Consistent Consequence Severity Estimation

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Abstract

Most risk analysis methods rely on a qualitative judgment of consequence severity, regardless of the analysis rigor applied to the estimation of hazardous event frequency. Since the risk analysis is dependent on the estimated frequency and consequence severity of the hazardous event, the error associated with the consequence severity estimate directly impacts the estimated risk and ultimately the risk reduction requirements. Overstatement of the consequence severity creates excessive risk reduction requirements. Understatement results in inadequate risk reduction.

Consistency in the Layers of Protection Analysis (LOPA) can be substantially improved by implementing consequence estimation tools that assist team members in understanding the flammability, explosivity, or toxicity of process chemical releases. This paper provides justification for developing semi-quantitative look-up tables to support the team assessment of consequence severity. Just as the frequency and risk reduction tables have greatly improved consistency in the estimate of the hazardous event frequency, consequence severity tables can significantly increase confidence in the severity estimate.

Introduction

Various types of process hazards analyses (PHA) are now in widespread use throughout the process industry [1]. These analyses evaluate process deviations that potentially lead to hazardous events and the safeguards that are implemented to reduce the likelihood of each event. Many PHAs incorporate risk analysis to determine the residual risk of each identified event. This is accomplished by qualitatively estimating the likelihood of the event given its causes and safeguards. The PHA process can be supplemented with Layers of Protection Analysis (LOPA) to provide an order of magnitude estimate of the hazardous event frequency by assessing the frequency of the initiating events that lead to the hazardous event and the probability that the safeguards fail [2].

One of the authors has often stated "A big risk is not addressed by a big list: it is addressed with the right list of independent protection layers." A big risk generally involves an event judged to have a consequence severity of a potential significant injury or fatality. PHA teams often deal with the big risks by making a big list of safeguards, thus making the event seem much less likely when the team is asked to qualitatively assess the potential event likelihood considering the causes and safeguards. In most PHAs, safeguards are recommended if they reduce the event likelihood a little or a lot. Yet, the expectation is that everything on the list is safety-related and is managed with sufficient rigor. Instead of a big list, an owner/operator needs the right list of protection layers that are known to demonstrate the claimed risk reduction.

The reduction of the big list to the right list is one of the primary benefits of LOPA. During the PHA, the team identifies process deviations that potentially lead to hazardous events and assesses the hazardous event frequency given the identified safeguards. LOPA seeks to analyze the root causes (or initiating causes) and enabling conditions that result in process deviations (or initiating events). Understanding the likelihood of the initiating causes and conditions enables the team to estimate the initiating event frequency.

In LOPA, the team recommends independent protection layers (IPL) rather than safeguards. IPL are designed and managed according to good engineering practices that are known to provide the claimed risk reduction. The characterization of the initiating event frequencies and IPL risk reduction in order of magnitude terms allows teams with little mathematical inclination to estimate the hazardous event frequency based on information and data that correspond to key performance indicators [3]. In most cases, the team is provided with look-up tables of typical initiating cause frequencies and IPL risk reduction values that can be adjusted based on specific site experience, so the estimated hazardous event frequency is generally very consistent from team to team. As advanced LOPA procedures make more precise estimates of the frequency of the events and probability of IPL failure, the hazardous event frequency estimate becomes more quantitative, but the method remains inherently semi-quantitative.

The logical next step in improving LOPA is to introduce guidance for estimating the consequence severity. The following discussion presents the authors' proposal for semi-quantitative selection of consequence severity associated with flammable releases. Simple look-up tables are presented that rely on equipment design specifications and process operating conditions – information that should already be maintained by the site and provided to the team that is conducting the analysis. Dispersion modeling based on conservative assumptions was used to correlate estimated release rates to "zones of damaging overpressure." Then, these zones were tied to the consequence severity rankings that typically support risk analyses during the PHA and LOPA. The look-up tables have been demonstrated to yield a consistent basis for estimating the consequence severity, leading to greater consistency in the risk estimate regardless of the team experience with harmful events.

LOPA is a Great Tool!

