ATTACHMENT 7

Hughes Report to PG&E Co., "Fire Hazard Area Evaluation, Radius of Influence for Jet Fires," 40 Rev 3, March 24, 2011, p. 7.

CONFIDENTIAL DUE TO NAMES

PACIFIC GAS & ELECTRIC COMPANY

FIRE HAZARD AREA EVALUATION

RADIUS OF INFLUENCE FOR JET FIRES

PREPARED FOR

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1 BACKGROUND

Gas Engineering at Pacific Gas & Electric Company (PG&E) has engaged Hughes Associates, Inc. (HAI) to explore the potential consequences of jet fire lifetime during a fire-following-release event. The project was intended to evaluate scenarios for a variety of Potential Impact Radii (PIRs) related to a jet fire following a full-bore release from transmission lines delivering natural gas. HAI was engaged to determine the distances at which standard residential materials will ignite after exposure for 15 or 90 minutes, or at which fire department efforts will be severely hampered over the same time periods, based on methodologies presented in a Gas Research Institute report (Stephens 2001) and supported by a literature review for thermal radiation effects. Damage from the initial release and flash fire following ignition were not evaluated, nor were contributions from secondary fires (e.g., materials ignited from the flash fire, explosion, or exposure to the jet fire), owing to the uncontrolled variables that can affect the radius of effect. The influence of these variables is discussed in the report, however.

This report provides the results of the analysis and discussion of other influences on the Radii of Interest (ROI), including findings from the literature review as regards ignition thresholds for materials in residential areas, similar information for firefighter exposures, and bibliography of reviewed materials.

2 EXECUTIVE SUMMARY

A simple fire model – based on an industry standard – has been used to provide a qualitative analysis of the effects of long-term jet fires resulting from pipeline releases. The model does not account for all variables that might influence the area of effect of the fire, including secondary fires, meteorological effects, and pipeline pressure loss. A discussion of the effects of variables not captured by the model, such as wind speed and housing density, is presented in the body of the report.

Ignition threshold for residential materials, following 15- or 90-minute exposures to a jet fire, have been identified from a literature review, for comparison to heat fluxes from a pipeline jet fire, which decrease with distance.

Heat flux thresholds under which firefighting operations reasonably can be expected to continue during 15- and 90-minute exposure durations have been developed from the literature, for comparison to expected heat fluxes from a pipeline jet fire.

In comparing the literature data to the results of the fire model, it has been determined that locations with a Potential Impact Radius (PIR) of more than 300 should have motorized valves. Locations with a PIR less than or equal to 200 likely do not require motorized valves, unless the areas have high population or fuel loads (e.g., high-density housing), or other significant effects on fire growth rate (e.g., high prevailing winds), in which case the potential benefits of motorized valves should be considered. Areas with a PIR between 200 and 300 require a case-by-case analysis to determine whether the specific hazards warrant motorized valve control.

3 OVERVIEW OF FIREFIGHTING STRATEGIES FOR GAS FIRES

There are numerous factors that will influence the effectiveness of firefighting activities when dealing with a gas pipeline fire. First and foremost will be the duration of the fire. In the event of a fire involving a gas pipeline rupture, the strategy of first responders (i.e., fire departments) is to wait until the fuel source is isolated to extinguish the natural gas fire at its origin, while limiting the effects and propagation of the fire prior to shutdown of the gas. Once the fuel supply is cut off, the fire will continue to burn until the residual gas in the pipeline system is consumed, at which point the fire department can focus on extinguishing the remaining fires in the affected areas. As such, the primary objective will be to stop the fuel supply. Natural gas fuel isolation is accomplished by utility employees using manual or automated shut-off valves in the pipeline system.

Until such time as the fuel supply is isolated, the fire department will set up a defensive line or perimeter to limit the spread of fire to public property. Where they establish this defensive line depends on numerous variables that affect firefighting capabilities, such as the terrain, potential fuel sources (houses, trees, etc), wind direction, water supply availability, and size of the gas fire. These variables are discussed below.

4 RADIUS OF INTEREST CALCULATIONS

PG&E currently characterizes the potential area of concern for a pipeline release and subsequent fire using a methodology presented in (Stephens 2001) to identify a Potential Impact Radius, or PIR, which is a function of the pipeline pressure and diameter and which defines a threshold heat flux of 5000 BTU/hr/ft^2 (15.8 kW/m^2). This threshold represents both the potential for 1% mortality rate for those exposed to the flux for more than about 30 seconds, and the flux at which American whitewood has been found to be ignitable after about an almost 20-minute exposure, per (Stephens 2001). Of interest for this effort was the determination of heat flux thresholds that would help to quantify the areas of concern, related to ignition of residential materials from fire exposure or to limiting distances for firefighter operations, for a 15- or 90-minute jet fire exposure. The basic methodology is discussed below, followed by the limitations and assumptions, and specific results for material ignition and for determination of potential operational perimeter for firefighting.

4.1 CALCULATION METHODOLOGY

The equation for the radius to a particular threshold heat flux, from (Stephens 2001), uses a point-source model for the thermal radiative flux, and assumes that the pipeline release is vertical in still air, has a time-averaged pipeline pressure, and includes no thermal contributions from the ignition of surrounding materials (a more in-depth discussion of assumptions and limitations is provided in the next section). Under these conditions, the radius to a particular threshold heat flux is $r = \sqrt{\frac{2348 \cdot pd^2}{I}}$, where pd^2 are characteristics of the pipeline, and I is the radiant heat flux (in BTU/hr/ft^2) at radius r. As noted above, PIR calculations – for which r=PIR – use a threshold of I = 5000 BTU/hr/ft^2 (15.8 kW/m^2) in that equation. PG&E has developed PIR values for various locations throughout the state.

