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FIRE HAZARD ANALYSIS

Quantifying and Mitigating Design-Basis Fire Events

BakerRisk Best Practice

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1. INTRODUCTION/ BACKGROUND

The concept of a Fire Hazard Analysis (FHA) is referenced in many of the standards, practices, and guidance documents that are applied in industry. It also has other names, such as Fire Risk Assessment (FRA) and Fire and Explosion Analysis (FEA). The analysis efforts may also be bundled with other hazard requirements in standards and guidance documents that are often vague and somewhat subjective when discussing FHA methodology. This document provides field-tested suggestions and best practices to help bridge the gap between the standards and fire hazard studies.

An FHA usually involves the identification of credible fire scenarios and the impacts that those fires pose to a facility, its employees, its neighbors, and the environment.

The primary objectives of an FHA, according to the Center for Chemical Process Safety (CCPS)[1] guidance, are to:

- Provide an understanding of the hazards.
- Enable the specification of performance-based fire protection.
- Form part of an overall risk assessment.

Per CCPS, a facility benefits by conducting an FHA in that it:

- Provides an inventory of fire hazards, including quantities (of flammable materials).
- Provides a comprehensive understanding of the fire hazard(s), including potential magnitude and duration.
- Provides an estimate of the potential impact of a fire on personnel, buildings, equipment, the community, and the environment.
- Allows for the development of a list of appropriate mitigation options.

Building on the CCPS guidance and years of experience conducting fire risk assessments internationally, BakerRisk has identified and developed a Best Practice methodology as it relates to performing an FHA. The focus of this Best Practice is to redefine the FHA to go a step beyond merely "developing a list" of mitigations. In our view, it is more desirable and effective to include a thorough review and analysis of available and necessary mitigations that already exist at the facility, and/or those that may be recommended, in addition to examining the hazards and consequences of the fire.

Such a process, which we refer to as Fire Hazard *and Mitigation* Analysis, or FHMA, ensures a more comprehensive examination of both the fire and consequences as well as the protection systems, emergency response capabilities, and other supporting resources.

2. FHMA BASICS

An FHMA can be performed in a variety of ways; however, the following steps should be included:

1. Identify fire scenarios onsite through a review of process flow diagrams, heat and material balances, available inventories, and tank lists.
2. Perform consequence modeling for the design-basis fires.
3. Build in mitigation layers such as the firewater system, which should include a site walkdown to verify the extent and condition of fireproofing, locations of fire monitors, coverage and condition of fixed protection systems such as deluge, and other factors that may affect fire geometry such as site drainage and potential obstructions.
4. Conduct a PHA-Style workshop with the ERT, safety group, operations, and others as needed to review the fire scenarios, expected responses, capabilities, and mitigation already in place at the facility.
5. Identify gaps in firewater coverage or deficiencies in firewater supply for each scenario.
6. Provide recommendations to close any gaps identified during the analysis.

WHY PERFORM AN FHMA? KEY BENEFITS ARE:

ACCURATE DETERMINATION OF FIREWATER DEMANDS

By reviewing design-basis fire cases, firewater demands can be calculated based on existing/proposed systems that will be deployed. This calculation can then be compared to prescriptive guidance estimates and can be used to validate or improve upon firewater demand estimate calculation methodologies, such as those published by American Petroleum Institute (API)[2] and CCPS[1].

CONSISTENT PROCESS SAFETY INFORMATION AND DOCUMENTATION

Quantitative results can be used to document the selected design-basis fire impacts, available firewater coverage, calculated firewater demands, and other information critical for emergency planning and response.

STAKEHOLDER INVOLVEMENT AND INTERACTION – FEELING OF OWNERSHIP

FHMA includes a facilitated workshop that encourages operations, emergency responders, safety personnel, support staff, and management to participate in reviewing the hazards, mitigations, response capabilities, and proposed improvements. One benefit of the workshop is that it identifies mismatches in expectations between various stakeholders.

EVERGREEN MODEL – EASILY UPDATED TO INCLUDE SITE CHANGES

FHMA directly links the results from existing consequence or facility siting studies to the fire protection coverage mapping, hydraulic modeling, response capabilities, and fireproofing evaluation tools. This approach allows for consistency between studies and provides actionable results. These can also be updated as conditions change or periodically as a part of an evergreen revalidation protocol.

Figure 3-1. Emergency Response Team Response

3. PREPARING FOR AN FHMA

One of the most important steps in conducting an effective FHMA is preparing for the workshop.

3.1 UNDERSTANDING THE SITE'S FIREFIGHTING PHILOSOPHY

Before starting to assemble the team or gather documentation, it is key to gain an understanding of the firefighting **philosophy** for the facility. Will the site rely on fixed fire protection systems such as deluge or sprinklers to protect their equipment? Or will the site rely more on prompt and effective emergency response team (ERT) actions to fight the fire with fixed monitors and mobile apparatus? Does the site depend on outside help such as the local fire department or a mutual aid group?

