Summary of Comments to Automatic and Remotely Controlled Shutoff Valves on Hazardous Liquids and Natural Gas Pipelines Draft Report

The following is a summary of the comments received during the public comment period, and any action taken by the contractor, for the Automatic and Remotely Controlled Shutoff Valves on Hazardous Liquids and Natural Gas Pipelines Draft Report by Oak Ridge National Laboratory (ORNL). The original comments can be read in their entirety at the Automatic and Remotely Controlled Shutoff Valves on Hazardous Liquids and Natural Gas Pipelines Draft Report comment website: https://primis.phmsa.dot.gov/meetings/DocHome.mtg?Doc=9

Comments were received via the website form via the following individuals/organizations:

- Terry DeLong, Kinder Morgan
- Daniel Scarberry, Dominion East Ohio

Comments were received by email via the following individuals/organizations

- Philip Bennett, AGA
- Richard Kuprewicz, Accufacts
- Peter Lidiak, API providing joint API-AOPL comments
- Dan Regan, INGAA
- Mark Stephens, C-FER Technologies

The comments and any action taken by the contractors with respect to changes to the Draft Report are broken up into two general categories:

- Technically substantive comments that resulted in a change by the contractor to the draft report (as well as what the change was)
- Technically substantive comments that did not result in a change to a draft report, but determined worthy of a response/explanation

Technically substantive comments that resulted in a change by the contractor to the draft report (as well as what the resulting change was)

1. **Comment:** *"Has PHMSA considered in their study the fact that many gas pipeline operators have experienced inadvertent ASV closures, without a plausible event? Operators are concerned with service disruptions from an inadvertent ASV closure."* **Mark Scarberry**

   Resulting Change: Inadvertent ASV closures and service disruptions are now discussed in Section 4.1.3 Automatic Shutoff Valve Operational Feasibility Assessment (Page 168) of the report.

2. **Comment:** *"I wanted to make some comments regarding Case Studies 7 and 8 (hazardous liquids release without ignition) as I do not believe the numbers presented are an accurate reflection of reality for a crude oil system. The issue is primarily with the calculation of release volumes. Assuming a constant flow velocity was maintained during a rupture (ie. not considering pressure) the volume released during, the 5 min release phase would be approx 5,670 BBL. Pressure would have a significant effect on this volume of course, but the amount would depend on the pump curve of the upstream pump station. So the pump would run out on its curve but there would be a limit of flow as it would, at some point, start to lose suction pressure. So the assumptions were not stated but the volumes given for this phase in all cases may be too conservative, especially in the 8C and 8D cases."* **Terry DeLong**

   Resulting Change: A review of case studies for liquid releases acknowledges your concern. Changes to the document were made. The estimated release volume is now consist with the methodology defined in 49 CFR §194 as described in Section 2.3 of the report.

3. **Comment:** *"After the initial detection and shut down phase the line would unpack relatively quickly. The estimate of 345,536 BBL being released in the 90 min following system shut-down (Case 8A) is not a realistic number. That would mean almost 52 miles of line fill has drained out in 90 minutes, yet the pumps are shut off and the drain down length is only stated as 3 miles. The issue is even more magnified for the higher volumes - case Study 8C and 8D. For 8D this would be 140 miles of pipe draining out. The resulting "Avoided damage costs" are much too high in the case studies. This is supported by the fact that the Gulf oil spill clean-up costs are currently at about $3 billion while the Enbridge Kalamazoo incident is at $800 Million. A 90 minute to 3 minute closure time resulting in a cost avoidance of $26.6 Billion is not realistic."* **Terry DeLong**

   Resulting Change: A review of case studies for liquid releases acknowledges your concern. Changes are being made to the document. The estimated release volume and associated damage costs are both reduced from the draft preliminary report and are now consist with the methodology defined in 49 CFR §194 as described in Section 2.3 of the report.

4. **Comment:** *"The use of the word "leak" as seen in the above quote, and throughout the report, should be replaced with the word "rupture," where the high rate mass releases associated with pipeline failure are appropriate. It has been Accufacts' experience that the public quickly understands and grasps the consequences and differences between a gas transmission pipeline leak versus a rupture. "* **Accufacts**

Resulting Change: The preliminary draft report has been revised to clarify this issue in Section 1.3 (Study Parameters and Boundaries) footnote 3.

5. **Comment:** *"The vast majority of high stress steel gas transmission pipe ruptures are very high mass rate releases associated with pipe failures for various reasons that are usually full bore, or guillotine-type like breaks. Valving decisions are largely intended to effectively address rupture, or rupture-like pipe failures (such as girth weld breaks), not leaks."* **Accufacts**

Resulting Change: The preliminary draft report has been revised to clarify this issue in Section 1.3 (Study Parameters and Boundaries) footnote 3.

