As seen in the January/February 2011 issue of
MIDSTREAM Business

Unintended Consequences

Pipelines pose adverse risks to the public and the environment only in the event of an unintentional release. Operators can mitigate the consequences by assessing risks.

By Brian Payne and Nicholas Gillette

The current political environment makes for stressful times for owners or operators of pipelines. New pipeline integrity regulations (e.g., 49 CFR Parts 192 Subparts O and P and 49 CFR 195.452) have been promulgated in recent years. Energy usage, throughputs and revenues are generally down because of the recession. Recent incidents, such as the San Bruno, California, and Carlsbad, New Mexico, catastrophes, which resulted in multiple fatalities, have heightened public interest. And every day, the nation's pipeline networks age.

Normally, a pipeline poses adverse risks to the public or environment only in the event of an unintentional release. Before such an event, operators can take action to assess the range of risks that may be posed by a given pipeline.

Potential consequences

An unintentional pipeline release can result in environmental damage, physical injuries and fatalities. The major hazards to the public include fire, explosions and toxicity. Natural gas and petroleum liquid releases can result in fires and explosions. Above certain concentrations, chemical releases, such as chlorine, can be toxic.

The physical characteristics of the pipe contents affect the severity of the consequences. Some of these charac-

This photo, taken on September 19, 2010, shows the extensive damage caused by a pipeline accident in San Bruno, California.

teristics include: flash point, lower flammability limit, upper flammability limit, auto ignition temperature, toxicity, temperature and pressure. For example, propane and gasoline are fairly easy to ignite and may result in an explosion under certain conditions, while crude oil is much more difficult to ignite and much less likely to cause an explosion.

Generally, the larger the pipeline, the higher the operating pressure, and the more densely populated the surrounding area, the higher the potential consequences may be to human life from an unintentional release. Potential environmental damage most often depends on these parameters, as well as the proximity to sensitive receptors and local terrain.

Determining consequences

A pipeline operator can evaluate the potential consequences of a pipeline release by performing consequence-release modeling. This technique can determine potential life, safety and environmental impacts. Release modeling can also be used to comply with the U.S. Department of Transportation's Integrity Management Program—Consequence Analysis (49 CFR 195.452).

The consequences of an unintentional release are normally evaluated using computer software specifically developed for this purpose. Among the available software packages are Aloha and Canary.

Areal Locations of Hazardous Atmospheres (Aloha) is a release-modeling program that estimates threat zones associated with hazardous-chemical releases, including toxic gas clouds, fires and explosions. A threat zone is an area where a hazard (such as toxicity, flammability, thermal radiation or damaging overpressure) has exceeded a user-specified level of concern. This software, and the accompanying operating manual, are available for free download from the U.S. Environmental Protection Agency website at *epa.gov/emergencies/content/cameo/aloha.htm*.

Canary, by Quest, is a commercially available software program that incorporates a series of input screens to allow the user to easily describe almost any scenario in which flammable or toxic fluid can be released from a pipe segment, tank, vessel or other process plant component.

Based on this input data and the type of hazard, Canary determines which internal programs are needed to model the specified scenario. Then, the software runs the required programs in proper sequence. The results of the calculations are presented in tabular and graphical formats that illustrate the hazard zones that would be created by the user-specified release scenario. More information may be obtained from Quest Consultants at *questconsult.com/canary.html*. Other software programs include Effects at *tno.nl*, Phase at *dnv.com* and Trace at *safersystem.com*.

TABLE 1 – EXPLOSION OVERPRESSURE DAMAGE THRESHOLDS

Side-On Overpressure	Damage Description
0.02 psig	Annoying noise
0.03 psig	Occasional breaking of large window panes under strain
0.04 psig	Loud noise, sonic boom glass failure
0.10 psig	Breakage of small windows under strain
0.20 psig	Glass breakage - no injury to building occupants
0.30 psig	Some damage to house ceilings, 10% window glass broken
0.50 to 1.00 psig	Large and small windows usually shattered, occasional damage to window frames
0.70 psig	Minor damage to house structures, injury, but unlikely to be serious
1.00 psig	1% probability of a serious injury or fatality for occupants in a reinforced concrete or reinforced masonry building from flying glass and debris, 10% probability of a serious injury or fatality for occupants in a simple frame, unreinforced building
2.40 psig	1% mortality to persons inside buildings or persons outdoors
3.10 psig	10% mortality to persons inside buildings
4.00 psig	10% mortality to persons outdoors
5.70 psig	50% mortality to those indoors
13 psig	50% mortality to those outdoors
13 psig	99% mortality to those indoors
72 psig	99% mortality to those outdoors

Various endpoints are suggested for evaluating pipeline-explosion impacts.
Source: EDM Services Inc.

Pipeline modeling takes into consideration the characteristics of the pipe (diameter, operating pressure, length to segmenting block valves and other variables), the physical characteristics of the pipe contents, the size of the release (a function of the hole's diameter) and the environmental conditions (wind speed, atmospheric stability, and other conditions), among other factors. For a gas pipeline, like the one that was involved in the catastrophe in San Bruno, California, vapor-cloud dispersion and torch fire are two scenarios typically modeled. For a hazardous-liquid pipeline, vapor-cloud dispersion and pool fires are typically modeled.

Vapor-cloud dispersion modeling

When flammable-gas vapor clouds are within the flammable range, they can be ignited. Depending on local conditions, this can result in either a flash fire or an explosion. In most cases, risk assessments assume that individuals exposed to a flash fire will be fatally injured, since they will be exposed directly to the flame.

