# High Risk Process Loops: A case study using Fire Hazard Analysis to effectively manage fire escalation risk

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The purpose of this paper is to introduce readers to the concept of high risk process loop risk reduction using a case study involving a novel approach to fire hazard analysis.

Worldwide, industry standards and best practices require personnel risk to be calculated and reviewed for existing and new petrochemical facilities. One way of addressing personnel risk is via a thorough Quantitative Risk Analysis (QRA), which identifies populations who may incur high risk as a result of working at the facility. Subsequent risk reduction may include relocation of personnel or providing better protection (i.e., new buildings or building upgrades). However, a QRA can also identify the "high risk process loops" (HRPLs), which are those areas of the process contributing the most risk to onsite and offsite personnel.

A process loop is a portion of a process unit where, if a release were to occur, the predicted consequence would be similar. For example, one of the process loops for a debutanizer may include the column, reboiler loop, bottoms pump, and after cooler, with the release point conservatively taken at the high pressure discharge of the pump. Depending on the complexity, a single process unit may include around 50 process loops with only a handful identified as HRPLs. By addressing HRPLs identified in QRAs and other risk studies such as insurance loss reviews, environmental studies, and other consequence or risk based analyses, facility management can potentially drive risk down without moving people, erecting new buildings, upgrading existing buildings, or conducting other costly actions to reduce population exposure. The approach enables not only a risk reduction to onsite and offsite personnel, but also can reduce the risk of asset damage, environmental impact and business interruption.

Risk reduction credit for HRPLs can be justified in a number of ways including demonstrating highly reliable and effective control systems, showing industry best practice Process Safety Management (PSM) programmes for those areas, and/or by performing specific safety studies that address the identified hazard. One example of such a safety study utilised to demonstrate risk reduction credit for thermal radiation impacts is a Fire Hazard and Mitigation Analysis (FHMA). FHMA is an analysis that can be performed for both existing and green field facilities with the intent to review design basis fire scenarios for each HRPL to aid identification of fire protection measures. Once design basis fire scenarios are defined, the FHA reviews both passive and active fire protection systems and emergency response arrangements to identify locations in which knock-on effects pose a high risk.

The case study involves propylene presenting a high thermal risk to indoor and outdoor onsite personnel. The FHMA methodology utilised combines quantitative calculations for thermal radiation, passive protection gaps, and water coverage with a qualitative review of fire protection systems and emergency response. The result is an integrated plan for reducing risk to personnel and assets as well as addressing areas at risk of escalation.

Keywords: HRPL, QRA, FHA, FHMA, Fire Hazard and Mitigation Analysis, Risk Assessment, High Risk

## Introduction

Globally, industry standards and best practices require the use of risk assessment to determine hazards to both onsite and offsite personnel. Risk assessment is defined as the determination of quantitative or qualitative estimate of risk related to a well-defined situation and a recognised hazard (Risk, 2017). Quantitative risk assessment requires calculation of the potential loss and the likelihood of loss to determine the overall calculation of a numerical risk whereas qualitative risk assessment uses a combination of industry experience, team judgment, and predetermined criteria to establish a subjective or numerical risk determination. Both quantitative and qualitative risk assessments are valuable for use in the industry, with a combination of the two often the most effective way to risk rank within a given project, unit, or facility.

There are a range of different types of quantitative and qualitative risk assessments, with some assessments having elements of both. Risk assessments commonly seen in industry include quantitative risk analysis (QRA), probabilistic risk or safety assessment (PRA/PSA), major accident hazard assessment (MAH), hazard and operability assessments (HAZOP), layer of protection analysis (LOPA), Bowtie studies, and many other techniques. However, all of these studies fall within the broad umbrella of risk management as defined by ISO 31000 – an analysis with the goal of identification, assessment, and prioritisation of risk (ISO 31000, 2015). Regardless of the risk analysis approach chosen for a particular goal, the end result should provide the ability to rank processes from high risk to low risk to facilitate targeted and effective risk reduction or risk mitigation actions. Once risk reduction/mitigation options are determined, risk should be re-evaluated to determine if it meets specified criteria (CCPS, 2000).