6. **Comment:** *""Detect" could be, and is most likely given the current state of technology, to be more than remote detection via SCADA or CPM. It might be productive to expand on the meaning of "detect," such as report of rupture by a reliable source."* **Accufacts**

Resulting Change: The method of detection is not relevant to this study provided the method of detection alerts the Operator that a break has occurred. We assume that action is taken by the Operator following the detection. Minor changes to the text in the description of the Detection Phase have been made for natural gas and hazardous liquid pipelines.

7. **Comment:** *"As in natural gas pipelines, the study should also be careful to identify the threat being addressed is more likely a liquid pipeline "rupture" not a leak, whether full guillotine-type break or not. For liquid pipelines, while the full bore guillotine-type break cannot be eliminated as a possible rupture like risk (more likely associated with girth weld failure from abnormal loading), liquid pipeline ruptures, though not full bore, will nevertheless be very high mass rate releases where the placement of prudent remote or automated valves will also prove very cost effective. "* **Accufacts**

Resulting Change: As for gas above, the preliminary draft report has been revised to clarify this issue in Section 1.3 (Study Parameters and Boundaries) footnote 3.

8. **Comment:** *"Accufacts believes a closer flow system analysis of flow rates immediately following a liquid pipeline rupture should indicate that release rates can easily exceed "the normal pipeline flow rate" as the pipeline system pressure curve is substantially changed by the rupture, and the pumps run out on their "pump curve." This substantial increase in flow rate is an important phenomenon often utilized by experienced control room operators to confirm a possible liquid pipeline rupture. "* **Accufacts**

Resulting Change: This issue has been addressed through changes in Section 3.2.2 and 3.3.2 (Analytical Approach and Computational Models).

9. **Comment:** *"For example, the Kalamazoo spill released a total of 20,000 bbls, compared to an estimated 430,000 bbls from Case Study 8A (90 minute closure) in Table 3.32. Based on this, ORNL's model produced a spill volume 21.5 times the real-world volume. Had ORNL used an appreciable sample of real-world cases to validate the number of barrels predicted in their theoretical case studies, a much more realistic evaluation of economic feasibility could have been achieved."* **API-AOPL**

Resulting Change: A review of case studies for liquid releases acknowledges your concern. Changes to the document have been made. The estimated release volume is

now consist with the methodology defined in 49 CFR §194.105 (b)(1) as described in Section 2.3 of the report.

10. **Comment:** *"The proposed hazard zone model is based on an extremely conservative and inappropriate approach to pipeline outflow estimation and a fire radiation model that ignores significant sources of conservatism inherent in using a point-source radiation model (without appropriate adjustments) to characterize a large-scale fire resulting from pipeline rupture." ; "No evidence is provided to demonstrate that validity of the assumptions employed in developing the proposed hazard zone model or in the sizes of the hazard zones predicted by this model."; "To the extent that the size of the zone of severe impact resulting from the San Bruno pipeline failure is perceived to be inconsistent with that predicted by the GRI model, it is emphasized that the final extent of the zone of impact was significantly influenced by factors not explicitly addressed by either the GRI model or the proposed new model. To adopt a grossly conservative fire hazard model to account for other case-specific factors is not the preferred approach because it masks the significance of these other issues and it compromises the validity of hazard distance estimates obtained from such a model."* **C-FER**

    Resulting Change: The models used in this study to estimate pipeline outflow and fire radiation for natural gas pipeline releases were developed as tools for identifying differences in release scenarios and for quantifying the effectiveness of block valve closure swiftness in mitigating fire damage. Simplifying assumptions and limitations of the models used to estimate the time-dependent pipeline outflow and thermal radiant intensity resulting from fires produced by combustion of the released natural gas are discussed in Sections. 3.1.1 and 3.1.2. These models are not intended to be exact solutions to these complex engineering problems.

    To further address this comment, the text in Section 3.1.2 will be modified as follows to clarify this concern and to minimize any possible confusion or misunderstanding in the application of these models.

    "Computational models used to determine time-dependent mass flow for different pipeline diameters, operating pressures, and detection and block valve closure durations are described in Section 3.1.2.1. Models used to compute heat flux intensities at different distances from the break (separation distances) are described in Section 3.1.2.2. These models are tools for identifying differences in release scenarios and for quantifying the effectiveness of block valve closure swiftness in mitigating consequences resulting from the natural pipeline release scenarios discussed in Sect. 3.1.4.

    The models are based on engineering principles and fire science practices but are not intended to be exact solutions to these complex engineering problems or for use in complying with the risk analysis requirements in 49 CFR 192.935 to identify additional measures to protect a high consequence area and enhance public safety. In addition, the mass flow and heat flux data computed using the models have not been validated by comparison with actual pipeline release events or experimental test data available to the public."