Many gases, such as natural gas, do not explode unless they are confined to some degree, are within a specific range of mixtures with air and are subjected to an ignition source. However, if an explosion does occur, the physiological effects of overpressures can be life threatening.

The degree of injury depends on the peak overpressure level that reaches a person. If a person is far enough from the source of overpressure, the explosion overpressure level would be incapable of causing injuries. Table 1 presents some of the endpoints suggested for evaluating explosion impacts.

For toxic gases, the seriousness of injuries depends on the gas toxicity, concentration and duration of exposure. These data can be obtained from Material Safety Data Sheets (MSDS), the Hazardous Substances Data Bank (HSDB), International Toxicity Estimates for Risk (ITER), and other sources.

Torch- and pool-fire modeling

Torch- and pool-fire models are used to evaluate the potential radiant-heat flux impacts to people exposed to a fire. A torch fire occurs when a combustible gas is released from a pipeline and is subsequently ignited. A pool fire occurs when a flammable liquid pool is formed and then ignited.

The physiological effect of fire to people depends on the rate at which heat is transferred from the fire to the person and the amount of time the person is exposed to the fire. Skin in contact with flames can be seriously injured, even if the duration of the exposure is just a few seconds. Thus, a person wearing normal clothing is likely to receive serious burns to unprotected areas of the skin when directly exposed to the flames. People in the vicinity of a fire, but not in contact with the flames, would receive heat from the fire in the form of thermal radiation.

Radiant-heat flux decreases with increasing distance from a fire. Those close to the fire would receive thermal radiation at a higher rate than those farther away. The ability of a fire to cause skin burns due to radiant heat depends on the radiant-heat flux to which the skin is exposed and the duration of the exposure. As a result, short-term exposure to high radiant-heat flux levels can be injurious. But if an individual is far enough from the fire, the radiant heat flux would be lower, likely incapable of causing injury regardless of the duration of the exposure.

For liquid spills and gases heavier than air, the surrounding topography can affect the impacts posed by an unintentional release, because it will affect the location where a pool may form. As a result, the local topography and drainage patterns must be evaluated.

The gradient, surface roughness and surface uniformity should be considered. Surface roughness and gradient affect the rate of flow away from the release site. Surface uniformity affects possible formation of multiple flow paths of varying depths and flow rates.

Quantitative risk assessment

Quantitative risk assessment (QRA) can be performed by pipeline operators. The process includes combining consequence-modeling results with population-density data to determine the number of potential fatalities for a given release for each possible release scenario. Then, the likelihood of occurrence is determined for each release scenario. These data are then combined to determine risk. In its most simple form, risk is equal to the consequences of a release times the likelihood of occurrence.

The likelihood of occurrence is determined by an evaluation process. First, a baseline incident rate must be determined. This is the probability of a release and is normally expressed as the annual number of incidents per mile of pipe. Historical data may be obtained from the U. S. Department of Transportation Pipeline and Hazardous Materials Safety Administration to assist in developing an appropriate baseline-incident rate. For hazardous-liquid and natural gas transmission pipelines, these data may be obtained from *phmsa.dot.gov/pipeline/library/data-stats*.

Once a baseline-incident rate has been determined from historical data, the following items are evaluated to determine the conditional likelihood for each release scenario:

- What percentage of pipe failures are relatively small leaks versus full-bore ruptures?
- What percentage of vapor clouds resulting from leaks and ruptures are ignited?
- What percentage of ignited vapor clouds burn versus explode?
- In the event of a fire or explosion, what is the degree of serious injuries or fatalities that may result?

These data are then combined for each possible release scenario. The results are often presented in two ways: individual and societal risk.

Individual risk is most commonly defined as the frequency that an individual may be expected to sustain a given level of harm from specific hazards, at a specific location, within a specified time interval. Individual risk is typically measured as the probability of a fatality per year. The risk level is typically determined for the maximally exposed individual. In other words, it assumes that a person is present continuously—24 hours per day, 365 days per year. The likelihood is most often expressed numerically. A typical individual-risk threshold is one in one million per year.

Individual risk most often varies as a function of distance from a pipeline. In most cases, the risk is highest directly over the pipeline and diminishes as the distance from the pipeline increases.

Societal risk

Societal risk is the probability that a specified number of people would be affected by a given event. The generally accepted number of casualties is relatively high for lower probability events and much lower for more probable events.

The societal-risk results are often presented in a cumulative frequency of fatalities (f/N) curve. These results show the annual likelihood of incurring a given number of fatalities. These data can then be compared to the societal risk acceptance criteria.

Conclusion

Pipeline-consequence modeling can allow an operator to assess the range of possible human life and environmental impacts that may result from an unintentional release. If desired, these data can be expanded to provide a quantitative assessment of probable risk.

For new pipelines, this can help operators select the pipeline route posing the least impact to the public or the environment, or develop mitigation measures to reduce risk levels. For existing lines, the results can assist the operator in developing emergency-response plans and mitigation measures, identifying high-risk areas and other issues. ■

__Brian Payne__ is a principal with EDM Services Inc., Simi Valley, California. He has 30 years of pipeline and utility design experience. __Nicholas Gillette__ is a project engineer with EDM Services Inc. and has provided engineering services for 50 natural gas transmission pipeline systems.