One of the most effective ways to quantify risk on a facility wide basis is the QRA, which is a method designed to assist a facility/company to evaluate the overall risk of a process by quantitatively calculating a full distribution of consequences and their associated frequencies, summing them up across a given unit or facility to determine overall risk (Crowl and Louvar, 2002). This method results in a clear picture of the distribution of risk, which allows for identification of high risk populations and high risk portions of each process. Identification of high risk items allows for additional analysis in risk reduction/mitigation review and/or identification in protection gaps. Note that it is critical that risk mitigation projects are clearly evaluated to confirm the current risk vs. the mitigated risk so that funds are spent wisely. This paper focuses on risk reduction and gap analyses associated with high risk process loops (HRPLs) identified during the QRA process using a case study for fire hazard and mitigation analysis (FHMA) at a propylene unit.

## High Risk Process Loops

### Introduction to HRPLs

Process loops are defined as a portion of a process unit where, if a release were to occur, the predicted consequence would be similar. HRPLs are the portions of process that contribute the most risk to onsite and offsite personnel, as defined by a previously performed risk study. Figure 1 shows an example of a process flow diagram (PFD) that has been sectionalised into individual "process loops", with each subsequently analysed in the QRA process. This example shows a vessel and the bottom discharge and recycle as a process loop, with the scenario conditions conservatively taken at the high pressure discharge of the second in series pump. Depending on the complexity, a single process unit may include around 50 process loops with a handful (~2-5%, depending on the risk distribution) identified as HRPLs.

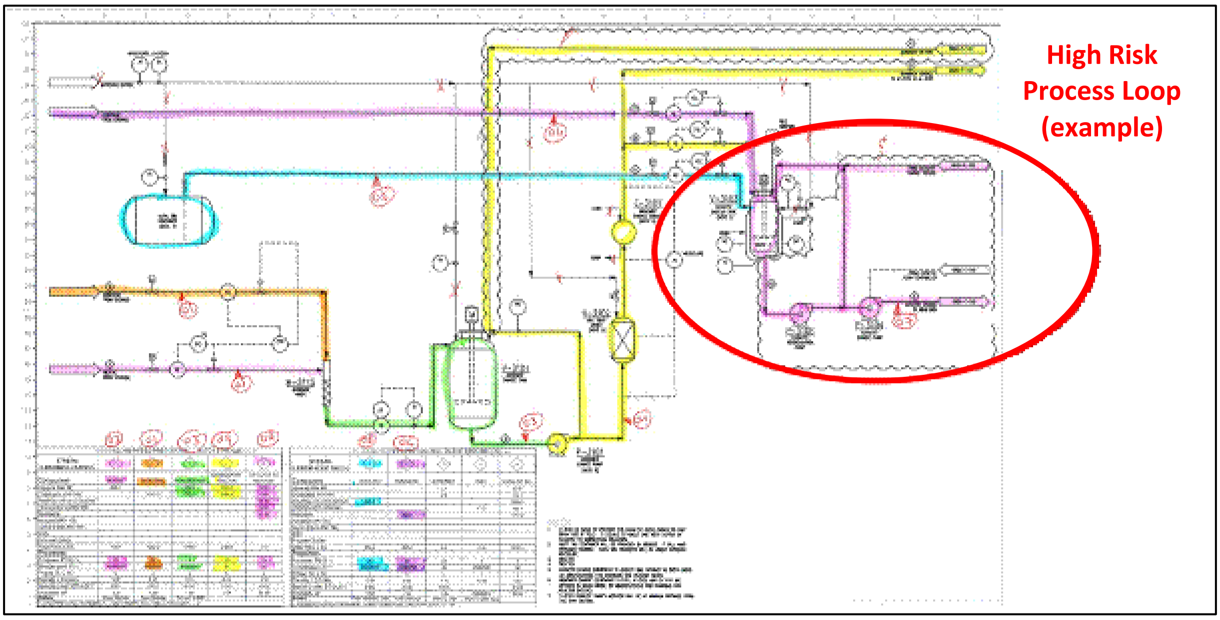


**Figure 1: High Risk Process Loop Example**

By addressing HRPLs identified in QRAs and other risk studies such as insurance loss reviews, environmental studies, and other consequence or risk based analyses, facility management can potentially drive risk down without moving people, erecting new buildings, upgrading existing buildings, or conducting other costly actions to reduce population exposure. The approach enables not only a risk reduction to onsite and offsite personnel, but also reduces the risk of asset damage and business interruption. Alternatively, interrogating HRPLs could identify gaps in safety system coverage or potential for knock-on effects that were previously unknown, allowing facilities to systematically drive down site wide risk by risk ranking process loops and implementing cost effective changes.