There is no "right" answer to what the firefighting philosophy should be; however, it is critical to ensure that the chosen philosophy aligns with the site's actual capabilities in order to achieve the ultimate goal of timely fire suppression with minimal potential for injury to personnel, damage to assets, impact to the environment, or other negative consequences.

For example, a site that plans to heavily rely on fixed protection must ensure that fixed protection is designed, installed, and maintained to a level that will support successful suppression. If the site plans to rely more heavily on the ERT response, the ERT staffing, equipment, and training plans must reflect that intent, and the ERT should have all the necessary assets and resources available to ensure the desired response is carried out with minimal delay.

Since most philosophies and related systems rely heavily on an adequate and reliable firewater supply, it is critical to ensure that there is enough water available to supply both the fixed and mobile delivery systems and that the supply components carry a high degree of reliability and resiliency.

Without an understanding of how the fires will be fought, it is difficult to determine the maximum firewater demand or to assess any gaps in the response plan or firewater coverage.

3.2 DESIGN CASE FIRE - CAN YOU KEEP IT MANAGEABLE?

Design-case fire scenarios are scenarios that are expected to be "credible" worst-case fire but still manageable by fixed system installations and/or emergency response procedures. It is critical to select appropriate design case fires and compare those to the available mitigations in order to determine whether the available systems and responses are adequate.

It is rarely practical to design fixed protection systems for the largest possible (worst-case) fire. Such scenarios would quickly defeat or overtax even the most capable of fixed systems, and response measures shift from attempting

THE IMPORTANT QUESTIONS TO ASK ARE:

Do your fire protection systems align with applicable RAGAGEP as well as corporate and site philosophy/ intent?	Do your firewater supply and delivery capability fully meet the maximum firewater demand for all fire areas in your facility?	Are there challenges to existing capabilities, such as obstacles that block coverage from fixed systems, access/egress challenges for mobile apparatus, or system degradation? What actions do you need to take to compensate for identified challenges?	Is equipment still performing as intended, or is age, wear, corrosion, or neglect preventing the system from performing as originally intended?	Is your system robust enough to allow for occasional, unplanned outages of key components, such as fire pumps and critical underground fire mains, without jeopardizing your ability to successfully suppress your design-case fires?

Figure 3-2. Automatic Deluge System Response

to suppress a fire to more defensive measures, such as attempting to limit fire spread to adjacent units/areas. Preventing catastrophic events is best done though good detection, isolation, and other preventive measures that stop a manageable event progressing to an unmanageable one. For this reason, catastrophic scenarios such as explosions preceding fire events are outside the scope of the FHMA as they are often times already unmanageable events.

Once the design-basis fire cases are identified, they can then be analyzed to determine the best combination of mitigations to control, suppress, and ultimately extinguish those fires. Once those fire cases are understood, the following questions can then be answered credibly:

- What prevention and mitigation systems will be required?
- What response capabilities are needed to augment fixed systems to ensure full suppression and extinguishment of a fire event?
- How will time of response impact success?

The goal of establishing a design case fire is to ensure a “likely to occur” fire can be managed effectively to prevent it from escalating to a catastrophic size.

Figure 3-3. Automatic Deluge System Response

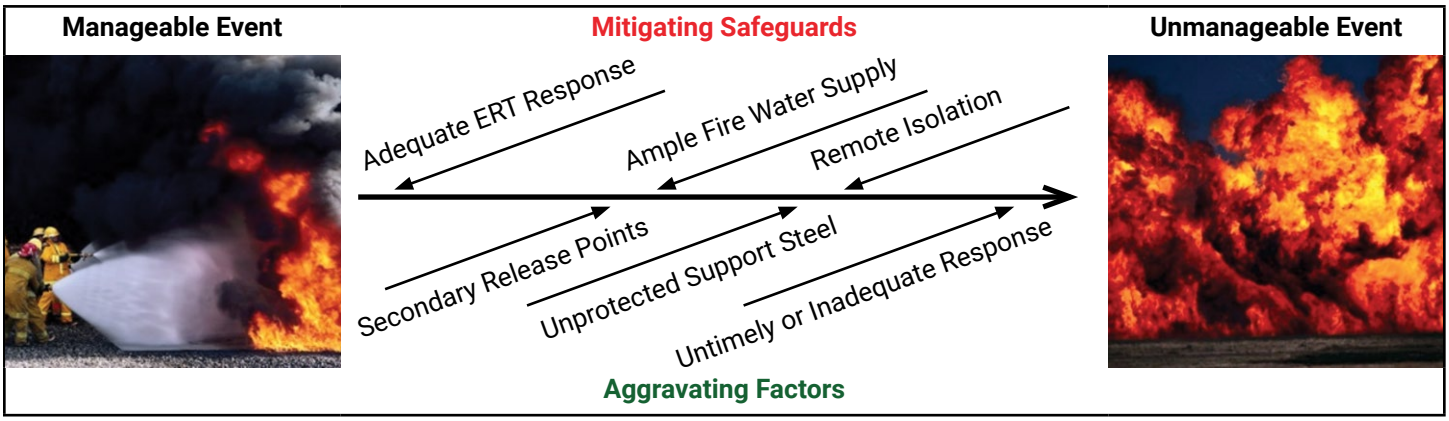


Figure 3-4. Design Case Fire—Is it Manageable or Catastrophic?

