A METHODOLOGY FOR ASSESSING AND MINIMISING THE RISKS ASSOCIATED WITH FIREWATER RUN-OFF ON OLDER MANUFACTURING PLANTS

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Many manufacturing facilities handle flammable and combustible materials. It is often not practicable to eliminate fire risks on older plants because of their original design features. Fire protection for these plants ultimately depends on some form of active fire protection system, using either dedicated deluge systems or mobile fire appliances. These systems will produce firewater run-off which can cause additional safety, environmental and business impacts away from the incident. These risks must be managed.

Keywords : firewater runoff, fire, risk assessment.

INTRODUCTION

Modern chemical manufacturing plants are often now designed using a structured programme of safety studies. Opportunities for promoting inherent safety are investigated and implemented into the design where practicable. Fire prevention measures can be used extensively to minimise plant fire risks. Firewater containment systems or procedures can be incorporated in the plant design to minimise firewater run-off risks. This allows a balance to be struck between investments in inherent safety, prevention, protection, containment and emergency response facilities.

Contrast this with a typical older plant. It may have been constructed before safety studies were integrated strongly into the design lifecycle or when process safety engineering techniques were less well developed than they are today. Opportunities for fire prevention are likely to be limited and design deficiencies may exist. Typical problems associated with older plants which can cause fire risks to be high include :

- inadequate separation distances between plant and storage areas.

- poor drainage away from high risk equipment.

- limited access for fire fighting in an emergency.

- proximity of plants to populated onsite and offsite populations.

- inadequate firewater supply and firewater run-off containment.

Operating companies are then faced with the dual problem of managing plants with high fire risks and high firewater run-off risks. This paper proposes a methodology for managing firewater run-off risks on older plants supported by practical examples. This allows risks to be identified and minimised using appropriate containment and protection systems.

HAZARDS CAUSED BY FIREWATER RUN-OFF

Although uncontrolled releases of firewater run-off are a well publicised cause of environmental damage to aquatic systems, it is important that all potential hazards are considered. Depending on the local plant design and surrounding area, the following hazards may also exist :

(i) local fire spread to escalate the fire incident to adjacent plant areas. This could occur if the fire extinguishing medium failed to extinguish the fire and acted to increase the pool area of the fire or if the firewater run-off was flammable and re-ignited.

(ii) fire spread to more distant areas. This would be most likely to be caused by re-ignition of flammable firewater run-off but could also occur if the fire extinguishing medium failed to be effective. The fire could start in a plant area where ignition sources were carefully controlled before escalating to an area which would not normally be considered to be a hazardous area. If this occurred, the emergency services would become stretched as they attempted to fight fires in multiple locations simultaneously.

(iii) toxic release in a distant area. The firewater run-off may contain toxic materials from the source of the fire or from other site areas, such as drains, open tanks or Intermediate Bulk Containers (IBCs). The toxic release may occur close to a populated area such as a road, railway, containment lagoon or sewage treatment works, causing risks to offsite populations, office workers or other site workers.

The assessment of firewater run-off risks must consider all of these hazards.

ASSESSMENT OF EXISTING FIRE RISKS

Before firewater run-off risks can be assessed, the fire hazards associated with the plant need to be identified. A Fire Risk Assessment (FRA) needs to be carried out using an appropriate quantitative or qualitative methodology. In practice, it is often most effective to use a semi-quantitative technique, with detailed fire and explosion consequence modelling.

Identification Of Fire Scenarios

Fire scenarios should be clearly identified and are likely to involve the following flammable and explosive events in different areas of the plant.

1. Pool fires at ground floor level, running down a slope or running through a structure from a high floor level.

2. Gas jet fires, liquid jet fires and flash fires.

3. Vapour cloud explosions (VCE) and internal vessel fires and explosions.

4. Proximate fires involving packaging, wood, pallets, vegetation.

5. Local escalations leading to BLEVE (Boiling Liquid Expanding Vapour Explosion) or damage to adjacent combustible materials.

6. Escalations to other plant or storage areas.

7. Fires in warehouses or Intermediate Bulk Container (IBCs) storage areas.

Defining The Current Basis Of Fire Protection

This needs to be investigated and clearly understood and will include :

1. **Inherent safety** features and prevention systems, such as double mechanical seals on pumps, all welded pipes, flange guards and pressure relief systems. These features either ensure that fires cannot start in the first place or reduce the frequency of fires.