### Mitigation and Path Forward

There are a range of ways to reduce/mitigate risk, which can provide both qualitative and quantitative credits within a QRA. However, the risk mitigation plan should be scenario specific and depend on whether the identified process loop is dominant for flammable (flash fire), toxic, explosion, or thermal hazards. An experienced team of individuals should review each HRPL using a brainstorming process, which can then be narrowed down to identify the most viable options for review from a cost vs. benefit perspective. A few examples of risk reduction/mitigation options include enhanced fire and gas detection, emergency isolation, special attention during maintenance activities, review of PSM practices on that loop, additional level of detail in HAZOP studies, review of knock-on potential, fire protection review, emergency response procedure review, increased inspection intervals, and many more options.

The case study presented in this paper involves the follow-up analysis of a facility's two highest risk process loops, which together totalled approximately 8% of the total onsite risk, and presented a dominant jet/pool fire risk. After a review of potential risk reduction measures, the team determined the most cost effective way forward was to further analyse potential risk by performing a FHMA to determine potential thermal exposure and knock-on effects resulting from that HRPL. The goal of this FHMA was to determine all factors that could potentially impact the fire scenario, either complicating it or mitigating it.

## Fire Hazard and Mitigation Analysis

### Introduction

Traditionally, FHMA involves a qualitative review of fire protection systems, large inventory hold-ups, emergency response procedures, and firewater systems. Based on the qualitative review, which is subjective based on the personnel performing the analysis, a wide range of action items and mitigation results may arise depending on the team. However, when coupled with jet/pool fire thermal radiation consequences and risks determined in a QRA, the qualitative approach can be coupled with quantitative data to provide a clear picture of areas of concern, potential knock-on effects, and potential risk reduction. The FHMA technique employed in our case study involves a methodology that was designed to leverage an experience-based qualitative approach, in combination with a quantitative modelling technique that helps illustrate both positive and negative aspects of a given fire scenario, resulting in a more robust picture of the scenario under examination.

### Case Study

The case study presented in this paper involves a propylene unit typical of those found in industry. It includes a reactor to polymerise propylene as well as separation and purification steps and supporting utilities. A QRA performed on this facility showed that two scenarios contributed approximately 8% of the overall site-wide risk, dominated mostly by flash fire and jet/pool fire thermal radiation. After a review of these HRPLs, the team of individuals determined a need to conduct further analysis through a FHMA before pursuing risk mitigation methods. This FHMA focused on the potential thermal boundaries for the scenarios, potential knock-on effects due to thermal degradation of the unit, emergency response procedures in the event of an incident, and the firewater demand from fixed and mobile apparatus likely to be deployed in such an event.

From an emergency response perspective, the unit has relatively good access from all directions and has the ability to shut down and isolate the process locally from a number of locations as well as from the central control building. A walk-down of the unit confirmed good fire proofing, emergency isolation on major liquid holdups, good drainage, and good housekeeping. See Figure 2 below for a general plot layout showing the egress routes and emergency response access roads.