3.3 ASSEMBLING SYSTEM DESIGN DOCUMENTATION

Figure 3-5. Flow Measurement to Confirm System Hydraulics

The final step for preparing for the FHMA is to gather the documentation related to the firewater and fire protection systems on site including:

- Supply and delivery systems.
- Fixed delivery system design data for deluge and water spray.
- Fire monitor flow ratings, locations, and intended coverage area.
- Underground main locations, age, condition, and size.
- Protection system inspection, testing, maintenance, and repair (ITMR) records.
- Mobile asset inventories including mobile apparatus and foam/dry chemical agents.
- ERT training records.
- Any other data that will help a site understand their own capabilities to respond to fire.

As with any other documentation classified as process safety information (PSI), these documents should be easily located, kept up to date, and accurately reflect what is currently installed. Fire protection systems/equipment, as with any other critical safety system, should be subject to strict governance under a site management of change policy.

Additionally, depending on the age of the underground piping, it may be critical to understand the internal condition of the firewater piping, including underground piping, that cannot be easily inspected. This is usually accomplished by performing firewater flow testing. Hydraulic models developed using actual test data will yield much more accurate predictions and provide a greater degree of confidence in solutions developed to close gaps. A hydraulic model can be used to estimate the flow and pressure availability at various locations throughout the facility; however, if the piping condition is not known, then hydraulic models may not accurately predict the performance of the system under high demand or if a portion of the network is out of service.

4. FHMA FUNDAMENTALS

4.1 UNDERSTAND THE IMPACTS OF FIRE

Many driving factors can cause a site to invest in fire protection equipment. While conducting an FHMA, it is important to understand the range of possible consequences of the potential fire, including impact to personnel, environment, assets, revenue, reputation, or market share. Reviewing and understanding the potential impacts are an important part of conducting the FHMA.

For most companies, the potential impact to personnel, assets, and revenue are obvious; however, the impact of a fire to the environment and company reputation are often overlooked. Large-scale fires and firefights can damage the company reputation due to visible smoke plume, etc. or the environment due to contaminated water runoff or foam/water runoff. These types of impacts should be considered as they may warrant a different response than if only impact to personnel/assets are considered.

It is also critical to understand the progression of fire events over time to determine whether the response capabilities are adequate. The flowchart below shows a typical response timeline for a fire scenario. Understanding response time and the potential consequences at each phase of the

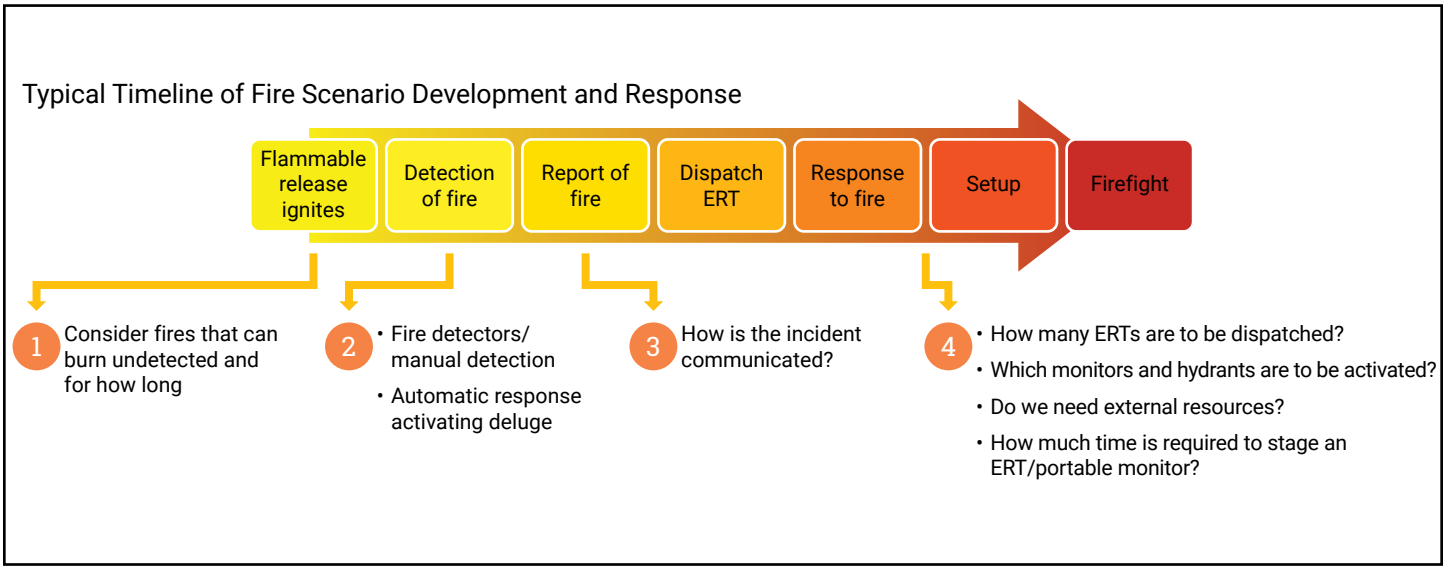


Figure 4-1. Typical Timeline of a Fire Scenario/Response

scenario's progression will help in identifying improvements at the facility that could reduce overall response time and what resources will be needed to accomplish that goal.