<u>Technically substantive comments that did not result in a change to a draft report, but determined worthy of a response/explanation</u>

1. **Comment**: *"I believe there are larger errors present in the calculation of block valve closure times. The report seems to assume that the line stays at full pressure after detection and pumping has ceased - this is not the case for a crude oil line."* **Terry DeLong**

    Response from contractor: The authors agree, but used the following methodology of 49 CFR §194.105 (b) (1): The pipeline's maximum release time in hours, plus the maximum shutdown response time in hours (based on historic discharge data or in the absence of such historic data, the operator's best estimate), multiplied by the maximum flow rate expressed in barrels per hour (based on the maximum daily capacity of the pipeline), plus the largest line drainage volume after shutdown of the line section(s) in the response zone expressed in barrels (cubic meters)…
2. **Comment:** *"Besides the volume calculation the spill clean-up costs used should be reviewed - is it appropriate to use a worst case scenario (ie, oil from a rupture needs to enter a stream) for this analysis? A land based spill would have a much smaller clean-up cost. Perhaps there are 2 scenarios worth considering, which would highlight the importance streams and rivers have with respect to EFRD considerations."* **Terry DeLong**

    Response from contractor: Please refer to Table 3.30. The most severe habitat and wildlife sensitivity category modifier of Wetland (4.0) was used in the study. River/Stream (1.5) and Agricultural (2.2) modifiers produces less clean up costs.
3. **Comment:** *"Most automated valves in the oil pipeline industry would have a closure time between 2 and 15 minutes. I assume that the 30, 60 and 90 minute closure times are meant to reflect response time to close manual block valves in the event of a rupture. If this is the case I believe longer response times should be considered - these may be several hours depending on time of day, time of year, weather, etc.. As a result we do not take credit for manual valves in our EFRD studies. After the initial detection, response and valve closure phases, the majority of volume draining out of the pipeline is due to gravity drain out, so the effectiveness of EFRDs is very much subject to local topography."* **Terry DeLong**

    Response from contractor: To evaluate the effectiveness of block valve closure swiftness, the study considered valve closure times ranging from 3 to 90 minutes. Longer valve closure times may be considered on a case-by-case basis.
4. **Comment:** "The complexity of the risk assessments for valves requires case-by-case analysis ." **AGA**

    Response from contractor: Feasibility evaluations conducted as part of this study show that under certain conditions installing ASVs and RCVs in newly constructed and fully replaced natural gas pipelines is technically, operationally, and economically feasible with a positive cost benefit. However, these conclusions may not apply to all newly constructed and fully replaced pipelines because site-specific parameters that influence risk analyses and feasibility evaluations often vary significantly from one pipeline segment to another, and may not be consistent with those considered in this study. Consequently, the technical, operational, and economic feasibility and

potential cost benefits of installing ASVs and RCVs in newly constructed or fully replaced pipelines need to be evaluated on a case-by-case basis.

5. **Comment:** *"There is a concern with disruption of gas service on gas distribution systems."* **AGA**

   Response from contractor: Installation of ASVs in newly constructed and fully replaced pipelines is considered operationally feasible provided: (1) inadvertent block valve closure does not cause damage to equipment or trigger other ASVs to close unnecessarily, and (2) the consequences of service disruptions to critical customers due to inadvertent block valve closure do not exceed the potential public and environmental safety benefits realized by rapid block valve closure. Installation of RCVs in newly constructed and fully replaced pipelines is considered operationally feasible provided inadvertent block valve closure does not cause damage to equipment, the communications link between the RCV and the control room is continuous and reliable, and the consequences of service disruptions to critical customers due to inadvertent block valve closure do not exceed the potential public and environmental safety benefits realized by rapid block valve closure.

6. **Comment:** *"Not all transmission pipeline ruptures result in catastrophic events."* **AGA**

   Response from contractor: In this study, modeling is limited to potential fire consequences and thermal radiation effects resulting from unintended releases from natural gas pipelines. The scope of the study is further limited by considering only worst case releases resulting from a guillotine-type break in the pipeline. Although ignition of the released product following a guillotine-type break is not ensured, this study only considers release scenarios that result in immediate ignition of the released product at the break location. Without an ignition source, the escaping gas disperses into the atmosphere resulting in little or no damage to buildings or humans.

7. **Comment:** *"The report is limited to worst case scenarios."* **AGA**

   Response from contractor: The scope of the study was purposely limited to consider only worst case pipeline release scenarios involving guillotine-type breaks rather than other more common breaks, such as punctures and through-wall cracks. A pipeline break can range in size and shape from a short, through-wall crack to a guillotine fracture that completely separates the line pipe along a circumferential path. A break that occurs adjacent to a block valve and renders the block valve inoperable will result in the greatest volume of natural gas released to the atmosphere compared to a break that occurs at another location along the same line section. Guillotine-type breaks with immediate ignition of the escaping natural gas produce thermal radiant intensities that are considered worst case because this type of rupture results in the greatest release of natural gas in the shortest time period.

