanks, pressure vessels, pumps, compressors, separation equipment (distillation towers, etc.), and heat exchangers. The type of hazard depends on the process fluid composition, the process conditions (temperature and pressure), the size and duration of the credible release, and the type and location of ignition sources.

Performance targets are defined with respect to the hazard scenario(s) that FGS design is intended to detect and adequately mitigate. This step can involve direct hazard identification (e.g., 50 kW radiant heat output fire, 10 m³ combustible gas accumulation, 20% LFL accumulation) or identification of credible scenarios involving release of hazardous material that could give rise to fire and gas hazards. These include corrosion-initiated leaks, flange gasket leaks, and small diameter tubing failures. Where scenarios are selected as the basis of design, the analysis should consider the attributes in sufficient detail to determine the potential physical characteristics of the hazard scenario, such as fire size or gas dispersion extent.

This step results in a list of equipment items and associated hazards/scenarios that are carried forward to subsequent steps.

4.6.3 Step 3 – Analyze consequences

Once a fire or gas scenario is identified, a consequence severity study should be undertaken to determine the physical extent of the hazard and the potential to escalate the severity if not detected. This either takes the form of a model that predicts the physical effects of the release, or is based on qualitative (e.g., PHA team judgment) or semi-quantitative techniques. The end user should decide the criteria used to analyze the extent of the unmitigated fire, combustible gas, or toxic gas hazard scenario (qualitative, semi-quantitative, and/or full quantitative). The following sections address quantitative methods only. The application of consequence modeling is not addressed in detail in this technical report. Refer to CCPS (reference 2.7) for more guidance.

4.6.3.1 Fire hazards

For fire scenarios, the extent of fire and thermal radiation effects are usually required to determine detector layout requirements. Fire detectors using optical or visual detection means are sensitive to the amount of radiant heat output from the fire, but limited by a threshold amount of radiation received at the detector below which a fire cannot be detected. Consequence models predict these physical effects as a function of orientation and distance from the fire. Results of fire models provide the basis to determine the number and location of fire detectors necessary to detect a given fire scenario.

The fire analysis should identify a threshold amount of radiant heat output that can result in a potential hazard, or escalation of a hazard based on the type of processing equipment and layout. The criteria should be used as the end point for the fire consequence analysis.

4.6.3.2 Combustible gas hazards

For a combustible gas hazard, consideration should be given to the dispersion and potential accumulation of gas in unconfined or semi-confined areas, and estimates should be developed of

the extent of the combustible gas hazard. Although this can be accomplished by defining the volume of the gas accumulation of concern, gas dispersion/accumulation modeling and explosion analysis in confined or congested areas should be considered.

Gas dispersion analysis using similarity models is adequate for some outdoor locations where dispersion is only affected by momentum jet effects as well as atmospheric effects. Dispersion modeling results should be generated for concentrations at the threshold for alarm for gas detectors. Similarity models and other simplified empirical models can be misleading when studying gas dispersion, especially for indoor releases. Simplified models can yield vastly different concentration profiles than full computational fluid dynamics (CFD) models. In most cases, ventilation and geometry dominate the dispersion, so most simplified/empirical models cannot accurately capture this information to a sufficient resolution. Further, simplified models frequently do not account for turbulence or the interaction with solid surfaces. These play a significant role in the shape, size, and concentration of the vapor cloud and thus need to be evaluated with sufficient resolution. Gas dispersion in confined or congested spaces or enclosed volumes should use consequence analysis methods (e.g., CFD) to examine concentration profiles under the influence of forced ventilation systems rather than atmospheric effects.

For flammable/combustible gas hazards, the gas concentration is the primary means of potential hazard detection; however, the actual hazard can include one or more of vapor cloud explosion (confined or semi-confined), fire, or toxic inhalation exposure.