Finally, it is necessary for FHMA participants to visualize the fire. Many response drills are based on a written or verbal description of a fire scenario; however, without a visual depiction of the hazard extents, the team may have differing mental images of the severity of a given fire scenario.

Below is an example of a visual representation of the thermal radiation from a fire using SafeSite$_{3G}$©.

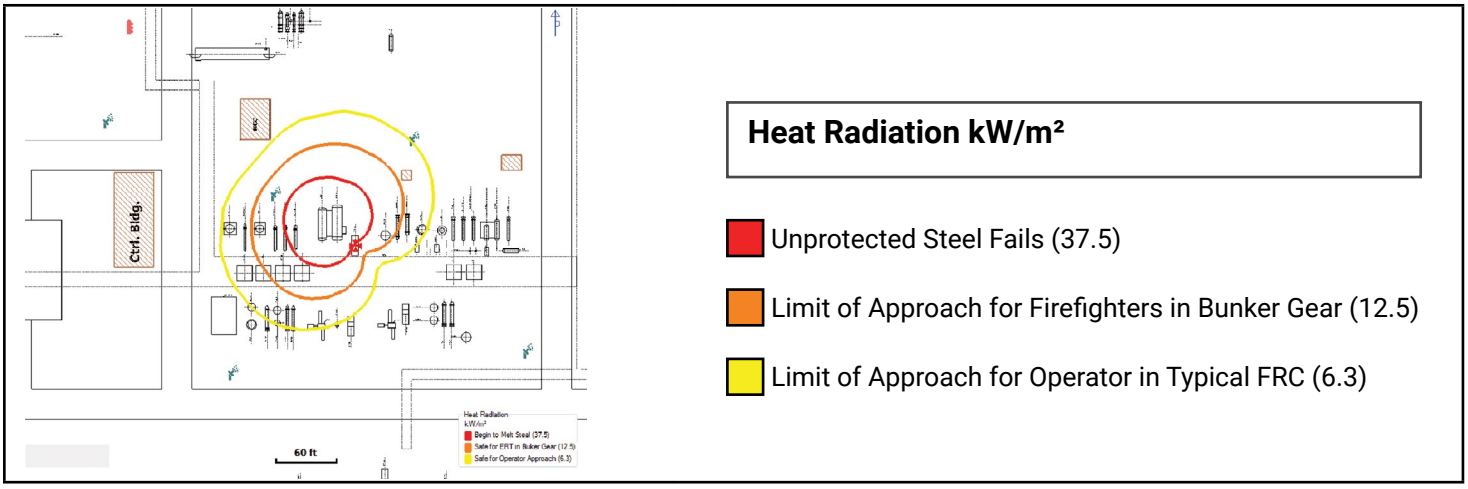


Figure 4-2. Thermal Radiation Contour

4.2 UNDERSTAND YOUR MITIGATION CAPABILITIES

After understanding the types of fires that could occur at the facility, the site should know and understand the facility's full range of mitigation capabilities and ensure that the right combination of fixed, mobile, and emergency response resources is available for a successful fire response. Further, the site must be confident that the mitigations will remain able to perform as intended through regular inspection, testing, and maintenance. Repairs to fire protection assets, when necessary, should be expedited and managed with rigor similar to that applied to repairs to other plant critical safety systems and assets.

Below is an example of a visual representation of the thermal radiation generated by a fire. This image also shows the potential range and coverage for fixed and mobile assets within reach of the fire. Such visual representations are extremely helpful in determining potential fire consequences (including possible knock-on consequences) and can help to determine whether the fixed and/or mobile assets can effectively reach a fire area.

Companies sometimes focus too much attention on one specific asset or resource without considering the relationship between different types of mitigations. For example, a site that relies on good flammable gas detection systems to alarm during a release may fail to recognize that those types of systems are not reliable for detecting an active fire. Other sites may rely on mobile response assets such as fire trucks, but they may not fully recognize the importance of the fire pumps and delivery systems that ensure the water source can actually reach the fire truck. Therefore, with regards to fighting fire, the plan is only as strong as the weakest link.

In short, an effective FHMA allows companies to develop a full understanding of both the fire and mitigation (fixed systems, response assets and teams, and other supporting measures). Any gaps between the two will emerge from this comprehensive analysis. Once those gaps are identified and remedied, a facility can have an enhanced level of comfort in its ability to combat design-basis fires and associated impacts to people and assets.