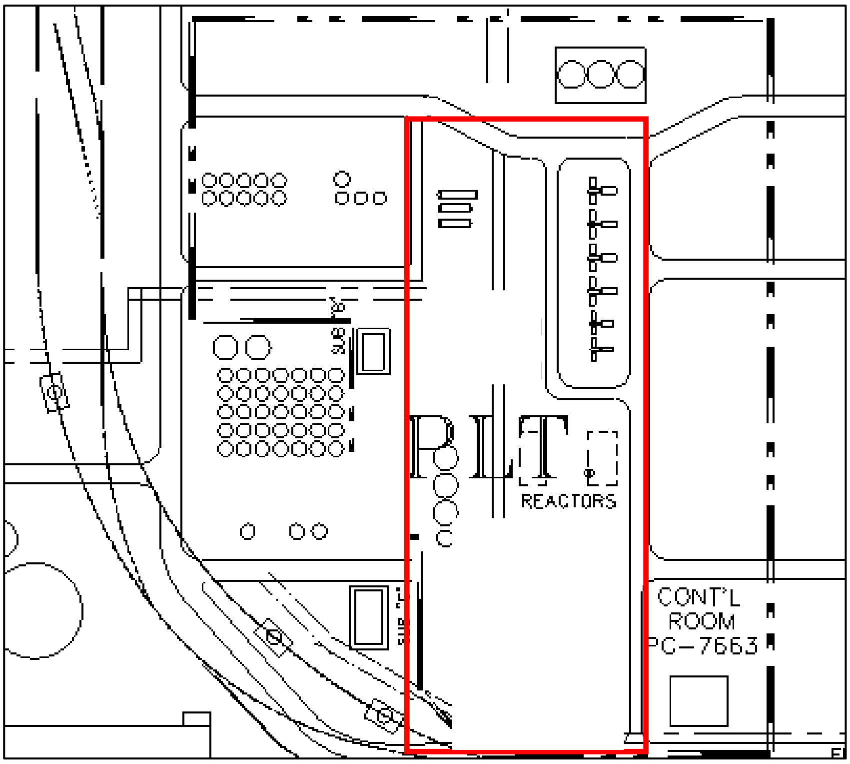


**Figure 2: General Plot Layout**

The facility has a firewater delivery system including a large firewater tank, multiple fire pumps, and well-gridded firewater mains throughout the complex. The propylene unit also has a number of fixed water spray systems that can either be actuated manually by operators in the control room or in the unit, or automatically via heat-actuated devices. In this case, the heat actuated device is a dry pilot head system tied to each system's deluge valve. Emergency responders also have the ability to reach most process areas and equipment with directed firewater monitor streams positioned throughout most of the battery limits of the units.

During the workshop comprised of FHMA team leads and experienced individuals provided by the site, the thermal radiation impacts for the HRPLs were reviewed in conjunction with the plot layout, walk-down observations, and engineer/operator knowledge. Figure 3 shows the detailed plot plan of the propylene unit along with deluge coverage areas. The evaluation of the fire scenario was derived using the results of the QRA, which were generated using BakerRisk's SafeSite$_{3G}$© software program to model a range of jet and pool fire scenarios for the unit as discussed above. The thermal radiation contours for the 2-inch release associated with the two identified HRPLs, oriented in the highest impact direction, are shown in Figure 4 and Figure 5 with the red dot indicating the scenario release point. Note that 2-inch releases were chosen for this case study because the team determined that larger fire scenarios would likely result in actuation of all fixed fire protection systems within the operating units, and firefighting efforts in most cases would be limited to defensive and rescue operations.

Fire scenarios for the three propylene units were limited to 0.5-inch and 2-inch release cases. Larger fire scenarios would likely result in actuation of all fixed fire protection systems within the operating units, and firefighting efforts in most cases would be limited to defensive and rescue operations. The consensus of the FHA team was that fires from 2-inch releases of available hydrocarbons represented a reasonable design limit for the purpose of evaluating current and future water supply capabilities.