An alternative Radius of Interest, or ROI, can be identified by multiplying the PIR by $\sqrt{\frac{5000}{I_{threshold}}}$, where $I_{threshold}$ is a radiative flux that represents a desired threshold (e.g., for ignition of a residential material after a particular exposure duration).

4.2 Assumptions and Limitations

This approach employs a number of simplifying assumptions. The calculations and the methodology associated with identification of PIRs disregard the effects of the variables identified in Section 5, Variables Influencing Radius of Interest; these variables include wind and meteorological influences, fuel loading proximate to the release, and terrain effects. Furthermore, the model simplifies the jet-fire radiation to a single point-source emitter, which may not be a valid assumption for all PIR (or effective radius) conditions under consideration. Temporal effects of the release have been reduced to a steady-state equation, which is based on an assumed effective gas release that is 33% of the initial pressure, based on an evaluation of pipeline pressures over the initial 60 seconds following the release event. The PIR model assumes a radiative combustion efficiency of 35%, and an emissivity of 0.2 for a jet fire involving methane. Thermal radiation contributions from sources other than the release-based jet fire – such as those provided by surrounding materials following their ignition – are not included, nor are damages or fires caused during ignition of the initial jet fire, following the release event. PIR calculations are based on a threshold that represents the heat flux that leads to 1% mortality for a moderate (~ 30 second) exposure, and piloted ignition of American whitewood within 20 minutes. This threshold may not be representative of mortality rates for specific releases, owing to initial conditions, available radiation shields, population density, and egress times for those proximate to the release location. The threshold may also not be representative of durations to piloted ignition for other materials near the jet fire.

As regards the calculations for Radii of Interest for this study, some additional assumptions and limitations must be considered. Orientation of target materials is not considered. Wood and asphalt-shingle ignition times are based on data from (Society of Fire Protection Engineers 2002). Firefighter exposure thresholds do not include evaluations of protection from fog-nozzle sprays or other radiation shields, such as nearby structures.

4.3 ROI Calculations for Ignition

This report considers residential materials, such as asphalt shingles or wood, when characterizing the distances at which materials may be ignited when exposed for extended durations. Technical literature reviews have identified exemplar heat fluxes that would likely lead to ignition of wood and asphalt shingles with exposure times of 15 or 90 minutes. This data is used in conjunction with the approach provided in (Stephens 2001) to identify a Radius of Interest (ROI) that represents the extent of the expected damage for a given jet fire for each of those durations, assuming that the fire source is constant and that there are no external influences (e.g., wind speed or secondary fires). It is expected that the ROI for longer durations will be larger, owing to the reduced radiative flux required for ignition. (Note that radiative flux is a function of distance from a fire, essentially decreasing as a function of the distance squared.)

A technical literature review has identified approximate heat fluxes for ignition of common materials in residential areas (e.g., wood and asphalt shingles) following exposure times of 15 and 90 minutes. Data from (Society of Fire Protection Engineers 2002) has been selected to develop the ignition heat fluxes for the selected materials. The results are based on Figure 2 in (Society of Fire Protection Engineers 2002) for dry thermally thick pine and Equation 3 and Table 4 in (Society of Fire Protection Engineers 2002) for asphalt shingles. The results are provided in Table 1, as follows:

Table 1: Piloted Ignition Data for Residential Materials Exposed to Long-Duration Thermal Radiation Sources, from (Society of Fire Protection Engineers 2002)

Material	Heat Flux [BTU/hr/ft^2 (kW/m^2)] for Ignition	
	After 15-minute Exposure	After 90-minute Exposure
Dry, Thermally Thick Pine	4320 (13.6)	3460 (10.9)
Asphalt Shingles	5170 (16.3)	3490 (11.0)

Based on Figure 7.4 in (Babrauskas, Ignition Handbook 2003), the ratio of white pine to western red cedar ignition times (at a flux of 15.4 kW/m^2) is 1.88.

Given the thresholds from the table, above, the ROI for ignition resulting from a 15-minute exposure fire ranges from ROI ∣ 1.07 ¬PIR └ for wood to ROI ∣ 0.98 ¬PIR └ for asphalt, regardless of the specific PIR. The 90-minute threshold leads to ROI ┘ 1.2 ¬PIR └ for a 90-minute exposure of either material. The ROIs provide a distance from the fire source to ignition of residential materials, which qualitatively indicates the range over which more substantial heat damage to houses might be expected for the different jet fire durations. The ROIs for a range of PIRs are provided in Table 2, below.

Table 2: Radius of Interest [ft] for Ignition

PIR	15-minute Exposure		90-minute Exposure
	Wood	Asphalt Shingles	
100 107		98	120
200 214	196		240
300 321	294		360
400 428	392		480
500 535	490		600

4.4 ROI Calculations for Firefighting

A second evaluation was performed to determine the effective range at which sustained firefighting operations could provide exposure protection for the duration of a jet fire. Those operations depend on the duration of exposure, heat fluxes to which firefighters are exposed, and other variables as discussed in Section 5, Variables Influencing Radius of Interest. As for the ROIs for material ignition, the ROIs for firefighter operations increase with duration; in other words, to limit firefighter injuries, the perimeter for exposure protection should be expected to be further from the jet fire for scenarios involving longer lifetimes for shut-in of the pipeline.

The data for exposures of extended durations are limited, and can be affected through the use of fog nozzles or other radiative shielding (e.g., standing behind walls or structures) at elevated heat fluxes. Based on the literature review, however, heat fluxes of 1600 $BTU/hr/ft^2$ (5 kW/m^2) and 2000 $BTU/hr/ft^2$ (6.3 kW/m^2) have been identified for the 90- and 15-minute exposures, respectively. The first threshold represents an exposure at which emergency actions lasting several minutes may be undertaken by people without shielding but with appropriate clothing (American Petroleum Institute 1999) (National Fire Protection Association 2009) (Raj 2008), whereas the latter is specified in (Butler and Cohen 1998) as the maximum level tolerable by firefighters wearing Nomex and protective head and neck equipment. (A third level, 3200 $BTU/hr/ft^2$ (10 kW/m^2) – identified in (Butler and Cohen 1998) as the flux of probable injury – was considered, but deemed too high a threshold, relative to other references.)