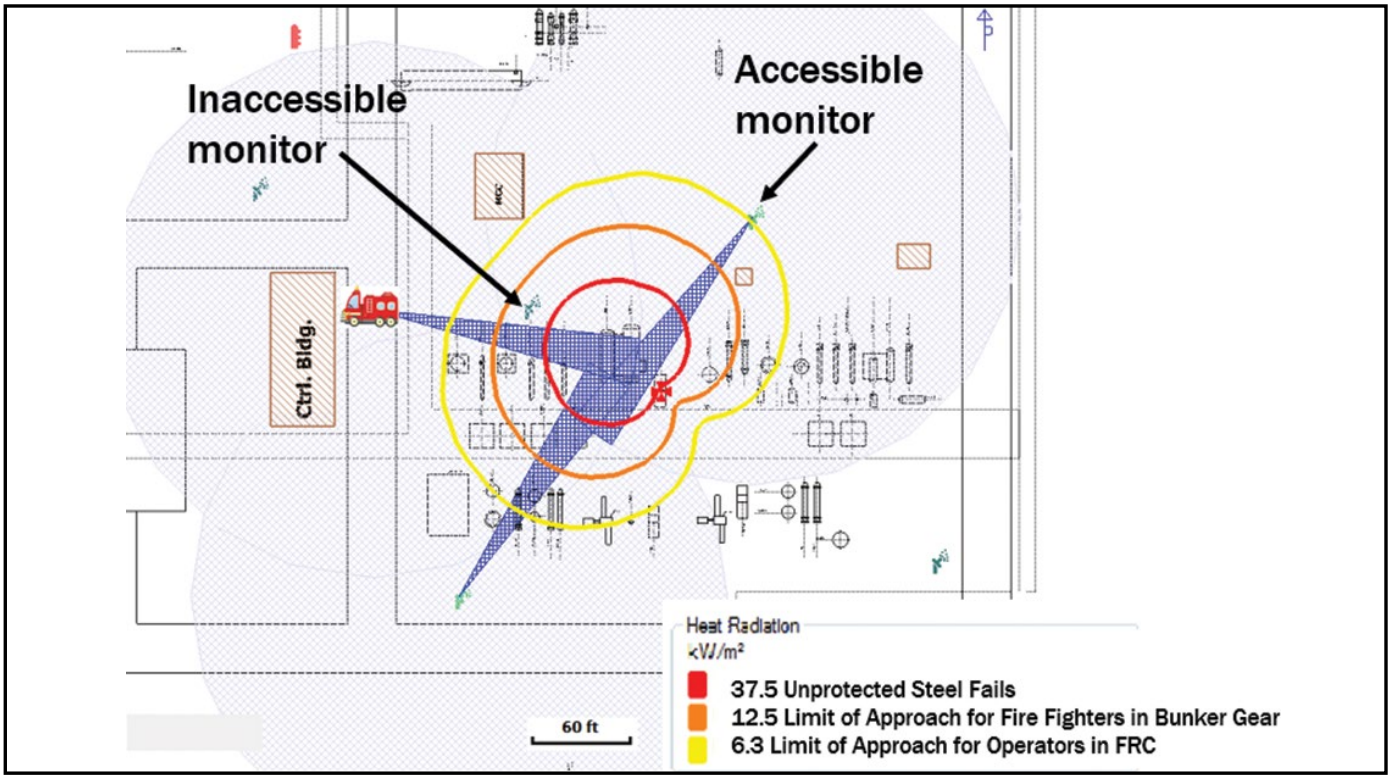


Figure 4-3. Thermal Radiation Contour with Firewater Overlay

5. APPLICATIONS OF FHMA

This section summarizes the main applications for the FHMA methodology highlighted in this best practice.

5.1 DETERMINING CREDIBLE MAXIMUM FIREWATER DEMAND

There are several techniques for estimating maximum firewater demand. API and CCPS offer two such methodologies to estimate maximum firewater needs, based on facility size and other factors. However, most estimating methods are one-size-fits-all approaches to complex occupancies, such as refineries and petrochemical plants with many different variables that can impact the severity of a fire. These also assume that the facility has the capability to deliver the estimated firewater demand where it is needed.

One important flaw in most estimation techniques is that those approaches do not consider actual capabilities or expectations at any specific site. For example, sites that have widespread fixed system coverage can often expect