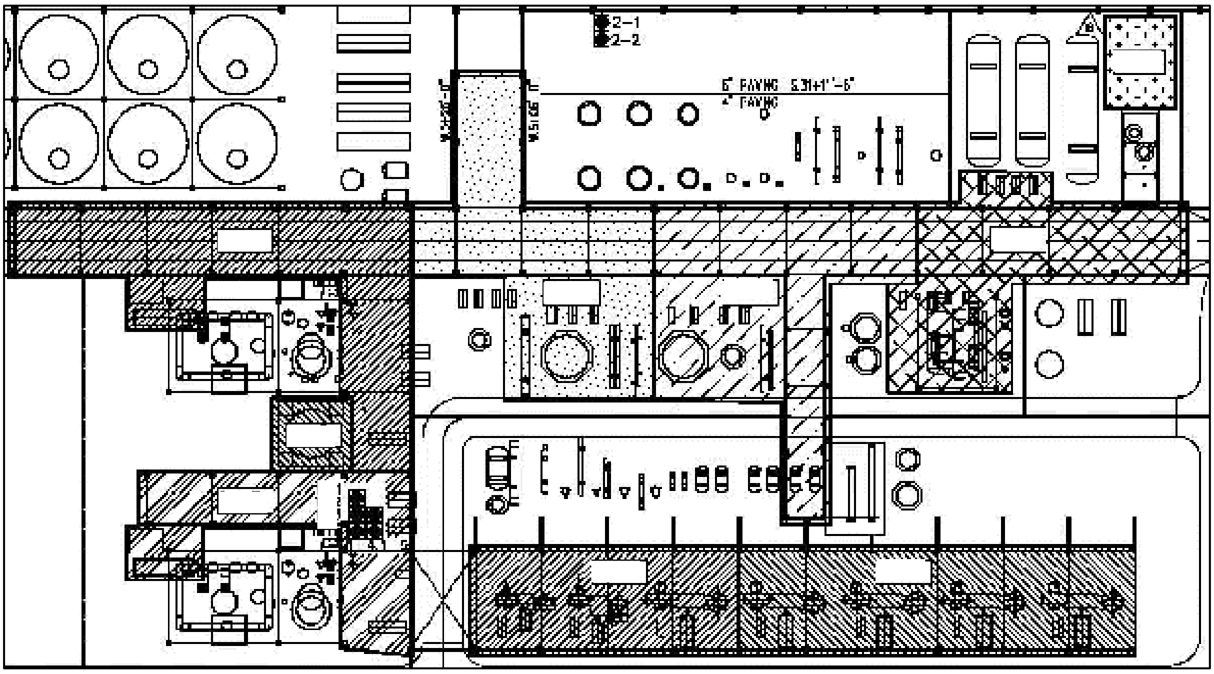


**Figure 3: Detailed Plot Plan with Deluge Coverage Areas**

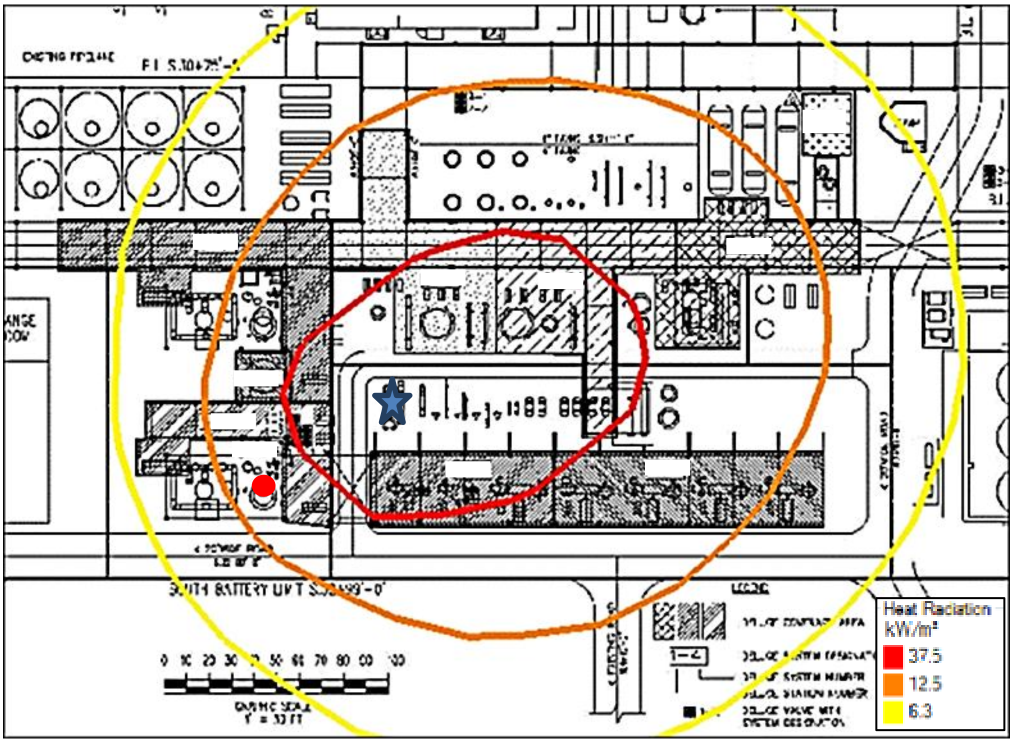


**Figure 4: Thermal Radiation for HRPL 1**

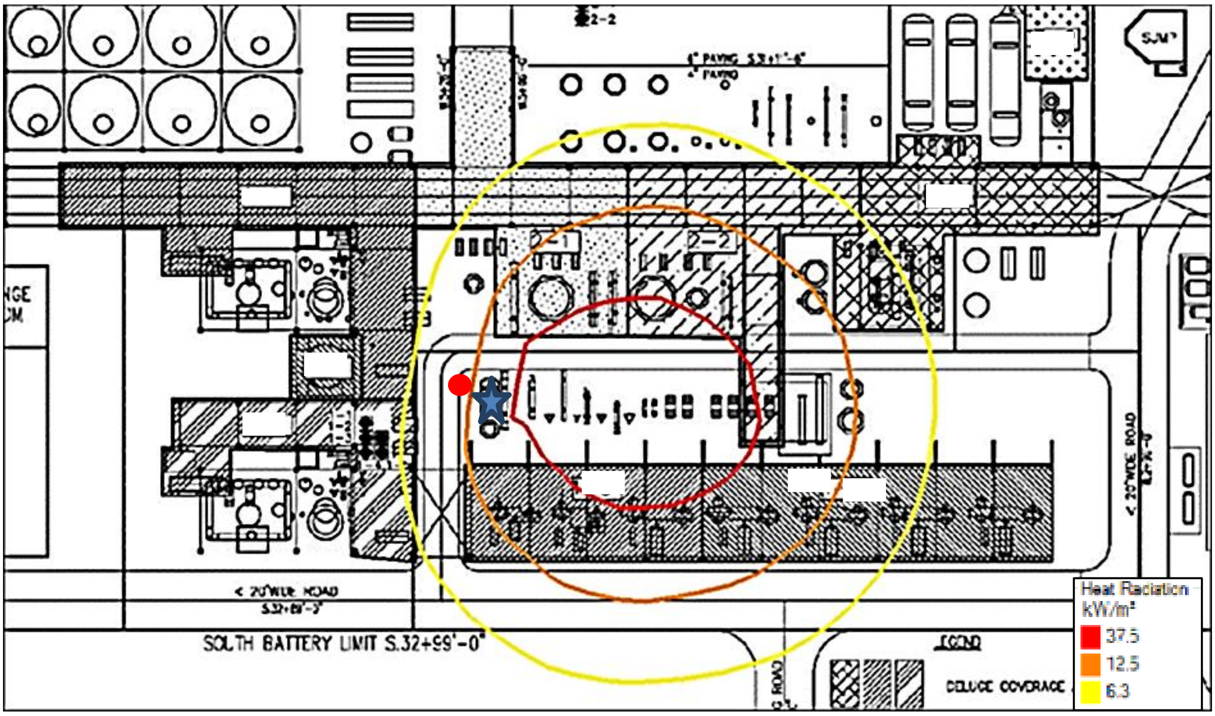


**Figure 5: Thermal Radiation for HRPL 2**

Review of these scenarios revealed that a refrigeration surge drum, identified with a blue star in Figure 4 and Figure 5 above, is exposed to jet/pool fire from either the reactor or the refrigerant loop, which could potentially result in a Boiling Liquid Expanding Vapour Explosion (BLEVE) of the vessel. It is critical that firewater spray systems are available to cool the vessel in the event of prolonged jet fire impingement. However, once the firewater coverage capabilities were reviewed based on available firewater capacity, automatic and operator activated deluge systems, and activation of fixed monitors, it was determined that the vessel does not have sufficient coverage from the site's firewater systems when equipment blockage of the firewater spray is accounted for. The FHMA showed that the vessel is not covered by any of the unit's fixed water spray systems, and the fire monitors in the vicinity are either obstructed or potentially unreachable due to the high temperatures likely to be present during the modelled fire scenarios. Figure 6 illustrates the monitor and deluge locations and the resulting firewater system coverage in the vicinity of the surge drum.