LOPA is an excellent tool for assessing a wide variety of process hazard scenarios and then crediting or applying protection layers of appropriately robust design. LOPA, as a semi-quantitative analysis, allows for efficient evaluation of process hazards by a multi-disciplined team of representatives that are experienced with the equipment under study. The results are based on a better estimate of the hazardous event frequency and therefore provide a stronger basis for recommending safety functions or layers.

LOPA supports performance-based process safety because it ties various quality assurance metrics or key performance indicators to the hazardous event frequency. As owner/operators track the challenges on their IPLs and failures of their IPLs, LOPA provides a means to tie order of magnitude estimates of historical performance to industry benchmarked values.

Fortunately, most teams have little experience with hazardous events, since a properly designed and operated chemical process will have adequate IPLs to reduce the event frequency to a sufficiently low level. On the other hand, they do have experience with the frequency of root causes (or initiating causes), the frequency of process deviations (or initiating events), and the frequency of work orders (or reported failures) of IPLs. The estimated hazardous event frequency can be understood by all disciplines and those disciplines that impact the estimate can better understand their role in hazardous event propagation. Done right, it gives the organization a firm and consistent basis for investment in protective systems.

LOPA is Inconsistent!

As organizations progress with LOPA throughout the entire organization, invariably the results are compared and questions asked. When LOPA results for similar process units are compared from company to company, facility to facility, and team to team, it is not unusual to see variation in the risk estimate for similar hazardous events. Since most LOPA procedures have well defined methods for estimating the hazardous event frequency, the inconsistency in the risk estimate is generally due to variation in the estimated consequence severity.

Most LOPA methods rely on a qualitative estimate of the consequence severity. Table 1 provides an example of typical consequence severity descriptions. These descriptions are essentially statements of harm which are not easily estimated by the team, which is expected to judge what happens when a process deviation leads to a hazardous event and what harm could potentially be posed by the hazardous event. While they may have experience in process deviations, hopefully, they have little experience with hazardous events and the resulting harm.

Table 1. Qualitative Consequence Severity Ranking

RANKING	SAFETY	ENVIRONMENTAL	ASSET
5	Multiple fatalities across a facility and/or Injuries or fatalities to the public	Catastrophic off-site environmental damage with long-term containment and clean-up	Expectant loss greater than $10,000,000 and/or substantial damage to buildings located off-site
4	Hospitalization of three or more personnel (e.g., serious burns, broken bones) and/or one or more fatalities within a unit or local area and/or Injuries to the public	Significant off-site environmental damage (e.g., substantial harm to wildlife) with prolonged containment and clean-up	Expectant loss between $1,000,000 and $10,000,000 and/or extended downtime with significant impact to the facility operation and/or minor damage (e.g., broken windows) to buildings located off-site
3	Hospitalization injury (e.g., serious burns, broken bones) and/or multiple lost work day injuries and/or Injury to the public	On-site release requiring containment and clean-up and/or off-site release causing environmental damage with quick clean-up	Expectant loss between $100,000 And $1,000,000 and/or downtime of several days severely impacting the facility operation
2	Lost work day injury and/or recordable injuries (e.g., skin rashes, cuts, burns) and/or minor impact to public	On-site release requiring containment and clean-up by emergency personnel and/or off-site release (e.g., odor) but no environmental damage	Expectant loss between $10,000 and $100,000 and/or downtime of more than day causing impact to facility operation and/or reportable quantity event
1	Recordable injury and/or no impact to the public	On-site release requiring containment and clean-up by on-site personnel.	Expectant loss of less than $10,000 and/or downtime of less than a day with minor impact to the facility operation

The severity estimate is often bounded with qualitative guidance that the team should estimate the “worst case consequence” or “worst credible consequence.” For example, the worst credible scenario is “the most severe incident of all identified outcomes and their consequences that is considered plausible or reasonably believable” [4]. The interpretation of these terms and their definitions has proven to be highly variable. The perceived error in this severity estimate is one of the chief criticisms of PHA and LOPA. And, unfortunately, perception often drives investment, so if it is perceived that the team was excessively conservative in the consequence severity estimate, it is easier for management to reject PHA and LOPA recommendations as unwarranted.