The hazard is a function of volume of hazardous material, concentration, and level of confinement in the case of vapor cloud explosion. As the volume increases, a more severe hazard becomes more likely. Therefore, the detector placement is predicated on criteria to detect the gas concentration early enough that action can be taken before the release becomes a larger gas cloud of potentially higher concentration. With earlier activation, the hazard potential can be lowered (e.g., maximum explosion overpressure that could be tolerated without severe damage or loss of life). The development of these criteria is provided by CCPS (reference 2.7) but is outside the scope of this technical report.

4.6.3.3 Toxic gas hazards

For facilities that store, handle, or process toxic gases, the worst credible scenario can be an uncontrolled release of a toxic substance to the atmosphere. Facilities that deal with these substances generally invest in equipment to handle the substance, such as vents to flares, scrubbers, incinerators, or alternate containment vessels. The failure of this equipment, its controls, or the piping system itself (leaks, erosion, and corrosion) can lead to a release. Gas detection systems are often utilized to help mitigate this potential hazard.

It is common practice for companies handling toxic gas releases to conduct dispersion modeling of credible scenarios to determine the potential effect of a given release. Dispersion modeling will address plant and surrounding area topography information, leak rate information, plant weather data, and toxicity information. ERPG (emergency response planning guidelines) numbers or IDLH (immediately dangerous to life and health) numbers are often used to characterize the extent of the acute toxicity hazard.

The design intent of toxic gas detection is to mitigate the severity of the unmitigated hazard scenario. This is typically accomplished by early detection that results in more effective emergency response, containment, or the evacuation of personnel to a safe location. Unmitigated consequences should define the extent of impact of the unmitigated hazard outcome, which can include onsite and/or potentially offsite consequences.

4.6.3.4 Escalation of flammable and toxic gas hazards

The design intent of fire and gas detection is usually to mitigate an already hazardous situation. This is typically accomplished by limiting the extent of the hazard or, in some cases, providing for

additional time before escalation to allow for effective emergency response and containment and/or to allow for the evacuation of personnel to a safe location.

In addition to an incipient fire or gas release scenario used for establishing detector location and placement, the consequence analysis should include an assessment of the potential outcome of that scenario if unmitigated by the FGS. This could result in escalation of the hazardous event into a larger, more severe consequence than the scenario selected as the basis of design for FGS detection. This severe consequence represents the potential outcome of FGS failure due to inadequate detector coverage, poor FGS availability, or ineffective mitigation actions.

4.6.3.5 Other consequence modification factors

Occupancy, time at risk, and ignition probability are other factors that could be considered when assessing risk to personnel safety. These factors should be justified through scenario-specific analysis that ensures that these factors are reasonable and appropriate for the scenario under consideration. For example, occupancy likely changes as plant personnel respond to potential or realized loss of containment. In contrast, the likelihood that a release is flammable is dependent on the chemical properties, release size and location, and dispersion potential. When flammable liquids or gases are involved in the scenario, it is possible to estimate the potential for a fire or explosion using qualitative, semi-quantitative, or quantitative methods. Ignition probability data for combustible liquids, flammable liquids, and flammable gases is provided by CCPS (reference 2.7). Guidance on determining appropriate values for these factors is outside the scope of this technical report.

4.6.4 Step 4 – Analyze hazard frequency

Before establishing FGS performance requirements, consideration should be given to the likelihood or frequency of the hazard(s) that could result in the unmitigated/escalated consequence severity. Further, a decision can be made about the tolerability of an unmitigated fire and gas risk, which can guide decisions about the scope of an FGS design. Release frequency can be determined by applying databases of equipment failure rates to the identified scenario, but could also be based on qualitative (e.g., PHA team judgment) or semi-quantitative techniques.

In many cases, a risk scenario arises from equipment damage and failure mechanisms, such as general corrosion, that are well understood. In these cases, application of industry failure rate data should be considered. For example, such databases include leak frequencies for components, such as piping, flanges, pressure vessels, and compressor seals. Methods for adjusting industry failure data based on site-specific inspection and maintenance histories are also available.

In some cases, the hazard scenario can arise from unique factors that should be addressed in a scenario-specific analysis. An example is an uncontrolled release of a flammable gas in gas production wells due to produced sand causing erosive damage to flowlines. In this case, industry failure rate databases are of limited value. The end user's prior experience and a considerable amount of judgment can be utilized to establish the frequency of the release scenario.