2. **Detection systems**, such as operator detection, gas detection systems and fire detection systems (pneumatic, infra-red, heat sensitive cable). On many older plants, fire detection is often dependent on operator vigilance and action. If the plant handles highly toxic materials or is largely unmanned, it may be fitted with a gas or fire detection system.

3. **Active Fire Protection (AFP)**, such as bund foam pouring systems, sprinkler systems, deluge systems and the Fire Brigade response. These systems allow fire fighting water (or foam / water mixtures) to be applied to the fire and / or around critical plant and equipment. Some plants rely on manual intervention by onsite and external fire fighters using fire appliances and portable foam units. Other plants are protected with fixed systems consisting of fixed pipework linking the firewater supply to a matrix of sprinklers, nozzles or foam pourers inside the plant area. Fixed systems can either be manually operated from a safe area away from the fire or automatically operated from fire detection systems and manual call points located around the plant area.

4. **Passive Fire Protection (PFP)** and fire escalation protection, such as firewalls, segregation of high risk areas, PFP for vessels and PFP for structural steelwork. These

systems are designed to protect vulnerable equipment to control the spread and the consequences of the fire. They will not extinguish the fire but will buy time for the Fire Brigade response. There are many different PFP systems. Commonly used technologies include fire insulation boards and lagging, intumescent paint coatings and vermiculite (concrete-like material) coatings. They are all designed to limit the heat transfer from the fire to the vulnerable equipment.

5. **Containment systems**, such as local bunds, drains, slopes and walls. These systems should be designed to direct leaks and fires away from vulnerable areas to a secure area.

6. **Emergency response**, using the onsite services (if they exist) or external Fire Brigade.

Examining The Effectiveness Of The Existing Fire Protection Systems

The effectiveness of the existing systems should be investigated carefully to identify typical problems such as :

1. **Inherent safety**. Corrosion, damaged or missing flange guards, undocumented pressure relief calculations.

2. **Detection systems**. Unreliable gas detection systems. Incorrect detection levels. Systems which have been disconnected. Reductions in manning levels.

3. **AFP**. Areas of the plant not covered by AFP systems because they have been added to the original plant. Damaged or corroded valves, sprinklers, nozzles and foam pourers. Manual deluge valves. Poorly located deluge valves. Poor firewater supply. Degraded foam. Poor system reliability.

4. **PFP**. Damaged PFP. PFP which uses inappropriate materials such as concrete. Unprotected vessels. Extensions to the steelwork which have no PFP.

5. **Containment systems**. Inadequate capacities, blocked or undersized drains, damaged bund walls, areas where large pools may develop due to inadequate drainage. Critical firewater disposal pumps which may fail in a fire situation or may become sludged up. Valves which could isolate or bypass the containment systems.

6. **Emergency response**. Poor access to the plant for emergency services. Slow Fire Brigade response times. Inadequate onsite Fire Brigade manning levels on nights and at weekends.

This stage of the assessment needs to be carried out carefully and tests are often required to verify the system performance. A team based approach is very effective using representatives from the production plant, engineering, process safety and maintenance. An experienced fire fighter should also be present to identify relevant practical fire fighting issues. The assessment should be focused on how each of the identified scenarios would be controlled.

Fire Risk Summary

A frequency and consequence assessment needs to be carried out for each fire scenario. Risks can be summarised using many different techniques. In most cases, a risk matrix is effective for summarising fire risk levels. Frequencies are grouped into a number of defined categories on one axis of the matrix from very low to high. Consequences are grouped into a number of defined categories (covering safety, environmental and asset damage impacts) on the other axis from trivial to catastrophic. Table 1 shows an example of a typical risk matrix.

At this stage, firewater run-off risks are not included in the risk matrix. The risk matrix can be used as a tool to ensure that fire risks are managed to a level which is 'As Low As Reasonably Practicable (ALARP)'. Further information is required before firewater run-off risks can be assessed.

ANALYSIS OF FIREWATER RUN-OFF RISKS

Fire scenarios which pose a high fire risk have now been identified. A quantity of firewater supply will be required for each scenario and this will in turn generate firewater run-off. The potential impacts of the firewater run-off now have to be considered.

Characterisation Of Fire Scenarios

It is very difficult to predict the volume and duration of firewater usage for each of the fire scenarios. In a real fire situation, the Fire Brigade will control the amount of firewater which is used to extinguish the fire and control the incident. An estimate of the firewater application rate and the total volume of applied firewater must, however, be made if firewater run-off risks are to be managed.