There are many legitimate reasons for variation in the consequence severity estimate across an organization, including differences in the specific process quantities, layout, location, equipment pressure ratings, etc. These differences are recognized by the respective teams and they may result in different consequence severity rankings. In many cases, these specific differences are not fully described in the PHA or LOPA documentation, so it is difficult for people who were not part of the team to understand why the differences exist. So, it is important to remember that not all apparent variation in results is bad; indeed it often reflects the very purpose that PHA and LOPA are performed on specific equipment and revalidated periodically to capture lessons learned in operating and maintaining the equipment.

A significant amount of variation is introduced due to perceptual differences of the hazardous situation created by the hazardous event. Bias may also be introduced into teams by the presence of risk-taking or risk-adverse people. Direct experience with the hazardous event is a strong influence on the estimate. For example, where a site or team member has experienced a fire and no one was hurt, the assumed outcome for any fire may become “no one gets hurt”. If there is experience where people were hurt or killed by the fire, even due to extremely unusual conditions, all events resulting in a potential fire may be regarded as a fatality event. While no one should take any fire lightly, the concept of risk analysis certainly incorporates the idea that large fires should receive more attention and effort in prevention than small ones, other factors being equal.

These qualitative biases may be great enough to push the severity estimate to a more or less conservative result than is appropriate. Overstatement of severity creates excessive risk reduction requirements and costs. Understatement results in inadequate risk reduction and a higher potential for loss events. Giving teams a consistent basis for the severity assessment can significantly reduce variability.

Conditional Modifiers Can (not) Fix it!

Basic LOPA analyzes the risk for each hazardous event resulting from one or more process deviations. Basic LOPA focuses the risk analysis on preventing hazardous events. This agrees with OSHA 29 CFR 1910.119 [5], which is dedicated to not just “minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals” but also to “preventing” such releases. The typical LOPA risk criteria are that the maximum hazardous event frequency should not exceed 1x10^{-4}/yr for events potentially leading for a worker fatality or 1x10^{-5}/yr for events potentially leading to a public fatality [6]. The overall frequency of all deviations leading to the same hazardous event should achieve these risk criteria. Many risk matrices have similar risk criteria built into the relationship between frequency and consequence severity as illustrated in Table 2 [4].

Table 2. Example Risk Matrix

		REQUIRED RISK REDUCTION FACTOR				
CONSEQUENCE SEVERITY	5	100,000	10,000	1,000	100	10
	4	10,000	1,000	100	10	TR
	3	1,000	100	10	TR	TR
	2	100	10	TR	TR	TR
	1	10	TR	TR	TR	TR
		1	10	100	1,000	10,000
		FREQUENCY (1 in x years)				

Hazardous Event Frequency = 1x10^{-4}/yr for impact to worker
or 1x10^{-5}/yr for impact to public

Some owner/operators use LOPA to support risk criteria based on the harmful event frequency. Some regulatory authorities require that the maximum individual risk or societal risk be determined and reported as part of permitting or safety cases. Once the hazardous event risk is known, the team assesses site specific conditions (e.g., probability of ignition and probability of occupancy) to determine the harmful event frequency. The probability values assumed for conditional modifiers whether used in LOPA or QRA (quantitative risk analysis) should be justified through application-specific analysis. Typical risk criteria are a maximum individual risk of $1x10^{-5}$/yr for a worker or $1x10^{-6}$/yr for the public [6]. Assessment against these risk criteria requires that the overall frequency of all deviations leading to the same hazardous event be determined.

Conditional modifiers are often proposed as a means to deal with overstated consequence severity. Since the conditional modifiers reduce the frequency, the “risk” is likewise lowered. However, the use of conditional modifiers also depends on the basis for the risk analysis. It is not appropriate to use conditional modifiers if the risk criteria are based on the hazardous event frequency (e.g., loss of containment) rather than on direct harm frequency (e.g., fatality). Regardless of the frequency basis, the use of conditional modifiers does not address or minimize the error associated with the consequence severity estimate. It does provide a means to rationalize that the likelihood of such harm is lower; however, the consequence is still overstated.