According to (Stephens 2011), the pipeline pressure continues to decay during a release, which also decreases the radiation from the jet fire. For firefighter response, the PIR should be adjusted to account for the drop in pressure. Within the first 15 minutes of release, this modified PIR (or MPIR) is approximately 77% of the original PIR, per (Stephens 2011).

Given that data, the radii of interest for the jet fire would be $ROI = 1.58 \times MPIR \approx 1.22 \times PIR$ for an expected 15-minute exposure and $ROI = 1.78 \times MPIR \approx 1.37 \times PIR$ for an expected 90-minute exposure. The ROIs for a range of PIRs is provided in Table 3, below. Note that the ROI for firefighting would be reduced following the successful isolation of gas release, owing to the reduction in radiant heat flux, and is also a function of firefighter response time, owing to time-dependent pipeline pressure. It is anticipated that the firefighters would set a perimeter based on the long-term (i.e., 90-minute) exposure, although certain operations (e.g., search and rescue) could be expected to occur at higher fluxes. It is assumed that a slight increase in the unprotected area (ROI minus the firefighters' hose reach), to approximately 105-110% of the PIR, is acceptable as regards the firefighting perimeter, given the imprecise nature of the underlying calculations. The response time of the firefighters, time to set up the defensive perimeter, and contributions from secondary fires will further affect the heat fluxes to which firefighters are exposed.

Table 3: Radius of Interest [ft] for Firefighting

PIR	15-minute Exposure	90-minute Exposure
100	122	137
200	244	274
300	366	411
400	488	548
500	610	685

5 VARIABLES INFLUENCING RADIUS OF INTEREST

The 1991 Oakland Hills Fire illustrates a number of the challenges associated with control of large-scale fires in a wildland/urban intermix region, and highlights the variables that have implications on the control and containment of fires, regardless of initial source. In this case, the source of the fire was an incompletely controlled grass fire on a steep hillside. An engine and crew was onsite, performing mop-up operations, when a sudden change in conditions – primarily wind speed and direction – led to a breach in the established perimeter. Insufficient water supplies, unusual meteorological conditions, narrow roads, terrain, and high fuel loads – due, in part, to a multi-year drought that killed vegetation and lowered moisture contents throughout the area – prevented the assembled mutual aid resources from controlling the fire until a change in wind conditions enabled containment. A fire by a pipeline rupture will also be influenced by the directionality of the release.

5.1 Available Resources

Firefighting operations during the initial stages of the fire are divided into life safety and perimeter control efforts. Some of the responding personnel will endeavor to ensure that buildings proximate to the fire source are evacuated or otherwise unoccupied, while others will start to provide exposure protection or will actively suppress the secondary fires (e.g., house or vegetative fires ignited by the initial event) at the periphery of the containment area. Throw from a hand-held firefighter line varies with the type of nozzle and available pressure, but ranges from approximately 40 to 180 ft. (Task Force Tips 1994) (Akron Brass Company 2011) For the hoseline pressures that can be handled by two-firefighter teams, with a reactive force of approximately 75 lbf (Grimwood n.d.), maximum throw is approximately 150 ft. Apparatus-mounted monitors, which can often be operated from within the cab of the vehicle (thereby providing the firefighters with additional protection from radiation) can have greater ranges, exceeding 150 ft.; not all jurisdictions will have access to such equipment, however, which may limit the applicability of such throw distances. Experimental data has shown that wind speed and direction can also affect throw distance, potentially reducing the maximum throw by approximately 50% at high wind speeds (Carhart, et al. 1987). Thus, 75 ft to 100 ft should be considered the limit of hose line throw, in the absence of other information, with greater ranges possible under lower wind conditions (e.g., wind speeds less than 15 kn).

Arrival times and activities of the initial and subsequent responders, relative to the release event, depends on the proximity of the time to detection of the release event, firefighting apparatus to the location, firefighter training, whether the local firefighters are paid or volunteers, and related variables. The community's Public Protection Classification (ISO n.d.), based on the ISO Fire Suppression Rating Schedule, may be used to qualify the firefighting capabilities for a particular area. It is highly likely that mutual aid, including resources from the California Department of Forestry and Fire Protection, will be required for full containment of such a fire. More attention will be needed in those areas with limited mutual aid support, including remote areas for which multiple-alarm responses may exceed 30-45 minutes.

Available water supplies, in combination with the other variables discussed below, affect the conditions under which full containment can be effected. Water for firefighting can be provided via pressurized municipal supplies, typically through hydrants, or from static sources like cisterns; tanks; or rivers, ponds, bays, and other open-water sources. Municipal supplies are characterized by the flow available at a given pressure, typically 20 psi, at hydrants throughout the area (California Building Standards Commission 2010). Spacing of hydrants is based on the expected fire hazards; for the residential areas of concern for this study, hydrants may be 500 ft. apart (California Building Standards Commission 2010), although rural areas may have greater separation (National Fire Protection Association 2007), where hydrants exist. Given that water mains and gas pipelines may be buried in proximity to each other, water availability from municipal supplies may be impaired by a water main breach caused by the pipeline rupture event; as such, redundancy of water pathways (e.g., as provided by a looped or gridded water main system) or proximity of static water sources should be considered when evaluating the availability of water for areas with high PIR. A lack – or shortage – of available water within reasonable proximity of a potential fire location is likely to cause a shift from active to passive firefighting, in which fire breaks are used to contain the fire. In this case, the radius of interest would be larger than the PIR, owing to the longer duration of fire exposure without sufficient suppression activities.