8. **Comment:** *"There are three phases involved in the response; detection, valve closure and blowdown. The report incorporates unrealistic time limits for each phase."* **AGA**

   Response from contractor: The work agreement between PHMSA and ORNL required ORNL to perform the five work activities listed in Sect. 1.2. Item 4 required ORNL to evaluate the fire science behind initial accident rupture and response time provided by ASVs and RCVs by developing models that show the benefits of rapid response

time. Analysis of heat flux versus time data and fire science practices showed that fire fighters are able to mitigate fire damage resulting from an unintended natural gas pipeline release provided all of the following conditions are satisfied.
The leak is detected and the appropriate ASVs and RCVs close completely so that the damaged pipeline segment is isolated within 10 minutes or less after the break, and fire fighting activities within the area of potentially severe damage can begin soon after the fire fighters arrive on the scene.

- **Fire fighters arrive on the scene and are ready to begin fire fighting activities within 10 minutes or less after the break.**
- **Fire hydrants are accessible in the vicinity of the potentially severe damage radius.**
- **Block valves close in time to reduce the heat flux at the potentially severe damage radius to 2.5 kW/m2 (800 Btu/hr ft2) within 20 minutes or less after the break.**

Achieving these results requires rapid leak detection and block valve closure within 8 to 13 minutes after the break. If the damaged pipeline segment is not isolated within 20 minutes after the break, fire fighting activities may evolve from controlling fire damage to preventing fire spread.

9. **Comment:** *"The report concludes that without timely first responder intervention the valve installation is not cost-beneficial."* **AGA**

Response from contractor:
This comment is consistent with the following statements in Section 5.2.1.:

> **The risk analyses show that there are no avoided costs for fire damage to buildings and property attributed to block valve closure swiftness because potentially severe damage occurs before block valve closure can isolate the damaged pipeline segment and begin limiting the amount of natural gas that escapes and burns. Immediately following the break, buildings and property located within the potentially severe damage radius (approximately 1.5 times PIR) are exposed to thermal radiation that exceeds the heat flux threshold of 40.0 kW/m2 (12,700 Btu/hr ft2) which can cause potentially severe damage. In addition, injuries to unsheltered humans and emergency responders located within this radius are very probable because the thermal radiation far exceeds the heat flux threshold of 1.4 kW/m2 (450 Btu/hr ft2) which is considered the acceptable level of thermal radiation for people in open spaces. Firefighting activities are also limited within areas where the thermal radiation exceeds the heat flux threshold of 2.5 kW/m2 (800 Btu/hr ft2) which is considered the acceptable level for common firefighting activities.**
> **Although the cost for adding either RCV or ASV closure capability is considered a negative cost benefit because the swiftness of block valve closure has no effect on mitigating fire damage to buildings and property located within the potentially severe damage radius, positive cost benefits attributed to block**

valve closure swiftness may be realized when all of the following conditions are satisfied.

- **Fire fighters arrive on the scene and are ready to begin fire fighting activities within 10 minutes after the break.**
- **Fire hydrants are accessible and uniformly spaced around the perimeter of the potentially severe damage circle.**
- **Block valves close in time to reduce the heat flux at the potentially severe damage radius to 2.5 kW/m2 (800 Btu/hr ft2) within 20 minutes or less after the break.**

10. **Comment:** *"Emergency response plans should be very different for gas transmission pipeline leaks versus ruptures."* **Accufacts**

    Response from contractor: Section 1.3.3.3.discusses Emergency Response Guidance applicable to natural gas and hazardous liquid pipelines.

11. **Comment:** *"The report should distinguish the significant rupture differential risks and consequences of a specific class of hazardous liquid pipelines, Highly Volatile Liquid, or HVL, pipelines over more traditional hazardous liquids (such as crude oil or gasoline) ruptures. A prudent risk management regulatory approach will specifically address certain distinguishing and higher risk characteristics concerning valve placement and automation decisions on HVL pipelines. HVL pipelines are an area where federal minimum pipeline safety regulations have historically been seriously incomplete, especially as it relates to valves and their automation. Given the wide ranging activity of shale gas development across the country, Accufacts is seeing significant new HVL pipelines in locations where additional prudent valve decisions are especially cost effective and warranted."* **Accufacts**

    Response from contractor: Section 3.2 discusses consequences of worst case releases of hazardous liquids with ignition, and Section 3.3 discusses consequences of worst case releases of hazardous liquids without ignition.

12. **Comment:** *"The study's modeling does not reflect real world scenarios pipeline operators encounter in the field, overstates the positive benefits of EFRD use, and does not fully consider the drawbacks of EFRDs."* **API-AOPL**

    Response from contractor: The study considered the worst case discharge as defined in CFR § 194.105 (b)(1). The scope of the study was limited to evaluating the effectiveness of the swiftness of block valve closure on mitigating consequences based on a worst case release.