Templates Can (not) Fix it

Some owner/operators have tried to get consistency in the LOPA by providing teams with standard LOPA scenarios. This is especially attractive in organizations with virtually identical units or highly standardized installations in multiple locations. These template scenarios can be very useful in giving specific guidance to a team. In many cases, the templates list IPLs that are considered good engineering practice, so teams have guidance on not only the risk but also the means for risk reduction. The use of templates does not restrict the team’s ability to analyze the risk of a specific installation, since the team is still expected to identify significant differences between their installation and the template and to make adjustments to the template as necessary. However, such templates have proven to be difficult to develop, approve, and implement, predominantly because consensus on an organization-wide consequence severity ranking is difficult to achieve.

Developing Consequence Severity Guidance

The authors developed a set of consequence severity look-up tables to support PHA and LOPA using dispersion modeling. The **K**eep **I**t **S**imple principle was applied to the modeling effort, since the model was intended to be conservative and support order of magnitude consequence severity estimation. It was also desirable to have tables that based the severity on something that the team could assess themselves using information typically provided to the PHA or LOPA team. The results also needed to be presented in a format that made the tool practical for the team to use. Ultimately, a set of look-up tables were developed which yielded a severity ranking or range of severities, depending on the equipment type and release conditions.

Since many events involve the release of flammable materials, the first look-up tables addressed flammable hydrocarbon releases. Alkanes and alkenes, including C1-C10, are widely used in the process industry, so these were selected for modeling using ALOHA®. It was determined that this set of hydrocarbons yielded relatively similar zones of damaging overpressure for a given hole diameter and release rate. Consequently, the tables were simplified by treating these compounds as a single class of hydrocarbons.

Guidance was also needed to relate the initiating event conditions to an expected hole diameter or damage estimate. This led to the development of tables relating pump size (shaft size or HP) to an equivalent seal hole diameter, % overpressure to an equivalent hole diameter, or firebox type to equivalent damage. This paper will only present the pump size correlations for the loss of a mechanical seal.

1 Disclaimer

This guidance is intended to produce consistent results for similar hazardous events, but no severity estimate is a perfect forecast of actual events. Where plant conditions are significantly different from the assumptions, additional studies and/or consequence modeling should be considered. The PHA or LOPA team is advised to reach a consensus on consequence severity, considering site specific factors, the consequence severity tables, specific modeling results, and other available information. Ultimately, the guidance is intended to release teams from concern that they are not treating safety seriously if they don’t consider all releases as high severity and the opposite concern that they are being too conservative about the process if they predict that many scenarios pose severe consequences.

2 Dispersion Modeling

Keeping everything simple was probably the highest hurdle to overcome. It was easy to become overwhelmed with the different modeling tools and the large number of parameters that could be specified. Fortunately, analysis paralysis was ended by accepting the standard assumptions in consequence analyses performed to support the EPA Risk Management Plan [7]. The simplifying assumptions made were:

- Weather/topographical Conditions
    - Wind: 3 knots from South at 3 meters
    - Ground Roughness: open country
    - Air Temperature: 95° F
    - Stability Class: B – software determined

      NOTE: ALOHA provides the stability class based on information about the time of day, wind speed, and cloud cover

    - No Inversion Height
    - Cloud Cover: 5 tenths
    - Relative Humidity: 50%

- Congestion
    - Congested – not open space, difficult to walk through

The dispersion modeling software chosen was ALOHA which was developed by the EPA's Office of Emergency Management and NOAA's Emergency Response Division [8]. ALOHA is an atmospheric dispersion model used for evaluating releases of hazardous chemical vapors, including toxic gas clouds, fires, and explosions. Using input about the release ALOHA generates a threat zone estimate. A threat zone is the area where a hazard (such as toxicity, flammability, thermal radiation, or damaging overpressure) is predicted to exceed a user-specified level of concern.