For larger-scale events, or for rural areas or those with limited site access, suppression and containment activities may require the use of aerial tactics (i.e., helicopter- or aircraft-dropped water or suppressants). In these cases, proximity to open-water sources and airfields will increase the effectiveness of the suppression efforts by reducing the recharging and refueling times, respectively.

5.2 Pipeline Pressure Decay

The methodology on which this project is based, with regards to material ignition, was intended for analyses of jet fire influence radii within the first minute of release. As discussed in (Stephens 2001), the gas pressure within the pipeline decays as a function of time following release, such that the heat released by the jet fire similarly decreases with time. (Stephens 2001) approximates the average pressure over the first minute to determine the heat release rate for the point-source model used for the PIR calculations. To be conservative, this report uses the same assumption. Because the pipeline pressure decreases with time, the amount of gas released is also a time-dependent; thus, heat fluxes from the jet fire are a function of both time and distance. Using a gas pressure that is based on the first minute of release results in a heat release rate that is conservative (i.e., higher) relative to pressures – and, hence, heat release rates – at later times. This assumption identifies the size of the steady-state fire, and is not related to damages from secondary ignitions from the flash fire or overpressure damage following ignition of the release cloud.

(Stephens 2011) provides a reduction factor for pipeline pressure over a 15-minute period (essentially 60% of the average pressure after 1 minute) and for longer duration events (40% of the same reference pressure). These values, developed from a time-dependent release, cannot be directly compared to the heat fluxes causing ignition of residential materials, as found in the literature, because the latter were developed from experiments with constant fluxes. The experimental data provides relationships between heat flux and time to ignition for constant heat fluxes. Data that incorporates a decaying flux is not readily available. Using the constant-flux data is not advisable, because the earlier, higher heat fluxes from the jet fire would pre-heat the material; as such, the surface temperature of the material becomes important, rather than a specific flux. The decay in pressure will result in a decrease in thermal radiation from the (smaller) jet fire, which leads to shorter radii of interest for ignition. Note, however, that an evaluation of the ignition distances using Stephens's reduction factor would result in calculations for which the ignition radius after 90 minutes is smaller than that at 15 minutes; this is an unsupportable result, as clearly the ignition distance cannot decrease with time, given that the materials would already have ignited. A more appropriate evaluation for a time-varying fire (and, thus, heat flux) would require consideration of the thermal mass of the target materials, and the surface temperatures developed as a result of the decaying thermal flux, to be compared to the ignition temperature of the materials.

Overall, the ignition distance results developed using a constant pressure (and, thus, heat flux) based on an average pressure from the first minute of release are expected to be conservative as compared to a decaying fire source. Pressure decay is considered for firefighter perimeter distances, however.

5.3 Meteorological Conditions

Several weather-based parameters – particularly wind speed and direction – can have a significant effect on the rate and direction of fire growth (Pagni 1993) and can also impact other aspects of the firefighting efforts, such as the maximum throw distances from hand-held hoselines. It is unlikely, however, that a pipeline rupture will occur at a time of unusual wind conditions; as such, it is acceptable to limit the maximum wind speeds for evaluation to a more probabilistic range. For example, (National Fire Protection Association 2009) excludes the top 5% of wind speeds when calculating exclusion distances following releases from LNG tanks and facilities.

Areas with high prevailing winds (e.g., the Altamont Pass) should be considered as having a higher risk, particularly if the wind may direct a fire from potential release locations toward an area of higher concern (e.g., higher population or fuel load). Prevailing wind directions should also be considered, particularly in cases in which the resulting fire may be induced to spread in undesired directions (e.g., toward challenging topography or toward high-population-density areas). Moisture content of vegetation and residential materials (e.g., following a multi-year drought, or at the height of summer), can reduce the energy required for ignition, extending those radii of interest.

5.4 SITE ACCESS AND TERRAIN

Site access and the specific terrain can have a significant impact on the growth rate, and direction, of the fire. Steeply graded hills can either enhance or hinder growth, as fire typically spreads faster uphill. (Krasnow, Schoennagel and Veblen 2009) (Mutlu, Popescu and Zhao 2008) Similarly, topography can affect firefighting operations, particularly in areas with restricted access roads for firefighting apparatus (i.e., fire trucks) (Weise and Martin 1995). Consideration must be given, therefore, to areas that have narrow or winding roads, significant elevation changes, and topographical features (e.g., canyons) that may hinder firefighter access or enhance fire growth. In addition, such areas often have limited water availability, such that pre-planned responses involving aerial suppression may be warranted.

5.5 OTHER FUEL SOURCES

The PIR-based methodology is predicated on the pipeline release as the single source of radiation (Stephens 2001). The proximity of other fuel sources, whether artificial (e.g., residences) or natural (e.g., forests or other vegetation), can lead to additional contributions that will augment the spread of fire. As noted in the 1991 Oakland Hills Fire (Pagni 1993), the moisture content of these fuels, which typically varies throughout the year – with a local minimum in late summer – can lead to materials that are more easily ignited. As the fire spreads away from the initial source, these secondary fires will have a greater impact on future fire growth. Firefighting efforts, therefore, will be focused on suppression of the secondary fires, in combination with exposure protection of those fuels that are not yet burning, until the primary fire source is eliminated. PIRs do not include the influences of the surrounding hazards; those areas in which the population density or specific occupancies (e.g., schools) warrant additional consideration. Areas without significant populations, but with high concentrations of vegetative fuels, may require evaluation owing to the likely combination of limited site access and water.