13. **Comment:** *"An example of the limited benefit of EFRDs is one of the very case studies ORNL examined. Delay in operator control room management actions and emergency response Page 2 of 3 identification during the release were the main drivers of the size of the 2010 Kalamazoo River spill. Most all of the crude was spilled before the operator determined a release and shut down the line. The ORNL study does not conduct this root cause analysis to determine whether EFRDs would have made a beneficial difference."* **API-AOPL**

    Response from contractor: The root cause analysis of the 2010 Enbridge spill was beyond the scope of this study.

14. **Comment:** *"Additionally, ORNL's improper assumptions overstate the benefits of EFRDs by failing to reflect how EFRDs operate in practice. ORNL improperly assumed a constant flow rate during the valve closure phase. Flow rate can be assumed constant through the detection and continued pumping phases, but not through the valve closure phase. When the pumps shut down soon after leak detection no new volumes enter the pipeline, the pressure source is gone and volumes slow down throughout the drain down phase. Therefore the calculated Shutoff Valve Closure volumes based on a constant flow volume during closure and included in the study by ORNL are highly inflated and do not accurately reflect a true spill volume. This overstatement of spill volumes also leads to excessively inflated estimated Damage Costs."* **API-AOPL**

    Response from contractor: The study considered the worst case discharge as defined in CFR §194.105 (b)(1).

15. **Comment:** *"ORNL's cost benefit analysis weighs the cost of adding closure capability against the benefit of avoiding a worst-case leak scenario. ORNL does not seem to have compared the relative efficacy of manual shutoff valves to RCVs or ASVs. This is not an accurate assessment of the risks and therefore overstates the relative benefits of EFRDs. PHMSA should be interested instead in the industry-wide cost of adding closure capabilities to all valves in newly constructed or fully replaced pipe compared to the benefit that would be realized by having closure capabilities on those same lines in the event of a leak. Benefits can be measured by extrapolating the historical frequency and severity of spills on newly constructed or fully replaced pipe."* **API-AOPL**

    Response from contractor: The report evaluates the effectiveness of block valve closure swiftness using the study variables in Table 3.24. This table includes the duration of block valve closure used in the analysis.

16. **Comment:** *"The study should have also addressed the detriments of EFRDs."* **API-AOPL**

    Response from contractor: Chapters 4.1.3 and 4.2.3 of the report includes discussion on operational feasibility assessments of ASVs and RCVs.

17. **Comment:** *"As indicated in our previous comments on the scope for the study, while coordination of operators and emergency responders is imperative, we do not think that is a primary consideration in the selection and placement of EFRD's and should not be included in the final study."* **API-AOPL**

    Response from contractor: The scope of the study was limited to evaluating the effectiveness of the swiftness of block valve closure on mitigating consequences based on a worst case release.

18. **Comment:** *"Such a model will significantly overestimate the release rate in the early stages of a release event. The ORNL report concedes this point, but its authors accept the approximation by noting that it produces conservative results. It is suggested that the overestimation of outflow that will result from the use of the ORNL model goes well beyond conservatism to the point where it can only be considered inappropriate for the intended purpose."* **C-FER**

    Response from contractor: The ORNL model predicts the transient gas release rate exactly at the instant of the break. It is true that the predicted release rate declines somewhat more slowly with time (conservatively high gas discharge rate) early in the transient than actually occurs because the model neglects pressure gradients

extending back along the pipe. For times late in the blowdown, the actual release rate is higher than in the ORNL model. However, the ORNL model indicates the discharge rate declines fast enough that damage zones for longer-time thermal radiation exposure lie inside the damage zone from the initial flux (for which the gas discharge rate is modeled exactly). Thus the overall conclusions of the ORNL report about the potential benefits of earlier valve closure in a natural gas release fire are still valid. It is important to remember that the GRI model also does not analyze a transient discharge or calculate pressure gradients extending back along the pipe. Including the pressure gradient would be a relatively complicated analysis, and ORNL has never seen a discharge model that explicitly modeled this effect. Instead, the GRI model incorporates an empirical release rate decay factor, λ, that is intended to yield an average discharge rate (and corresponding average heat flux) over the first 30 seconds of the transient. GRI bases all their damage estimates on such an integrated average heat flux for the first 30 seconds. However, the curve for the time it takes a given heat flux to produce damage is highly nonlinear because very high fluxes lead to almost instantaneous damage or ignition. Thus the thermal damage criteria is based on a transient flow rate model that includes the high initial flux at the time of the break, rather than an integrated average flux as used in the GRI model. That is why the present approach was adopted in the ORNL report.