The major reasons for selecting this software were that it was:

- developed by EPA/NOAA for use in a site's Risk Management Plan (RMP) and Emergency Response Plans (ERP)
- familiar to Local Emergency Planning Committees (LEPC) since many companies used the software for their RMP case(s)
- user friendly
    - often provided suggested/recommended values for parameters making it more suitable for the what-if type of modeling required
    - includes guidance on severity based threat zone
    - availability of large database of hazardous materials
- available at no cost to the user as well as the general public (LEPC)

3 Covered Chemicals

The consequence severity look-up table addresses the hazards associated with the release of flammable liquids and vapors in the range of C1-C10 (alkanes and alkenes). The consequence severity of the hazardous event was defined by the zone of damaging overpressure generated when the flammable hydrocarbons were released from a defined hole diameter and a specified rate. This model did not consider jet fires that might impinge process equipment and cause additional failures.

4 Hole Diameter Estimate

Hole diameter look-up tables were developed for vessel and piping overpressure and seal leaks. This paper only presents the results for estimating the hole diameter for single mechanical seals. As shown in Table 3, the hole diameter can be estimated based on the pump shaft size at the seal or on horsepower. The shaft size (Table 3A) may be a more accurate predictor of hole diameter, but experience indicates that horsepower (Table 3B) is more commonly available to the team. The information may be included on unit P&IDs or in mechanical data sheets.

Table 3. Estimated equivalent hole diameter for single mechanical seal failure.

A. Shaft Size versus Equivalent Hole Diameter

Shaft Size vs Equivalent Hole Diameter							
Shaft	0.5	1	2	3	4	6	8
Hole	1/8	3/16	1/4	3/8	1/2	5/8	3/4

Note: The equivalent hole diameter estimate assumes that the carbon faces and their support within the seals provide no sealing. The remaining leak path is limited by the clearance between the shaft and the seal housing/support. An annular radius of 0.01 was used for small shaft sizes (up to 3 inch) and 0.016 was used for larger shafts.

B. Horsepower versus Equivalent Hole Diameter

Horsepower vs Equivalent Hole Diameter							
HP	<5	5-10	10-50	50-150	150-300	300-600	>600
Hole	1/8	3/16	1/4	3/8	1/2	5/8	3/4+

Note: The equivalent hole diameter estimate was developed by reviewing the output shaft size of typical industrial motors rated for various HP. The review indicated that the pumps could be grouped for simplification of the look-up table. The stated equivalent hole diameter is based on the shaft sizes for the upper boundary of each group.

5 Release Rate Estimate

For the flammable hydrocarbons, separate release rate tables were developed for liquid and vapor releases. The team determines whether the release will be liquid or vapor considering process conditions when the hazardous event occurs. Table 4 is for liquid releases through holes of 1/16 inch to 6 inches in diameter at pressures of 10 to 50,000 psig. The presence of an “X” in the table indicates a release that exceeds the threshold of 10,000 lbs/min, which was determined to correlate with a category 5 consequence severity.

Table 4. Liquid release rate (lb/min) as a function of pressure (psig) and hole diameter (inch)

Liquid Release Rate (lb/min) Pressure (psig) vs. Hole diameter (inch).										
Psig / inch	1/16	1/8	1/4	1/2	1	1.5	2	3	4	6
10	2	8	31	120	500	1100	2000	4500	7900	17900
50	4	17	69	280	1100	2500	4400	9980	17700	X
100	6	25	98	390	1600	3500	6300	14100	X	X
150	8	30	120	480	1900	4300	7700	X	X	X
300	11	42	170	680	2700	6100	10900	X	X	X
500	14	55	220	880	3500	7900	X	X	X	X
1000	19	77	310	1200	5000	11200	X	X	X	X
2000	27	110	440	1800	7000	X	X	X	X	X
6000	47	190	760	3000	12100	X	[illegible]	[illegible]	[illegible]	[illegible]
10000	61	250	980	3900	X	X	[illegible]	[illegible]	[illegible]	[illegible]
30000	110	420	1700	6800	X	X	X	X	X	X
50000	137	550	2200	8800	X	X	X	X	X	X