5.6 CONDITIONS OF THE RUPTURE

The methodology for calculating PIRs assumes that the primary fire source is a vertical flare (Stephens 2001). Pipeline ruptures are more likely to impart a horizontal momentum to the jet fire, owing to the gas flow and orientation of the pipe. The directionality of the fire may shift the centroid of the area of influence of the fire, although wind speed and direction may counteract (or enhance) the pipeline momentum. The influence of pipe orientation, therefore, is smaller than the other influences, in that it is likely to cause a shift in the center of the area reflected by the PIR. A possible exception lies with very large PIRs, for which flow rates will cause a jet fire that is substantially horizontal, which would change the areas subject to threshold radiant fluxes.

6 POTENTIAL RECOMMENDATIONS

As noted above, there are a number of external factors that will impact the ability of firefighters to control the radiant heat from a pipeline fire, such as the firefighting resources (e.g., available water, equipment, and manpower), meteorological conditions (e.g., wind speed and direction or moisture content of combustibles), site access and terrain (e.g., access roads and topographical challenges), fuel loading in the area (e.g., density of housing and types and quantities of vegetation), and conditions of the rupture (e.g., pressure during release and rupture orientation). In any case, the application of water is the key to effectively controlling the effects of a fire. Water will help mitigate the effects of the source fire, as well as any secondary fires that result.

As such, the ability to deliver water to the source of the heat is the determining factor in evaluating what fires can be effectively controlled. Given that water from a typical hose can reach 75 ft (depending on supply and meteorological conditions described above), the affected areas for a given Potential Impact Radius (PIR) can be modified by this throw distance. This reduction would be applied to the Radius of Interest (ROI) for the PIR, which simplified concept has been utilized to determine the conclusions outlined below.

In the event of a pipeline rupture fire, the first priority for PG&E is to stop the flow of gas to the affected area as soon as reasonably possible. For the remaining items below, it is assumed that there are no extreme conditions associated with the pipeline fire.

For PIRs below 200, it is anticipated that firefighting activities can mitigate the effects (i.e., limit damage beyond the PIR) of the gas fire until the fuel source is isolated, although consideration should be given to the variables influencing the radii of interest (e.g., prevailing wind conditions, combustibility of surrounding materials, and the impact on population). This expectation is based on an assumption that the affected area will have sufficient firefighting capabilities, equipment, and water available to develop an appropriate defensive perimeter. Given the throw from a typical hose stream, it is reasonable to assume that firefighters can provide exposure protection until the gas release can be controlled.

For PIRs from 200 to 300, the ability of firefighters to control the radiant heat from the gas fire will greatly depend on the conditions involved. As such, these areas will need to be evaluated on a case-by-case basis.

For PIRs above 300, it is expected that firefighters will not be able to approach this type of fire to contain the fire within the PIR. As such, it is recommended that automated valves be provided to stop the flow of gas as soon as possible.

High-Consequence Areas with high population or fuel load densities, or other effects that could considerably increase the fire growth rate or consequences, should be evaluated separately.

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ATTACHMENT 11

C-Fer Technologies letter to PG&E, "Adaptation of C-FER PIR Formula to Alternative Hazard Assessments," dated March 10, 2011.

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C-FER Technologies

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March 10, 2011

C-FER File: M075

Pacific Gas and Electric Company
375 N. Wiget Lane, Suite 170
Walnut Creek CA 94598
USA

Attention: Mr. Dan Menegus

Dear Dan:

Re: Adaptation of C-FER PIR Formula to Alternative Hazard Assessments

The Pipeline Impact Radius (PIR) formula, as developed by C-FER Technologies (1999) Inc. ("C-FER") for the Gas Research Institute ("GRI")[1], is based on an estimate of the heat intensity that is associated with thermal radiation from the initial stage of the fire resulting from gas pipeline rupture and subsequent product ignition. More specifically, it is based on the effective radiation characteristics of the fire during a time period that is consistent with the so-called 'reference expose time', a 30-second period that begins when product ignition takes place. Given that model development assumed (based on historical data) that ignition is usually delayed by some tens of seconds, the fire characteristics implicit in the PIR formula are effectively those of the fire within the 30-second time period starting 20 to 30 seconds after line rupture.

This fire characterization is considered appropriate for assessing the potential for fatality of people located outdoors at the time of line failure (assuming that they will reach shelter within 30 seconds). In addition, given that the radiant energy of the fire is proportional to the gas release rate, and given further that the gas release rate will decrease rapidly with time, the fire characterization implicit in the PIR formula can be interpreted to provide a reasonable if somewhat conservative basis for assessing the short-term impact on structures and building materials. However, the fire characterization implicit in the PIR formula is considered overly conservative for assessing the longer-term impact on building materials and for assessing the impact on emergency responders who will not arrive at the incident location until sometime after rupture occurs.

To provide a less conservative and more analytically defendable basis for assessing the impact of a gas pipeline rupture fire on building materials and emergency responders, a release rate decay model was employed to quantify the reduction in release rate, and thereby radiant energy, with time. The model chosen for this purpose was referenced in the original GRI report[1] that forms the basis for the PIR formula. This model, as developed by the Netherlands Organization of Applied Scientific Research, Division of Technology for Society ("TNO")[2], is a closed-form approximation to a

[1] Stephens, M.J. 2001. A Model for Sizing High Consequence Areas Associated with Natural Gas Pipelines. Gas Research Institute, GRI-00/0189, December.

[2] Netherlands Organization for Applied Scientific Research. 1982. Safety Study on the Transportation of Natural Gas and LPG by Underground Pipeline in the Netherlands. Ref. No. 82-04180, File No. 8727-50960, translation of a report by the Division of Technology for Society, commissioned by The Minister of Public Health and Environmental Hygiene, The Netherlands, November.

computer-based modelling approach originally developed by N.V. Nederlandse Gasunie ("Gasunie") that considers realistic gas flow and decompression characteristics and acknowledges both the compressibility of the gas mixture and the effects of pipe wall friction on release rate.