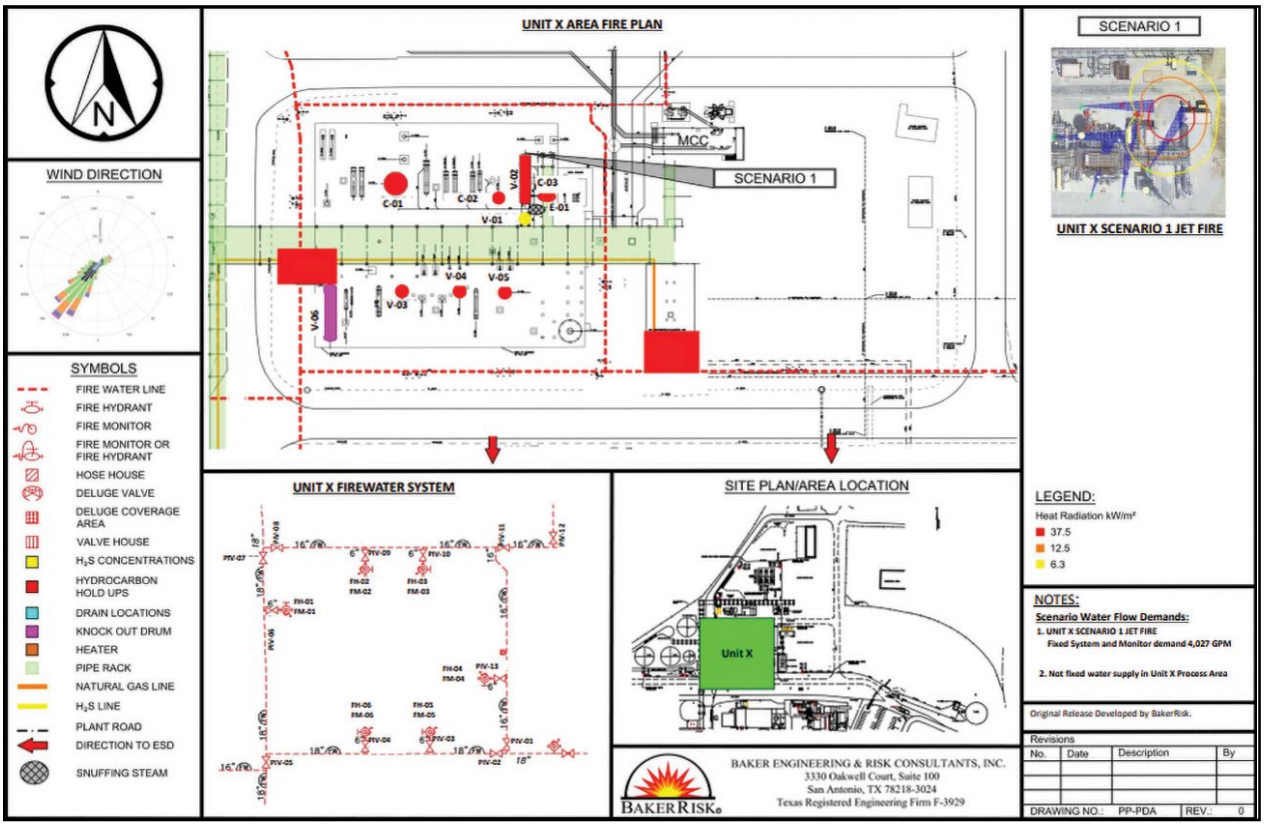


Figure 5-1. Fire Pre-Plan

a design-basis fire to be controlled using only the water needed for those systems, and an additional allowance for hoses to complete extinguishment. In cases such as those, a firewater demand estimation may over-predict the actual maximum credible firewater demand if that demand is determined based on the size/footprint of an entire operating area or process unit.

Conversely, a site that relies more on mobile response may require higher volumes of firewater than the estimate would predict, especially once fire escalation is factored into the estimate. This becomes increasingly important if a site's ERT could expect delays in reaching the fire area or deploying their equipment. Delays usually translate into fire growth due to additional failures in primary containment loops, which add more fuel to a fire. In cases where a fire could escalate to involve an entire process unit, the maximum firewater demand may indeed be based on the entire footprint of the unit, but the estimated density of application needed would then be much higher than most estimating techniques would predict.