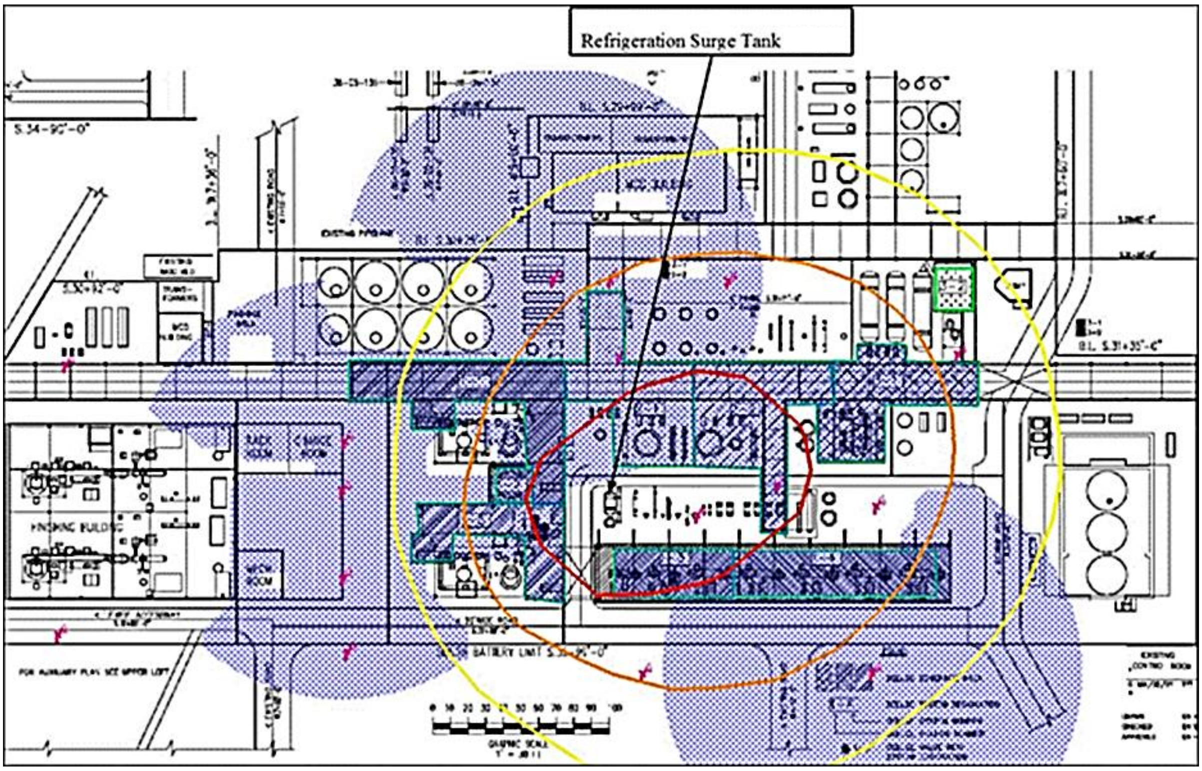


**Figure 6: Firewater Coverage for HRPL 1**

During the FHMA workshop, the team conducted a review of past events and responses and what kinds of actions are expected of the operators, emergency response team, and outside assistance. Inspection, testing, and preventive maintenance (ITPM) records on the fire systems were also reviewed to gauge their level of readiness and reliability if called on in a fire. This exercise resulted in the determination that a long duration direct jet fire impingement could occur on the refrigerant surge drum before mobile response was available during off-shift and holidays, potentially resulting in a BLEVE scenario.

The workshop team also reviewed in detail the specific high-risk scenario involving exposure of the surge drum to impacts from the two dominant HRPLs. Various options were evaluated to mitigate the fire exposure to the unprotected vessel and the feasibility, cost, and secondary disruption for each option were discussed. Options considered included additional fire monitors, improved passive fire protection, better fire pre-plans for emergency responders, and improved fixed water spray coverage.

At the conclusion of the workshop, two key recommendations were made to the site:

1. Improve fixed water spray coverage to include the vessel and nearby equipment.
2. Develop better scenario-specific fire pre-plans and include specific information about HRPLs and the potential for knock-on effects.

Both recommendations are consistent with the plant's existing fire mitigation philosophy and address a previously unidentified gap in the intended coverage of the fire systems. The recommendations also better align the site's fire protection coverage with industry best practice (API-2001, CCPS 2003) and were accepted by the plant. Although in this case, specific risk reduction for the HRPLs were not directly identified as a result of the FHMA, potential knock-on effects due to high risk scenarios were identified as high priority candidates for mitigation.

## Conclusion

High risk scenarios identified by risk analyses present a challenge to plant operations staff, emergency responders, and site management. For these high risk scenarios, whether they are identified as HRPLs in a QRA or in another analysis methodology, the risk mitigation/review process should always include a full review by an experienced team to brainstorm options and select a process to further analyse or mitigate the risk based on a cost vs. benefit analysis.

In our case study, the experienced team selected the option to do further analysis on fire scenario impacts and potential knock-on effects as well as review mitigation options through a FHMA before selecting mitigation options. The options to reduce risk for fire scenarios, whether through QRA, FHMA, or another type of consequence/risk review, should always include a full review of fire scenario impacts and mitigation options. Our case study shows one very beneficial application of the post-identification analysis using FHMA techniques to reduce the potential consequences of high-risk fire scenarios; the facility personnel were able to identify a potential gap in coverage related to a high risk scenario and develop a plan to mitigate the potential knock-on effects.

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