“X” = no details are provided, since the release is equivalent to category

6 Zones of Damaging Overpressure

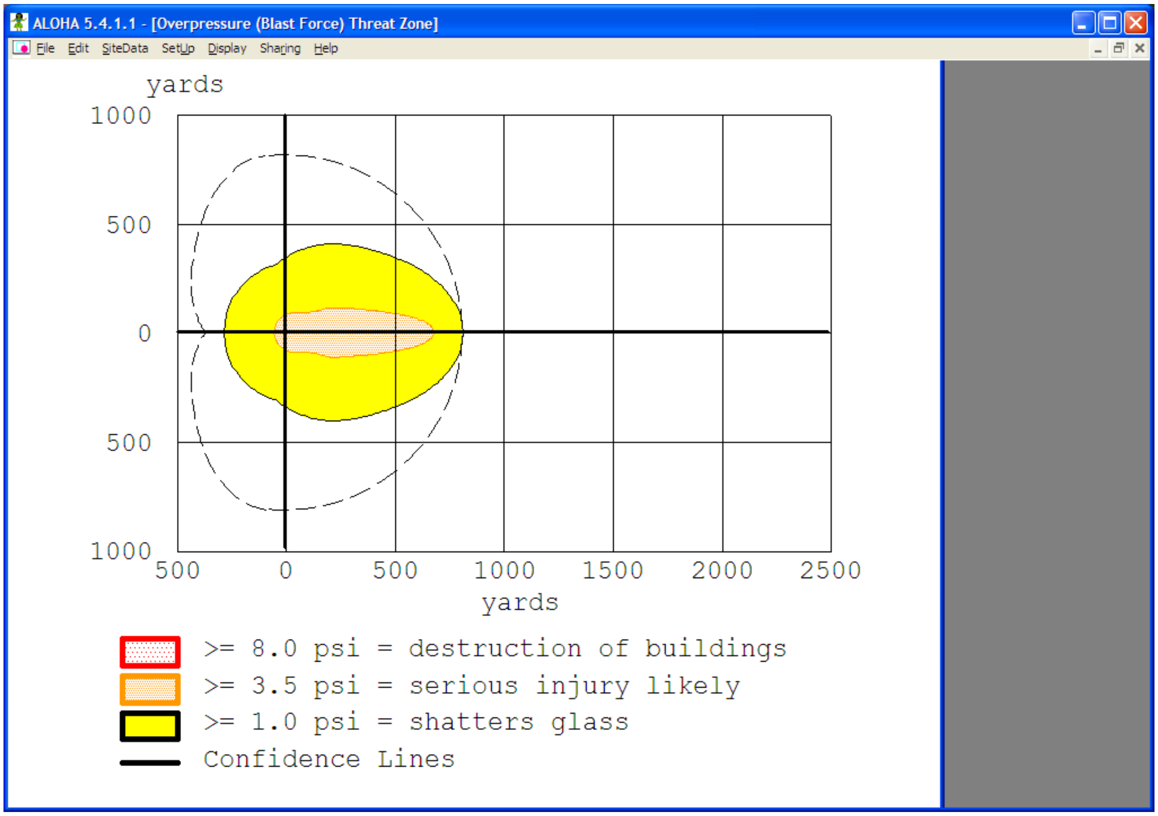
Modeling showed that the majority of releases reach steady state with clearly identified zones of hazardous conditions within 5 minutes, which is consistent with the EPA’s RMP guidance to use an endpoint of 10 minutes for scenario modeling. Figure 1 is a screen capture showing a typical output from ALOHA® [8]. The ALOHA output depicts three predefined “zones of damaging overpressure.” The yellow zone (outer ellipse) is an overpressure greater than 1 psi. This pressure typically causes minor damage to structures and minimal direct harm to humans. The ALOHA output includes a reference to shattered glass to indicate that 1 psi is a minor impact. The orange zone (inner ellipse) is an overpressure greater than 3.5 psi. This pressure typically causes structural damage to buildings and direct harm to humans. The ALOHA output includes a reference to serious injury to indicate that 3.5 psi represents a point where injuries are likely due to the overpressure, but this reference does not consider the potential for flying debris or structural damage. There is a potential for a red zone to appear on the graphic when there is an overpressure greater than 8.0 psi. This pressure is known to cause significant structural damage to structures and buildings as well as direct harm to human. The ALOHA output includes a reference to destruction of buildings to indicate the severity of this overpressure.