19. **Comment:** *"The discussion provided therein states that the efficiency factor is intended to address a number of conservatisms inherent in using a simple point-source radiation model to characterize large-scale fires associated with gas pipeline ruptures. Specifically, the issues addressed by the inclusion of an efficiency factor include the following: 1) the effect of high speed jetting and fire size on the total radiant energy produced; 2) the effect of flame opacity on the amount of radiant energy released from the flame; 3) the effect of flame height on the effective radiation distance to ground level receptors; and 4) the effect of atmospheric absorption on the amount of radiant heat reaching ground level receptors. By replacing the efficiency factor in the GRI point-source fire radiation model with a transmissivity factor that accounts only for atmospheric absorption of radiation three of the four sources of model conservatism outlined above are effectively ignored in the ORNL model."* **C-FER**

    Response from contractor: These are actually accident mitigating mechanisms, which tend to reduce the thermal heat flux to the surroundings, not sources of conservatism in the hazard models. Taking credit for these mechanisms to mitigate fire damage requires a clearly defensible justification, which is not given in the original GRI model report. Both the API 521 and GRI thermal radiation models appear to be widely used despite some significant differences in the calculated heat fluxes. With no clear choice between the two models, ORNL decided to use the more conservative, higher heat flux API model and base thermal radiation attenuation results on only the clearly documented atmospheric transmissivity effects.

20. **Comment:** *"In this regard, it is noted that the implied claim of non-conservatism is not supported by the model verification exercise that was carried out as part of the original GRI study."* **C-FER**

    Response from contractor: A search by ORNL did not find such data (from model verification exercises/experiments) in the public literature. Also, ORNL did not have access to the data cited despite requests for data through official channels.

21. **Comment:** *"The PIR formula was developed to delineate the zone of significant impact resulting directly from a natural gas pipeline rupture. It was not intended to account for follow-on effects that can be significant in unusual situations. If other factors are to be accounted for in determining the likely extent of the zone of significant impact in the event of gas pipeline rupture, it is suggested that adoption of a grossly conservative fire hazard model is not the preferred approach."* **C-FER**

    Response from contractor: Again, ORNL does not feel that the models are grossly conservative, especially when used for their intended purpose. Any pipeline rupture incident (such as San Bruno) has its own unique characteristics which determine the damage zone. No simple, general model can account for such factors, and there is certainly room for disagreement about precisely what gas discharge coefficients, combustion efficiencies, atmospheric transmission factors, etc. are most appropriate. However the ORNL models serve primarily as a simple means of comparison to evaluate the impact of valve closure time on transient heat flux at various distances from the break. These comparisons are more important than any claim to precisely calculate the radius of the affected area. ORNL feels that the models are adequate to show that in a pipeline rupture and fire, damage zones for longer duration thermal exposures lie inside the region already affected by the high initial heat flux, and that earlier valve closure can help mitigate damage when combined with prompt firefighter emergency response.

22. **Comment:** *"Finally, with regard to the adoption of 2.5 kW/m2 (800 Btu/hr-ft2) in the ORNL report as the threshold heat intensity for conducting continuous fire fighting and emergency response activities, it is noted that a significantly higher threshold value of 5 kW/m2 (1,600 Btu/hr-ft2) is cited in various standards and guidance documents (including the National Fire Protection Association's LNG Standard, NFPA 59A, and by reference in 49 CFR 193.2057) as a tolerable threshold heat intensity level. Furthermore, recent field tests conducted by Technology Management Systems, 3 which were funded in part by PHMSA, suggest that extended exposure to a heat intensity of 5 kW/m2 can be sustained without injury by persons wearing normal civilian clothing. Given this, the selection of 2.5 kW/m2 as the heat intensity threshold for emergency responders wearing protective clothing would appear to be unduly conservative."* **C-FER**

    Response from contractor: Table 1.1 identifies the effects of thermal radiation intensity on buildings and humans used as the basis for the risk analyses discussed in the report. Review of each specific thermal radiation intensity listed in Table 1.1 and the supporting information in the associated reference suggests that effects and consequences of exposure to a specific thermal radiation intensity cannot be precisely quantified. Consequently, there is no consensus within the fire science community concerning an acceptable heat flux threshold for incident and continuous fire fighting

activities. In addition, fire fighter burn injuries are influenced by the ability of fire fighter protective clothing to store heat energy and the effects of moisture accumulation inside the fire fighter protective clothing.

This observation is supported by the following statement from the final report presented to the Fire Protection Research Foundation titled Thermal Capacity of Fire Fighting Protective Clothing, IA 07-25, Center for Research on Textile Protection & Comfort College of Textiles North Carolina State University, October 2008.

Development of a qualified understanding of conditions that produce stored energy burns presents a significant challenge. This is because of the physical complexity inherent in actual fire fighting operations and the complicated interactions of many variables of use or exposure that may cause stored energy burns. Technically qualified characterization of these conditions, including specifics of the thermal exposure scenario or the moisture present in the turnout suit, often rely on anecdotal description of these events.