In general, four factors tend to dominate firewater usage :

(i) fixed active fire protection systems, such as sprinkler systems, deluge systems and bund foam pouring systems.

(ii) onsite firewater supply capacity through hydrant systems and from fixed storage tanks. This can be used by onsite and external Fire Brigades. The distribution systems will often also feed the fixed active fire protection systems.

(iii) offsite firewater supply capacity such as local lakes, ponds, rivers, canals, water distribution mains. These would probably be used by the external Fire Brigade if the incident was serious.

(iv) rainfall, effluent generation and chemical spills from different plant areas.

Estimates need to be made of the contribution to overall firewater usage for each fire scenario.

Table 1 : Typical Risk Matrix For Assessing Fire Risks.

Frequency Category	Trivial	Significant	Serious	Major	Catastrophic
High		4a			
Moderate	2a	8			
Medium		11 2b	10 6		
Low		3 1	5 4b	9	
Very Low				7	

Consequence Category

Fire Scenario Summary

1	Main transfer line leak.
2a	Small leak in day tank area.
2b	Large leak over day tank bund.
3	Leak in line to adjacent plant.
4a	Small pump leak.
4b	Day tank drains out through pump.
5	Leak from day tank to process.
6	Major leak in blending vessel.
7	Reactor feed line rupture.
8	Reactor vapour space leak.
9	Reactor liquid leak.
10	Major release through filters.
11	Recycle line rupture.

Fixed Active Fire Protection Systems

These systems are normally designed to be compliant with a standard such as NFPA15 (NFPA, 1) or NFPA16A (NFPA, 2). These standards specify minimum required water or foam / water application rates per square meter of protected plant. For example, NFPA15 recommends an application rate of at least 10 LPM / m^2 (litres per minute per square metre) for water spray protection to vessels and NFPA16A recommends an *application rate of at least 6.5 LPM / m^2 for foam / water sprinkler protection systems.*

The firewater application rate can then be calculated for each fixed system from 1 :

$$LPM = Q \times A \times SF \quad (1)$$

where LPM is the overall firewater application rate in litres per minute, Q is the NFPA recommended application rate per square metre, A is the surface area of the equipment to be protected in square metres and SF is a Safety Factor. The Safety Factor is required because most systems will be designed to work to NFPA application rates or better when some of the firewater supply system is impaired. The designer of the active fire protection system may be able to advise on actual flow rates, from which the safety factor can be calculated. If this information is not available, a factor in the range 1.1 to 1.3 could be used as a default value.

The LPM could also be obtained by monitoring system water demands when the system is tested or by taking measurements at points on the plant during a test.

Fire Brigade Usage

The Fire Brigade will extract firewater from dedicated firewater supply mains (which may also be supplying fixed active fire protection systems) and from other water sources using mobile pumps. Table 2 shows typical firewater application rates for fires on chemical plants.

It is difficult to predict these usage rates accurately. It may be possible to obtain additional information from experienced fire-fighters in the onsite or external Fire Brigades.

Rainfall, Process Effluent And Chemical Spills

Firewater may be applied at a time when the site effluent systems are fully loaded with process effluent or when storm conditions exist. This will create an additional demand on the site drainage and containment systems. Data can be obtained for stormwater flow rates (eg. a 1 in 25 year 8 hour duration storm event) in mm of rainfall per square metre. This rate has to be adjusted to account for the surface area which feeds into the drains to produce a rate of drainage in LPM.

Process effluent generation rates also need to be assessed in LPM. This should include any unburnt chemicals released during the fire.

Table 2 : Typical Firewater Application Rates For Chemical Plants.

Type Of Fire	Typical Usage In LPM		Typical Duration (hours)	Typical Inventories
	From	To		
High Severity	27000	54000	4	Hundreds of tonnes of flammables
Medium Severity	18000	27000	3	Tens of tonnes of flammables
Low Severity	9000	18000	2	Less than 10te of flammables

In most cases, stormwater and process effluent generation rates are much lower than the rates produced by fixed active fire protection systems and the Fire Brigade.

Duration Of Firewater Application

This is again very dependent on the individual fire scenario and the fire fighting strategy adopted by the Fire Brigade.

Typically, firewater may be applied to a large fire for about four hours and to a small fire for about two hours. After this time, cooling or damping down may occur for up to 24 hours at rates of about 4500LPM.