Examination of the results obtained from the modeling of the hydrocarbon class (consisting of C1-10 alkanes and alkenes) identified no red zones (8 psi). This agrees with other data reviewed prior to modeling which suggested that it was unlikely that typical hydrocarbon releases within process units would achieve this degree of overpressure.

The zone represented by the 3.5 psi overpressure seemed like a conservative selection for determining the potential area impacted by the overpressure, since this overpressure was judged to be significant enough to cause direct injury and to result in flying debris. It was also felt to be more intuitive for the correlation since the qualitative consequence severity descriptions include the potential for injury and fatality. Selecting a higher overpressure for the correlation would have resulted in a smaller impact area, but a more severe outcome within the area.

To correlate overpressure damage to differing levels of consequence severity, it was necessary to establish a relationship between zone of damaging overpressure (impact area) and area of occupancy (unit area). The premise is that as the impact area becomes larger there is greater likelihood that personnel in the unit or in surrounding units will be impacted. Using 400 foot by 400 foot as a typical unit footprint, an effective unit area was determined. The ratio of impact area derived from the model (3.5 psi zone) and the theoretical unit area was used to scale the overpressure damage to the different consequence severities as shown in Table 5.

Figure 1



Table

Table 5. Potential Safety Consequence Severity.
Release of flammable gas or flashing liquid within an operating unit.

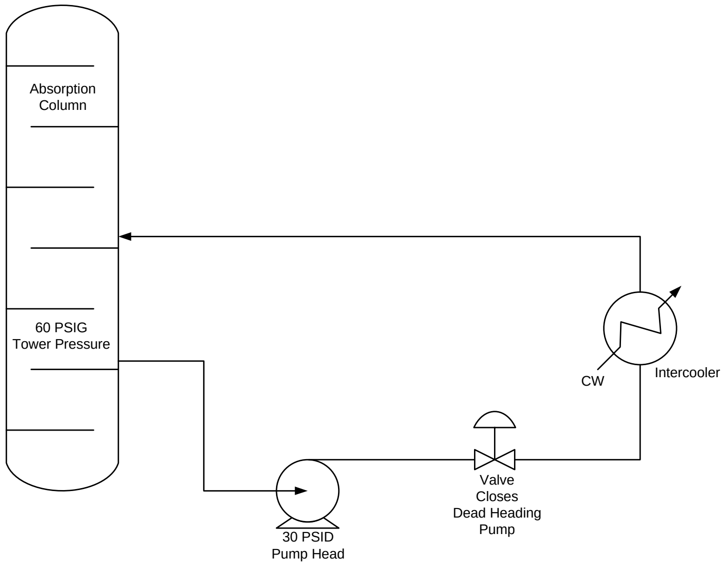
Leak Rate		Impact area Unit area	Severity
10,000 lb/min	And Over	>1.00	5
1,000 lb/min	10,000 lb/min	0.66-0.99	4
100 lb/min	1,000 lb/min	0.33-0.66	3
10 lb/min	100 lb/min	0.16-0.33	2
0 lb/min	10 lb/min	<0.16	1

Worked Example

A LOPA team was considering a potential pump seal leak (Figure 2).

Tower intercooler pump, 15 HP, pumping a rich oil saturated with C4.
Scenario – Deadheading pump resulting in a seal leak.
Leak pressure – Pump head (30 psi) plus tower pressure (60 psig).
PHA severity – 3 (severe injury).

Figure 2. Example Diagram Showing the Scenario under Review



The PHA team had previously ranked this seal leak as a serious injury event or a 3 on a 1-5 severity scale shown in Table 1. As described by LOPA team members who were also in the PHA, the severity had been heavily debated and in the end no one wanted to underestimate the hazard. The consensus was that this scenario involved a hydrocarbon release and other hydrocarbon releases had been ranked as a consequence severity of 3 by the team.