In this study, use of 5 kW/m2 rather than 2.5 kW/m2 as a tolerable threshold heat intensity level decreases the time fire fighters are able to initiate fire fighting activities within a distance of 1.5 times PIR. However, without swift block valve closure fire fighters are unable to initiate fire fighting activities immediately upon arrival because the heat flux at a distance of 1.5 times PIR exceeds 5 kW/m2 at least 20 minutes after the break. The addition of 1,600 Btu/hr-ft2 curves to Figs. 3.15, 3.16, 3.17, and 3.18 support this conclusion.

23. **Comment:** *"Misunderstanding the Potential Impact Radius (PIR)"* **INGAA**

Response from contractor: ORNL understands report GRI-00/0189 and the PIR concept quite well. The PIR definition does use a thermal radiation model and also includes transient aspects of a natural gas release through use of a "release rate decay factor" which specifies how quickly the gas outflow rate decreases with time. As defined in GRI-00/0189, the PIR is the radial distance at which people or property would be exposed to an average thermal radiation heat flux of 5000 Btu/hr-ft2 over the first 30 seconds following a natural gas pipeline break with immediate ignition. Since the PIR is a familiar distance concept in the gas industry, it serves as an excellent measuring unit to express the standoff distances corresponding to other thermal radiation heat flux levels during a transient gas fire. The distance for each heat flux level will correspond to some specified multiple of the PIR.

ORNL used the PIR as a scalar for quantifying the radial distance from the break for different heat flux intensities resulting from natural gas pipeline releases. As stated in Section E.2 of the Executive Summary; "Exposure to a heat flux of 40.0 kW/m2 (12,700 Btu/hr ft2) for any period of time is considered the maximum tolerable level of radiation at the facade of an exposed building and the threshold for severe damage to buildings. Based on analysis, the potentially severe damage radius for a natural gas pipeline release is approximately 1.5 times the potential impact radius (PIR)."

24. **Comment:** *"Inaccurate Severe Damage Diameter Assumptions"* **INGAA**

Response from contractor: Table 1.1 describes the effects and consequences of different thermal radiation intensities on buildings and people used in this report as the basis for characterizing damage caused by a pipeline release and subsequent fire. The data sources are referenced. ORNL agrees that a heat flux of 39.4 kW/m2 requires piloted ignition and that a higher heat flux is needed for spontaneous ignition. For these reasons, ORNL established the potentially severe damage radius based on a heat flux threshold of 40.0 kW/m2 because heat flux levels within this radius are greater than this threshold.

ORNL addressed the transient nature of the thermal radiation heat fluxes by recognizing that the transient heat flux remain at or above the tabulated steady-state damage threshold value for the entire specified time (either 15 minutes or 30 minutes) in order to indicate that level of damage. Thus it should be entirely appropriate to expect that the transient heat flux would inflict thermal damage at least equal to that seen in steady-state tests at the tabulated flux level.

25. **Comment:** *"Optimistic Leak/Rupture Detection Time"* **INGAA**

Response from contractor: The study variables are summarized in Table 3.1 of the report. The duration of block valve closure at 3, 30, 60, 90, and 180 minutes provides a large variation for consideration by the reader. The work agreement between PHMSA and ORNL required ORNL to perform the five work activities listed in Section 1.2. Item 4 required ORNL to evaluate the fire science behind initial accident rupture and response time provided by ASVs and RCVs by developing models that show the benefits of rapid response time. Analysis of heat flux versus time data and fire science practices showed that fire fighters are able to mitigate fire damage resulting from an unintended natural gas pipeline release provided all of the following conditions are satisfied.

- **The leak is detected and the appropriate ASVs and RCVs close completely so that the damaged pipeline segment is isolated within 10 minutes or less after the break, and fire fighting activities within the area of potentially severe damage can begin soon after the fire fighters arrive on the scene.**
- **Fire fighters arrive on the scene and are ready to begin fire fighting activities within 10 minutes or less after the break.**
- **Fire hydrants are accessible in the vicinity of the potentially severe damage radius.**
- **Block valves close in time to reduce the heat flux at the potentially severe damage radius to 2.5 kW/m2 (800 Btu/hr ft2) within 20 minutes or less after the break.**

Achieving these results requires rapid leak detection and block valve closure within 8 to 13 minutes after the break. If the damaged pipeline segment is not isolated within 20 minutes after the break, fire fighting activities may evolve from mitigating fire damage to preventing fire spread.

26. **Comment:** *"New Thermal Flux Criteria"* **INGAA**

Response from contractor: Table 1.2 shows the heat flux threshold basis for the study using information from Table 1.1 in order to establish safe separation distances for fire fighters, emergency responders, and the public. These heat flux criteria are consistent with heat flux criteria adopted by HUD in Ref. HUD, 2011a.