Using the TNO model, the gas release rate associated with full-bore rupture was calculated for lean gas pipelines[3] having diameters in the range of 12 to 36 inches and operating at pressures between 250 and 750 psi. The analysis demonstrated that while the mass flow release rate at any point in time varies dramatically with pipeline diameter and initial pressure, the relative release rate (i.e. release rate as a faction of an initial reference value) as a function of time is effectively constant over the range of pressures considered. A plot of the relative release rate versus time, where the relative release rate is defined as the ratio between the point in time release rate and the average release rate over a 30-second time period starting 30 seconds after line rupture, is shown in Figure 1.

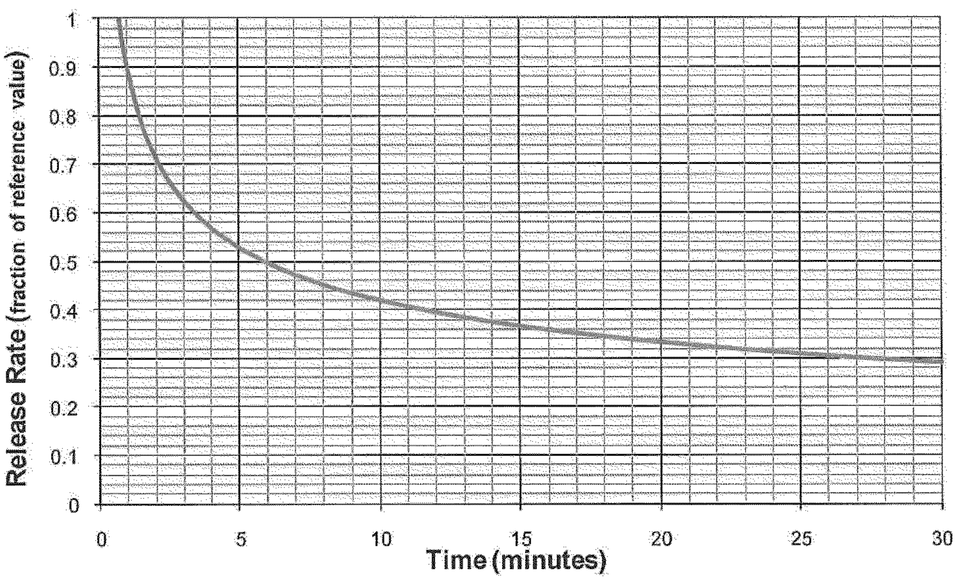


Figure 1 Gas Rupture Release Rate Relative to Initial Reference Value

The figure shows that the gas release rate, and by implication the associated radiant energy, is expected to be significantly less than that assumed in the PIR formula within a few minutes of line rupture. It is noted that the rate decay results obtained from the TNO model are based on simplifying assumptions with regard to upstream and downstream boundary conditions. While the rate of release rate decay during the initial stage of the fire (e.g. within the first 10 to 15 minutes) will be relatively insensitive to those boundary condition assumptions, the rate of decay in later stages will be progressively influenced by the distance from the break point to the upstream and downstream stations and by the pressure and flow conditions at those locations. Release rate decay projections beyond 15 minutes should therefore be interpreted with caution.

[3] Lean gas as represented by pure methane at a temperature of 59°F (15°C) with line pipe having a surface roughness in the range of 40 to 180 micro-inches.

Relevant release rate characteristics, as calculated from the results plotted in Figure 1, are as follows:

- The average release rate over the initial 15 minute duration of the fire is 0.54 times the reference release rate[4], and
- The release rate at 15 minutes after line rupture is 0.37 times the reference release rate[4].

Given the above, and acknowledging the approximate nature of the release rate decay model developed by TNO, it is suggested that the 15-minute average release rate ratio, calculated to be 0.54, should be conservatively rounded to 0.6. Similarly, it is suggested that the release rate ratio at 15 minutes, calculated to be 0.37, should be conservatively rounded to 0.4.

The suggested applications of these release rate ratios are as follows:

- For assessing the response of building materials to a 15-minute period of exposure, use a modified version of the PIR formula that incorporates an effective release rate obtained by multiplying the reference release rate by the 15-minute average release rate ratio (i.e. 0.6).
- For assessing the approach distance for first responders that are assumed to arrive no sooner than 15 minutes after pipeline rupture, use a modified version of the PIR formula that incorporates an effective release rate obtained by multiplying the reference release rate by the release rate ratio at 15 minutes (i.e. 0.4).

Consistent with the above, the impact radius equation (see Equation [2.7] in the GRI report) should be modified to read

$$r = \sqrt{\frac{2348\,\alpha\, p\, d^2}{I_{th}}} \quad \text{(ft)}$$

where I_{th} = threshold heat intensity (Btu/hr/ft^2);

p = line pressure (psi);

d = line diameter (in); and

α = exposure adjustment factor (equal to 0.6 for assessing impact on building materials over a 15-minute exposure period, and equal to 0.4 for assessing impact on the first emergency responders subject to exposure starting 15 minutes after line rupture).

[4] The reference rate is the release rate implicit in the original PIR formula, which is effectively the average release rate over a 30-second time period starting 30 seconds after line rupture.

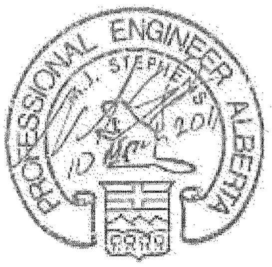
C-FER Technologies

Mr. Dan Menegus, Pacific Gas and Electric Company

March 10, 2011

Thank you for providing C-FER with the opportunity to make available this information for the purpose of adapting the original PIR formula for use in other hazard assessments.