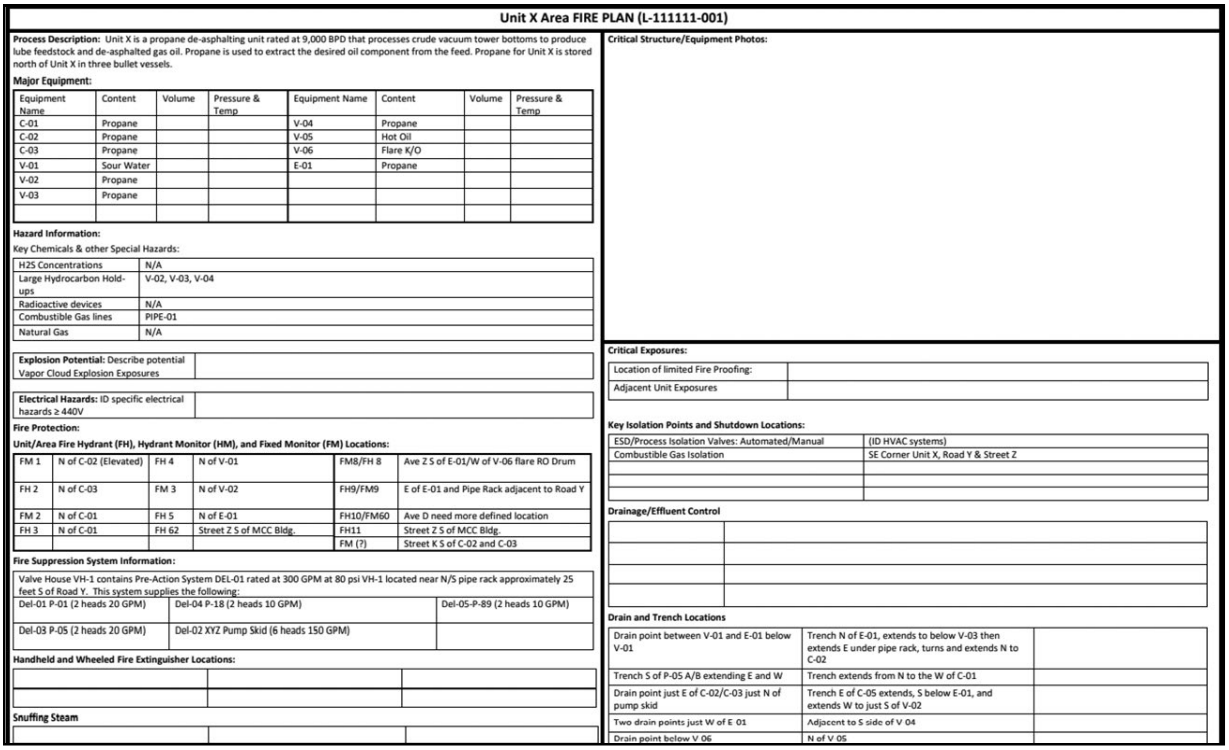
The workshop-based FHMA approach allows the site to calculate their maximum firewater demand by first determining the applicable firefighting philosophy, then determining and summing individual demands from those assets that are expected to be deployed simultaneouly. More importantly, by reviewing the existing coverage capabilities versus the expected extent of the fire, gaps can be identified and closed, and the maximum firewater demand can be kept evergreen based on the changes and improvements implemented.

By ensuring the needed coverage and the existing or recommended delivery needs are taken into account, a much more credible maximum firewater demand can be determined with greater confidence.

5.2 CAPITAL PROJECT DESIGN REVIEWS

New facilities under design need careful review to ensure they meet corporate and RAGAGEP best practices. Experience has shown repeatedly that it is cheaper and less disruptive to design and install good fire protection during initial construction, rather than attempting to retrofit needed systems after a unit or facility is built.

Experience has also shown that there are often misalignments between capital projects stakeholders (builders) and site safety/operations staff (owners) whose lives and assets depend on the protection schemes built into a new unit. Capital projects managers are often pressured to achieve an optimal design for the lowest cost - sometimes at the detriment of the safety systems. If it is determined that a site needs to close gaps in the original design after the facility is constructed, higher costs and disruptions emerge.



Unit X Area FIRE PLAN (L-111111-001)

Process Description: Unit X is a propane de-asphalting unit rated at 9,000 BPD that processes crude vacuum tower bottoms to produce lube feedstock and de-asphalted gas oil. Propane is used to extract the desired oil component from the feed. Propane for Unit X is stored north of Unit X in three bullet vessels.

Major Equipment:

Equipment Name	Content	Volume	Pressure & Temp	Equipment Name	Content	Volume	Pressure & Temp
C-01	Propane			V-04	Propane		
C-02	Propane			V-05	Hot Oil		
C-03	Propane			V-06	Flare K/O		
V-01	Sour Water			E-01	Propane		
V-02	Propane						
V-03	Propane						

Hazard Information:

Key Chemicals & other Special Hazards:

H2S Concentrations	N/A
Large Hydrocarbon Hold-ups	V-02, V-03, V-04
Radioactive devices	N/A
Combustible Gas lines	PIPE-01
Natural Gas	N/A

Explosion Potential: Describe potential Vapor Cloud Explosion Exposures

Electrical Hazards: ID specific electrical hazards ≥ 440V

Fire Protection:

Unit/Area Fire Hydrant (FH), Hydrant Monitor (HM), and Fixed Monitor (FM) Locations:

FM 1	N of C-02 (Elevated)	FH 4	N of V-01	FM8/FH 8	Ave Z S of E-01/W of V-06 flare RO Drum
FH 2	N of C-03	FM 3	N of V-02	FH9/FM9	E of E-01 and Pipe Rack adjacent to Road Y
FM 2	N of C-01	FH 5	N of E-01	FH10/FM60	Ave D need more defined location
FH 3	N of C-01	FH 62	Street Z S of MCC Bldg.	FH11	Street Z S of MCC Bldg.
				FM (?)	Street K S of C-02 and C-03

Fire Suppression System Information:

Valve House VH-1 contains Pre-Action System DEL-01 rated at 300 GPM at 80 psi VH-1 located near N/S pipe rack approximately 25 feet S of Road Y. This system supplies the following:

Del-01 P-01 (2 heads 20 GPM)	Del-04 P-18 (2 heads 10 GPM)	Del-05-P-89 (2 heads 10 GPM)
Del-03 P-05 (2 heads 20 GPM)	Del-02 XYZ Pump Skid (6 heads 150 GPM)	

Handheld and Wheeled Fire Extinguisher Locations:

Snuffing Steam

Critical Structure/Equipment Photos:

Critical Exposures:

Location of limited Fire Proofing:	
Adjacent Unit Exposures	

Key Isolation Points and Shutdown Locations:

ESD/Process Isolation Valves: Automated/Manual	(ID HVAC systems)
Combustible Gas Isolation	SE Corner Unit X, Road Y & Street Z

Drainage/Effluent Control

Drain and Trench Locations

Drain point between V-01 and E-01 below V-01	Trench N of E-01, extends to below V-03 then extends E under pipe rack, turns and extends N to C-02	
Trench S of P-05 A/B extending E and W	Trench extends from N to the W of C-01	
Drain point just E of C-02/C-03 just N of pump skid	Trench E of C-05 extends, S below E-01, and extends W to just S of V-02	
Two drain points just W of E-01	Adjacent to S side of V-04	
Drain point below V-06	N of V-05	

Figure 5-2. Fire Pre-Plan

Some important questions to ask at the beginning of a facility design:

- Does the design meet the intent of RAGAGEP, corporate, and site protection expectations?
- Will external stakeholders, such as joint venture partners, lenders, or insurers, apply pressure to increase protection levels beyond those in the original design?
- Do site personnel have an opportunity to review the design at each decision stage of the project?
- Is the project budget for fire protection systems sufficient to address gaps between minimal design conformance and desired intent of the owners and external stakeholders?

FHMA–if done at the earliest stages of design and reviewed periodically as design changes are incorporated–can help maintain alignment between the stakeholders and help ensure that there are no last-minute surprises that impact the project scope and schedules.

5.3 FIREPROOFING GAP ANALYSIS

An FHMA can be performed or expanded to evaluate the adequacy of installed fireproofing or planned fireproofing for an existing or new asset. Fire consequence information can be used to determine where within the facility pool fires are likely to occur, and a review of the grading/terrain on site can

be used to evaluate where the pools can travel. Firewater system capabilities to keep steel cool as well as fixed fireproofing are then reviewed and overlaid with the potential pool fire locations to determine where the gaps in fireproofing exist.

5.4 FIRE PRE-PLAN DEVELOPMENT

Fire pre-plans can easily be developed based on the scenarios evaluated during an FHMA. The FHMA analysis provides credible hazard scenarios and evaluates available mitigations. With little additional effort, unit-specific fire pre-plans can be developed using the data derived from the FHMA.

5.5 ERT TRAINING

The interactive hazard workshop allows the site to better understand the impact of process fires in relation to available protection and response capabilities. This can be leveraged as a training tool to support realistic drills and exercises as well as fine-tune capabilities.

5.6 SPECIALIZED APPLICATIONS

The FHMA approach is flexible enough to apply to a wide range of applications where fire is the critical exposure. The FHMA approach has been applied to evaluating protection for safety critical process components, such as emergency isolation valves and cable trays. It has also been used to determine credible exposures related to atmospheric PSVs by evaluating the benefit of cooling equipment before a PSV can lift.

6. CONCLUSIONS

Properly aligned with your site or corporate fire response philosophy, FHMAs provide a thorough understanding of the potential fire exposures and help determine whether those exposures are being adequately managed. This methodology of combining the best elements of qualitative and quantitative review provides a sound basis for understanding gaps between fire risks and fire mitigation capabilities, as well as produces valuable data to use in event response planning, capital projects resourcing, and training.

7. REFERENCES

[1]. Center for Chemical Process Safety (CCPS), *Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities*, 2010.

[2]. API RP 2001, "Fire Protection in Refineries," American Petroleum Institute Recommended Practice 2001, 10thEdition, Washington D.C., 2019.

OUR EXPERTS

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Joe Chew is a Principal Consultant and Supervisor for Fire Protection with 40 years of industrial emergency response expertise. During his tenure as a chief officer, Mr. Chew was heavily involved with community emergency preparedness activities, pre-fire planning, drills, and training. Mr. Chew's various specializations incorporate the following: Developing scenario specific drills to test the ability of the plant personnel and the emergency response teams and the auditing of emergency response team organizations, safety programs and equipment, among multiple other areas of Fire Protection expertise.

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Dan Bushey, CSP, is a Principal Consultant with over 20 years of loss prevention and control experience, primarily in oil, gas, petrochemical, and related energy industries. His professional expertise includes the execution of loss prevention/risk improvement assessment surveys, fire protection system evaluations, natural perils exposure evaluations, and the development of loss estimates. Mr. Bushey's emergency response background further supports BakerRisk's FHMA services in the evaluation of clients' emergency preparedness and response programs.

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ABOUT BAKERRISK

With over 200 owners/experts across nine global offices, Baker Engineering and Risk Consultants, Inc. (BakerRisk®) delivers full-spectrum risk management solutions through transparent, data-driven advice. Our comprehensive suite of services incorporating consulting, engineering, and full-scale testing services ensure companies in high-risk industries continue to operate efficiently by prioritizing hazard mitigation, personnel and property protection, and regulatory compliance.

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