Composition Of Firewater Run-off

In most cases, especially when the fire involves a mixed storage area, it is almost impossible to quantify the likely composition of the firewater run-off. The run-off is likely to consist of a complex mixture of unburnt chemicals, partially combusted chemicals, by-products from the combustion process, fire fighting foam and materials which are stored in the path of the firewater run-off.

If detailed water pollution consequence modelling is being carried out, source terms will need to be derived for each release scenario. This may concentrate on the predicted dominant cause of pollution or contributor to fire and safety risks.

Definition Of Firewater Scenarios

Many of the fire scenarios will produce firewater run-off incidents which have similar safety, environmental and asset damage consequences. These scenarios can be grouped into firewater scenarios. Table 3 illustrates a typical set of firewater scenarios for a plant.

The adequacy of the existing containment systems also needs to be assessed. Calculations need to be performed to understand when each element of the containment system will become overwhelmed (eg. the intermediate bund will fill in 8 minutes, cascade into the main bund and fill this bund in 14 minutes, and then cause an *uncontained release. It is also important to calculate the maximum flow rates (LPM)* which can be accommodated by relevant plant drains.

Identification Of Firewater Pathways

A pathway is a mechanism by which firewater can be transported from the source of a fire to a vulnerable plant area, populated area or sensitive environment. Pathways need to be identified for each firewater scenario. This can best be achieved by :

1. Identifying the plants, storage areas, offices, offsite populated areas, streams, culverts, rivers and ground which could be susceptible to damage from firewater run-off.

Table 3 : Typical Firewater Scenarios For A Plant.

Scenario	Description	Bund Foam Pouring System	Plant Deluge System	Building Water Curtains	High Level Fixed Monitors	Fire Brigade	Storm Water	Process Effluent	Total Firewater Run-off
FW1	Transfer line leaks	0	0	0	6000	9000	2000	500	**17500**
FW2	Day tank leaks	1000	0	1100	3000	9000	2000	600	**16700**
FW3	Low severity fire in process area	0	2900	3300	0	9000	2000	800	**18000**
FW4	Medium severity fire in process area	0	8800	3300	0	9000	2000	2300	**25400**

All firewater run-off volumes in LPM (litres per minute)

2. Deciding if each firewater scenario can credibly affect any of these areas.

3. Identifying protection and containment systems which must fail to cause damage to be realised by each scenario. This should include hardware, such as valves, and software, such as emergency procedures.

It is often useful to show each pathway using an event tree format. If a quantitative frequency assessment is being used, branch probabilities can be inserted to calculate the frequency of causing different types of damage. Figure 1 shows how an event tree can be used to define pathways.

Onsite And Offsite Impact Assessment

Each firewater scenario with the potential to cause significant damage should be assessed to determine it's impact on man, the environment and the business. These consequences can either be assessed using a qualitative risk matrix based approach or using quantitative modelling techniques.

If quantitative modelling is used, factors such as composition, pool size, dilution rates and flow rates can be calculated. These parameters can then be fed into the appropriate consequence modelling software for fire damage, groundwater pollution, river pollution or toxic impacts.

Risk Summation

Risks can either be summarised using quantitative techniques or using risk matrices (as shown in Table 1).

RISK ASSESSMENT

Decisions now need to be made about the tolerability of the firewater run-off risks. It is very rare to find that these risks can be eliminated entirely. There is normally some combination of hardware failures, natural events and human error which could lead to a pollution incident, asset damage or impacts to people.

Risk tolerability criteria need to be used to determine whether risks are :