Yours sincerely,



Mark J. Stephens, MSc, PEng
Sr. Engineering Consultant, Pipelines and Structures

APEGGA Permit Number: P 04487

MJS/cac

Reviewed by,

Q. Chen
March 10, 2011

Qishi Chen, PhD, PEng,
Director, Pipelines and Structures

ATTACHMENT 12

ENengineering Report prepared for PG&E, "Industry Survey of Operation Natural Gas Pipeline Operators on Automatic Valves," dated April 4, 2011.

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Industry Survey of
Natural Gas Pipeline Operators
on Automatic Valves

Prepared by:

ENengineering

April 4, 2011

1.0 ASSESSMENT OF INDUSTRY USE OF ASV AND RCV TECHNOLOGY

In an effort to gage the industry perspective on the use of Automatic Line Isolation Valves (AV) to respond to line breaks in the gas transmission industry, ENE Engineering contacted 25 large interstate, intrastate and local distribution companies with gas transmission pipeline. A total of 6 interstate, 1 intrastate, 2 inter/intrastate, 1 intrastate/LDC, and 2 LDC companies responded to a brief questionnaire. A copy of the complete questionnaire as released to participating pipeline operators is available in **Appendix 1**.

Responding companies operate a total of 69,000 miles of transmission pipeline with individual companies operating as few as 200 miles to as many as 25,000 miles. All but two of the responders use some automatic valves to manage line system flow in the event of a line break. The two responders who do not use automatic valves do use them at compressors stations to manage station operations.

The subparagraphs below summarize the responses. A complete summary of operator responses is located in **Appendix 2**.

1.1. Summary of Responses

In general, survey respondents had a strong preference to use Remote Controlled Valves over Automatic Valves. The primary concern with the use of RCV's is the dependence on communication and power in order to operate the valve. While Automatic Shut-Off Valves have the advantage of rapid response, it is clear that inadvertent closures make the choice less desirable. When considering the spacing between valves, most rely upon the requirements of 49 CFR 192.179.

While over 80% of respondents perform analysis prior to installing automated valves, only 27% indicate that they have written guidance covering factors to consider when deploying valves.

1.2. Industry Perspective on Automated Valves

The use of ASV and RCVs on natural gas transmission pipelines is a topic that has been researched and discussed for decades. Listed below are summary of responses for questions specific to Automated Valves:

- 38% of the companies responding indicated there is a standard applied when installing automatic line isolation valves.
- The greatest single factor considered when installing an automated valve is population which drives Class Location (population) and High Consequence Area (HCA). The next most mentioned factors were operational concerns and time to isolate a pipe segment.
- Similarly the greatest single factor under which an operator may evaluate automating an existing valve would be change in population density around an existing line.
- With the exception of recent projects subject to special permits, formal documented studies are not completed regarding installation of automated valves on new pipelines.
- The primary consideration to determine automated valve spacing is 49 CFR Part 192 maximum valve spacing requirements.

- When considering Automatic Shut-off Valve (ASV) or Remote Control Valve (RCV), the preference is to use a RCV because it requires human intervention to reduce the likelihood of inadvertent valve closure.
- In lieu of automatic valves in high population areas or HCAs, operators indicate they employ additional mitigative measures such as increased aerial or foot patrols or other increased monitoring.

1.3. Industry Perspective on Automatic Shut-off Valves

Approximately 58% of the respondents have some Automatic Shut-Off Valves installed on their pipeline system. Listed below are summary of responses for questions specific to Automatic Shut-off Valves:

- Approximately 70% of those respondents have experienced false closures of ASV's on their system.
- Unusual operating conditions, freezing of the signal line, or instrumentation failure were stated as factors causing false closure of ASVs.
- Operator efforts to minimize false closure included wholesale disabling of the ASV controls, modifying the ASV set point, and converting valves from ASV to RCVs.
- The primary advantage of an ASV is the quick response time without the requirement of external power or communication.
- Rate of pressure drop is the most common parameter used to trigger ASV operation. Other parameters used include low pressure and high flow.

1.4. Industry Perspective on Remote Controlled Valves

Approximately 70%the respondents have some Remote Control Valves installed on their pipeline system. This survey specifically relates to RCVs used for Line Rupture Control rather than flow control or other purposes. Listed below are summary of responses for questions specific to Remote Controlled Valves:

- When using RCVs all respondents use the valves for the dual purpose of operation control and rupture/line break control.
- Only one company identified an incident which occurred causing the valve to close inadvertently. Two companies indicated an incident where the valve failed to close when commanded.
- Operators view the primary advantage to a RCV is the human evaluation of the condition of the pipeline before closure. The primary disadvantage is the potential interruption of power or communication with the valve controller.
- Communication with the SCADA system is accomplished via leased land line, radio, dial-up phone or satellite.
- Most operators do not utilize automatic line break detection software. Operators monitor pressure flow and rate of change alarms to identify potential line breaks.
- Respondents were split on the existence of a formal procedure to recognize and confirm a line break prior to closing a valve.

GasPipelineSafetyOIR_DR_TURN_015-Q03Atch01-CONF

- Pipeline operators rely upon Operator Qualification and written procedures to maintain the readiness of staff to recognize and respond appropriately in the event of a failure.