The LOPA team was introduced to the draft consequence severity guidance. It was emphasized that they had full authority to overrule the results based on their experience or on site specific factors, such as location of the pump.

Step 1

Estimate the hole diameter expected from a mechanical seal failure. The pump shaft size was not available to the team, but the pump horsepower, 15 HP, was shown on the P&ID. This yielded an equivalent hole diameter of ¼ inch.

Table 7. Table 3B with the Team Choice Highlighted

Horsepower vs Equivalent Hole Diameter							
HP	<5	5-10	**10-50**	50-150	150-300	300-600	>600
Hole (inc)	1/8	3/16	**1/4**	3/8	1/2	5/8	3/4+

Step 2

Find the intersection of leak diameter and highest credible pressure. The team used 100 psig (the next selection higher than the 90 psig expected), the intersection with ¼ inch gives an expected leak rate of 98 pounds per hour.

Table 8. Table 4 with the Team Choice Highlighted

Liquid Release **Pressure vs. Hole diameter. Rate in lb/min.**										
Psig / inches	1/16	1/8	**1/4**	1/2	1	1.5	2	3	4	6
10	2	8	31	120	500	1100	2000	4500	7900	17900
50	4	17	69	280	1100	2500	4400	9980	17700	X
100	6	25	**98**	390	1600	3500	6300	14100	X	X
150	8	30	120	480	1900	4300	7700	X	X	X
300	11	42	170	680	2700	6100	10900	X	X	X
500	14	55	220	880	3500	7900	X	X	X	X
1000	19	77	310	1200	5000	11200	X	X	X	X
2000	27	110	440	1800	7000	X	X	X	X	X
6000	47	190	760	3000	12100	X	X	X	X	X
10000	61	250	980	3900	X	X	X	X	X	X
30000	110	420	1700	6800	X	X	X	X	X	X
50000	137	550	2200	8800	X	X	X	X	X	X

Step 3

Use the expected leak rate to determine the consequence severity. The team chose severity 2 based on the calculated leak rate. Though the 98 pounds per hour is close to 100, the team discussed other factors associated with the release to determine whether severity 2 was appropriate versus severity 3. The scenario involved the release of a lean oil mixture containing light and heavy hydrocarbons. The heavier fractions in the lean oil are not expected to flash to a vapor as easily as the general hydrocarbon class. Consequently, the team selected consequence severity 2.

Table 9. Table 5 with the Team Choice Highlighted

Leak Rate		Severity
10,000 lb/min	And Over	5
1,000 lb/min	10,000 lb/min	4
100 lb/min	1,000 lb/min	3
10 lb/min	100 lb/min	**2**
0 lb/min	10 lb/min	1

98 lb/minute

Moving Forward

LOPA continues to be a great tool for the semi-quantitative analysis. A case can be made for alternatives to LOPA but in most organizations these alternatives are applied to specific hazards or applications. LOPA teams, which include supervisory, technical and worker participation, can often address many hazardous events in a single meeting. All involved gain an appreciation of the thoroughness of the analysis and the suitability of the IPL and recommendations.

These teams apply LOPA to risks that range from relatively minor issues to scenarios that could potentially destroy facilities and the lives of employees and neighbors. Different levels of protection are appropriate for different levels of risk, but inconsistent levels of protection for the same level of risk can bring the LOPA process into question. Given the importance of achieving consistent results it is important that tools be provided to the teams to assess risks in an accurate and consistent manner.

Attempts to improve consistency using standard LOPA templates or conditional modifiers introduce new variables into the assessment but do not address the root of the problem, which is often an inconsistent consequence severity assessment. This paper proposes that PHA and LOPA teams be provided with look-up tables that give guidance on consequence severity based on equipment type and release conditions.

LOPA can be substantially improved by implementing consequence estimation tools that assist team members in understanding the flammability, explosivity, and toxicity of process chemicals. When these tools can reliably and simply distinguish different size events they can be used to separate the severity of large loss of containment events from small. The consequence severity tool has proven to be a welcome development to the teams that have tried it. By increasing consistency in severity classification, the consistency of the final result is likewise improved.

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