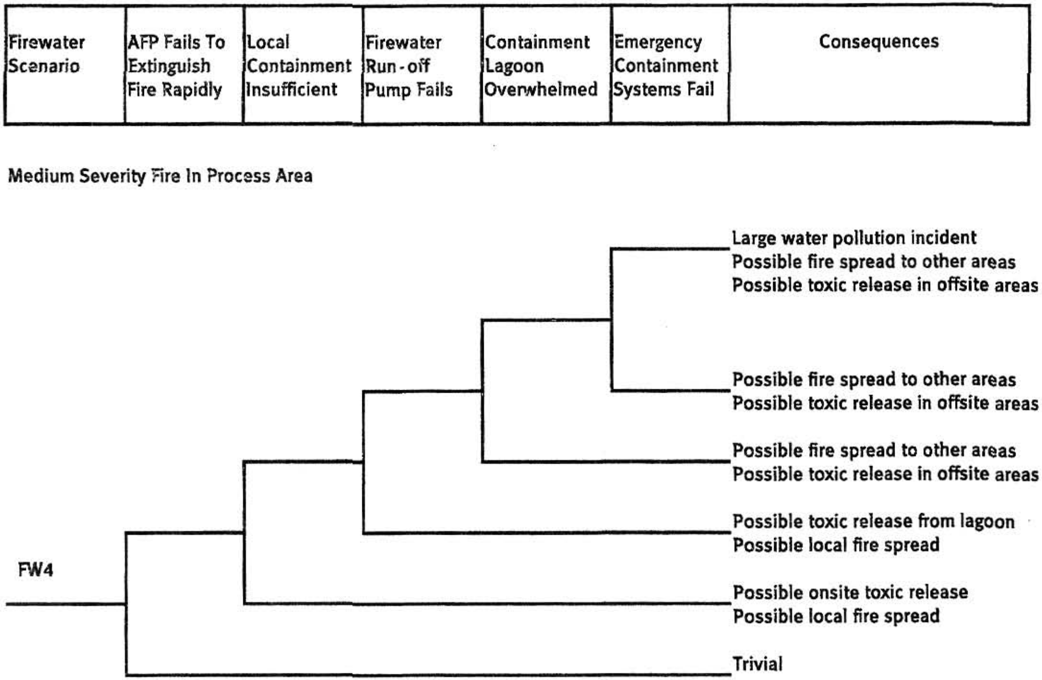
1. So high that they should be considered to be intolerable.

2. Sufficiently low that they can be regarded as broadly acceptable. or

3. Somewhere between these two levels, where risks should be managed to a level which is considered to be ALARP (As Low As Reasonably Practicable).

Most plants fall into this middle ALARP band. It is therefore necessary to examine a series of risk reduction options and assess their cost and the reduction in risk that they produce. An optimal series of risk reduction measures can then be developed to ensure that this ALARP criterion is met.

Figure 1 : Definition Of Firewater Pathways Using An Event Tree Format.



Risk Reduction

There are a large number of risk reduction measures which could be adopted. These are described in a number of publications including (HSE, 3) and (NRA, 4) and include :

Reduction Of Fire Risks

By eliminating or reducing fire risks, the frequency of producing a firewater run-off incident is automatically reduced. Typical risk reduction may include :

1. Design changes to minimise leak frequencies and measures to control ignition sources in hazardous areas.

2. Passive fire protection to control fire escalation or isolate the plant into smaller fire zones.

3. Fire and gas detection systems to provide early warning that an incident has occurred.

4. Fixed active fire protection systems to allow fires to be extinguished rapidly before they have been able to develop.

5. Trained on-site fire fighting teams equipped with mobile fire fighting equipment.

Improved Containment Systems

These measures are designed to control the flow of firewater run-off and ensure that it is directed to a safe area. Typical measures include :

1. Improved bund designs, increasing bund heights, making greater use of mini-bunds and installing spillways at the top of bund walls to direct bund overtopping spills in a preferred direction.

2. Dedicated firewater run-off drains feeding to a large containment lagoon located in a safe area.

3. Temporary booms and sandbags to direct spills to safe areas or sacrificial areas.

Emergency Response

These measures are aimed at minimising the impact of any releases and include :

1. Training onsite teams to deal with emergencies.

2. Improving links with external bodies who are responsible for fire fighting and pollution control.

CONCLUSIONS

This paper has shown how systematic risk assessment techniques can be used for managing and minimising firewater run-off risks on older manufacturing plants. It can be integrated with quantitative and qualitative techniques and can also be used in conjunction with the risk management systems used by individual operating companies.

REFERENCES

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4. NRA, 'Pollution prevention measures for the control of spillages and fire-fighting run-off', National Rivers Authority, 1994.

SUMMARY OF ACRONYMS

AFP	Active Fire Protection
ALARP	As Low As Reasonably Practicable
BLEVE	Boiling Liquid Expanding Vapour Explosion
FRA	Fire Risk Assessment
HSE	Health & Safety Executive
IBC	Intermediate Bulk Container
LPM	Litres Per Minute
NFPA	National Fire Protection Association
NRA	National Rivers Authority
PFP	Passive Fire Protection
VCE	Vapour Cloud Explosion