APPENDIX 1

ASV / RCV SURVEY

ENEngineering

For the purpose of this survey, use the following definitions for automated valves:

Automated Line Isolation Valve (AV) *is an automated valve for isolation of a section of pipeline in the event of a line break or other major event impacting the pipeline. Two types of AVs are Automatic Shutoff Valves and Remote Control Valves.*

Automatic Shutoff Valve (ASV) *is a valve that works with an actuator that responds to changes of pressure or flow and will close the valve upon the detection of a dangerous event. Automatic Control Valves do not require an external power source, meaning that the actuator stores sufficient energy to operate the valve. Typical actuators include pneumatic cylinders, hydraulic cylinders, or compressed spring.*

Remote Control Valve (RCV) *means any valve that is operated from a location remote from where the valve is installed. The RCV is usually operated by the supervisory control and data acquisition (SCADA) system. The linkage between the pipeline control center and the RCV may be fiber optic, micro-wave, telephone line, or satellite communication. This survey specifically relates to RCVs used for Line Rupture Control rather than flow control or other purposes.*

1 My company is: ☐ Interstate Transmission ☐ Intrastate Transmission ☐ LDC ☐ Other: ____________

2 My company's natural gas pipeline assets are in (check all that apply): ☐ U.S. ☐ Canada ☐ Mexico ☐ Other international

3 Number of transmission miles in transmission system: ____________

4 Do you currently have AVs installed in your system? Yes ☐ No ☐
If yes, where do you use them? ____________
If yes, do you have any standards or guidance documents for when/where to install? ____________
If yes, do you have any standards or guidance documents for how to use them? ____________

5 Do you currently have Automatic Shut-off Valves (ASV) in your system? Yes ☐ No ☐
If yes, number of ASVs ____________ total # of transmission valves ____________
If yes, do you still install ASVs? Yes ☐ No ☐

6 Do you currently have Remote Control Valves (RCV) for Line Rupture Control in your system? Yes ☐ No ☐
If yes, number of RCVs ____________ total # of transmission valves ____________
If yes, do you still install RCVs? Yes ☐ No ☐

Additional comments:

ASV / RCV QUESTIONNAIRE

ENEngineering

Date Survey Conducted: ____________ Survey Conducted by: ____________ ____________

Operator: ____________ Name and Title of Interviewee(s): ____________ ____________

____________ ____________

For the purpose of this questionnaire, use the following definitions for automated valves:

Automated Line Isolation Valve (AV) *is an automated valve for isolation of a section of pipeline in the event of a line break or other major event impacting the pipeline. Two types of AVs are Automatic Shutoff Valves and Remote Control Valves.*

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A. Automated Line Isolation Valves	
A.1 Miles of transmission main in system?	
A.2 Do you use valves classified as AVs?	
If no, then the remainder of the questionnaire is not applicable.	
A.3 What type of analysis does your company do to determine where to install AVs?	
A.4 Do you have any standards or guidance documents for the implementation and use, including installation, of AVs?	
A.5 What specific factors do you consider when considering deployment of AV equipment? Examples: Class location, HCA, Pipe Size, Operating Pressure, Pipe Stress level, Outside Force Threat, Branch/End Points.	

A. Automated Line Isolation Valves (cont'd)	
A.6 How does line configuration affect your decision making on the use of AVs? Example: Looped lines, Single lines.	
A.7 Do you perform a formal study on new pipelines to determine if AVs are warranted? Describe.	
A.8 Under what circumstances would you evaluate if existing manual valves should be automated?	
A.9 What spacing do you use when installing AVs?	
A.10 When would you use RCV over the ASV or vise versa? Why?	
A.11 For high population or other high consequence of failure areas where AVs are not installed, you do employ any additional preventive and mitigative measures? Describe.	
B. Automatic Shut-off Valves	
B.1 Do you have Automatic Shut-off valves in your system?	
B.1a If yes, how many ASVs do you have in your system? What approximate percent of total transmission valves does this represent?	
B.2 Have you had any reliability issues with ASVs? Describe.	
B.3 Have you had any false closures? If so, explain the circumstances.	
B.4 What have you done to minimize false closures?	
B.5 Describe any additional experiences with ASVs.	
B.6 What do you feel are the advantages of an ASV?	
B.7 What do you feel are the disadvantages of an ASV?	

C. ASV Equipment and Monitoring	
C.1 What type of equipment do you use?	
C.2 What parameters are monitored to activate the ASV? Example: Low Pressure, Rate of Pressure Change, High Flow, Rate of Flow Increase	
C.3 Is data integrated from multiple points or is a single localized data point used to determine whether to activate the ASV?	
C.3a If multiple, what is the configuration of typical monitoring points?	
C.4 What type of equipment do you use for the detection of line break?	
C.4a If computer/electronic controller based, is it an "off the shelf" program or custom software?	
C.5 Does your SCADA system monitor to determine whether or not the ASV is closed?	
D. Remote Control Valves	
D.1 Do you use RCVs with dual intent - automated valve for line operation and also rupture/line break control?	
D.2 Have you had any RCV malfunctions causing the RCV to close unexpectedly? Describe.	
D.3 Have you had any occurrences of the RCV failing to close when commanded by the dispatcher? If so, what has been the cause?	
D.4 Have you experienced any other reliability issues? If so, describe.	
D.5 Describe any additional experiences with RCVs.	
D.6 What do you feel are the advantages of an RCV?	
D.7 What do you feel are the disadvantages of an RCV?	

E. RCV Equipment and Monitoring	
E.1 What type of equipment (valve type, actuator, controls) do you use?	
E.2 What type of communication system do you use?	
E.3 What parameters are alarmed to notify an operator of the potential need to operate a RCV? Example: Line Break Detection Algorithm, Low Pressure, Rate of Pressure Change, High Flow, Rate of Flow Increase	
E.4 Do you utilize automated line break detection software? If yes, is it an "off the shelf" program or custom software, and how does it identify a line break?	
E.5 Do you have formal procedures and protocol for when to initiate a closure?	
E.6 Describe your procedures (formal or informal) for how to recognize and confirm a line break prior to closing a remote valve.	
E.7 Do you have a process for confirming your primary line break detection system? Describe. Example: Visual confirmation of line break.	
E.8 What is your protocol for re-opening an RCV after closure due from suspected line break?	
E.9 What is your operator training program for monitoring and operation of RCVs?	