It is often the case that fire and gas detection is provided in an area to detect release from multiple sources of potential release. In these cases, there should be some effort taken to aggregate the frequency of the potential hazard scenarios in the area of concern. This is accomplished by accounting for a number of equipment leak scenarios with similar consequences and generating the sum total or cumulative frequency of release. This aids in minimizing the number of scenarios that need to be individually analyzed. For example, sum the frequency of all scenarios with 50 kW radiant fire in the area of concern.

4.6.5 Step 5 – Assess unmitigated hazard/risk

Unmitigated hazard/risk is measured before considering the benefit of the proposed FGS. The most conservative approach is to assume that the FGS is unavailable in the event of the hazard. The unmitigated/escalated consequence severity and hazard frequency can be compared to end-

user criteria for tolerability. This can be accomplished through application of a hazard/risk matrix with sufficiently detailed information regarding consequence severity and likelihood. Alternatively, quantitative risk criteria can be stated in terms of tolerable mitigated event likelihood. If the criteria indicate that the unmitigated hazard/risk scenario is tolerable, additional risk reduction using FGS function(s) is not required unless otherwise mandated by local legal requirements. If the hazard/risk is higher than target criteria, then the risk reduction requirements should be established for the applicable fire, combustible gas, or toxic gas detection function in the FGS.

If the outcome of this step results in an acceptable situation with no additional risk reduction, further analysis of performance-based requirements for FGS design is optional. Design of the FGS and sensor placement should be based on existing methods for system design, such as the applicable national standard or industry guidelines and relying on the judgment of a qualified engineer for sensor placement. Good practice guidelines in Annex B should be considered for sensor placement.

4.6.6 Step 6 – Identify FGS performance targets

After previous steps in the hazard/risk assessment, equipment of concern and hazards of concern will have been identified and the consequence severity/likelihood and acceptability of an unmitigated hazard will have been considered. The presentation of this information can vary in format. The information can take the form of a qualitative hazard assessment, a fully quantitative risk assessment, or a semi-quantitative assessment of hazard/risk. FGS designers with more qualitative hazard input can apply broad guidance from industry or company practices to establish a single and uniform performance target (e.g., 85% target detector coverage). FGS designers with more quantitative hazard information can establish performance targets that are specific to the hazards being assessed.

More information on the selection of FGS performance targets is included in the annexes of this TR. Annex A contains an example of a semi-quantitative approach for selecting FGS performance targets, and Annex D contains worked examples of FGS performance target selection, using a variety of methods for a variety of applications.

4.6.6.1 FGS performance metrics

FGS performance targets should be consistent with the end-user philosophy for hazard detection and mitigation, based on the level of hazard and risk associated with process hazards in a monitored area, and agreed upon by the end user. Achievement of FGS performance targets should be through application of one or more of the listed FGS performance metrics shown in table 4. In the absence of specific guidance from the end-user philosophy, the following options should be considered for metrics:

1. Applications with claimed FGS risk reduction factor ≤ 10 : Quantification of detector coverage as FGS performance metric. Qualitative consideration of other performance metrics.
2. Preventative FGS safety functions: Applications with claimed FGS risk reduction factor (RRF) in excess of 10. Quantify detector coverage and safety availability.
3. Mitigative FGS safety functions: Applications with claimed FGS RRF in excess of 10. Quantify detector coverage, safety availability, and mitigation action effectiveness. Note that for these types of functions it is difficult to achieve target RRF, as they require strong FGS detector coverage, as well as FGS mitigation effectiveness.

Classification of an FGS function as either preventative or mitigative is the responsibility of the end user of this technical report. Where unmitigated hazard severity is deemed to pose an elevated level of hazard/risk, FGS mitigation as well as other non-FGS means of risk reduction should be considered. Target FGS performance can be defined in various ways, such as an FGS risk reduction factor, percent reduction in risk of unmitigated hazard severity, or maximum allowable