… ORNL understands the PIR concept and how the PIR defines the radius for a particular average thermal radiation flux. ORNL used the PIR (or any other clearly defined radius) as a normalizing distance unit when plotting instantaneous thermal flux data. Using the PIR works particularly well because the PIR itself also scales with the thermal radiation flux intensity. The fact that each combination of heat flux and duration associated with particular levels of damage falls at a specific normalized multiple of the PIR (~1.6*PIR for severe damage, ~0.75*PIR for moderate damage, and ~0.5*PIR for minor damage) over a wide range of pipe diameters and pressures illustrates the validity of this normalizing approach. Normalizing distances by the PIR is thus an effective way to express the damage zone results.

27. **Comment:** *"Lack of Impact Methodology Validation"* **INGAA**

Response from contractor: ORNL used the PIR as a scalar for quantifying the radial distance from the break for different heat flux intensities resulting from natural gas pipeline releases. It is stated in discussions on the San Bruno accident, that the analytical approach and computational models do not consider terrain features or wind effects, which are factors that contributed to the distribution of fire damage for this release. Fig. 3.69 shows that the computed potentially severe damage radius of 1.5 times PIR envelopes most of the damaged and destroyed buildings located in the area surrounding the rupture site in San Bruno. The study results are consistent with the timeline for emergency response and the damage assessments discussed in the NTSB accident report for the San Bruno natural gas transmission pipeline rupture and fire. They also provide the basis for concluding that the analytical approach and computational models produce credible results. The models are based on engineering principles and fire science practices but are not intended to be exact solutions to these complex engineering problems or for use in complying with the risk analysis requirements in 49 CFR 192.935 to identify additional measures to protect a high consequence area and enhance public safety. In addition, the mass flow and heat flux data computed using the models have not been validated by comparison with actual pipeline release events or experimental test data because these data are not available as a public resource.

28. **Comment:** *"Optimistic Fire Mitigation Assumptions"* **INGAA**

Response from contractor: As stated in Section E.2 of the Executive Summary, concerning the San Bruno accident:

"The analytical approach and computational models used to assess the hypothetical natural gas pipeline release scenarios were also used to study the San Bruno natural gas pipeline accident that occurred in a residential area in San Bruno, California on September 9, 2010. Study results for this actual natural gas pipeline release provide

evidence that the analytical approach and computational models produce credible results." In addition, analysis of heat flux versus time data and fire science practices show that fire fighters are able to mitigate fire damage resulting from an unintended natural gas pipeline release provided all of the following conditions are satisfied.

- **The leak is detected and the appropriate ASVs and RCVs close completely so that the damaged pipeline segment is isolated within 10 minutes or less after the break, and fire fighting activities within the area of potentially severe damage can begin soon after the fire fighters arrive on the scene.**
- **Fire fighters arrive on the scene and are ready to begin fire fighting activities within 10 minutes or less after the break.**
- **Fire hydrants are accessible in the vicinity of the potentially severe damage radius.**
- **Block valves close in time to reduce the heat flux at the potentially severe damage radius to 2.5 kW/m2 (800 Btu/hr ft2) within 20 minutes or less after the break.**

29. Comment: *"Inaccurate Benefit Analysis"* **INGAA**

Risk analysis results discussed in Section 3.1.4 show that without fire fighter intervention following natural gas pipeline releases, the swiftness of block valve closure has no effect on mitigating potential fire damage to buildings and personal property in HCAs. Block valve closure swiftness also has no effect on reducing building and personal property damage costs because thermal radiation is most intense immediately following the break. Consequently, without fire fighter intervention, there is no quantifiable benefit in terms of cost avoidance for damage to buildings and personal property attributed to block valve closure swiftness in natural gas pipelines. However, when combined with fire fighter intervention the swiftness of block valve closure has a potentially beneficial effect on mitigating fire damage to buildings and personal property in HCAs. Closing block valves sooner decreases the natural gas release rate which in turn reduces the thermal radiation intensity at a specific location and point in time. After the heat flux at a particular location decreases to an acceptable level, fire fighters can safely initiate fire fighting activities.

30. Comment: *"Cost Benefit Analysis"* **INGAA**

Response from contractor: Cost benefits are discussed in Sec. 5.2.1. The following sentences from this section describe the conditions used to evaluate cost benefits. Risk analysis results presented in Section 3.1 demonstrate that there are avoided fire damage costs attributed to block valve closure swiftness following a guillotine-type break and subsequent fire in natural gas pipelines located in Class 1, Class 2, Class 3, and Class 4 HCAs. The magnitude of these avoided costs depends primarily on the type, configuration, and density of buildings located within the particular HCA and the replacement value of the buildings and property damaged by the fire, but also on the efforts of fire fighters to mitigate fire damage to buildings and property located within the potentially severe damage radius.

Although the cost for adding either RCV or ASV closure capability is considered a negative cost benefit because the swiftness of block valve closure has no effect on mitigating fire damage to buildings and property located within the potentially severe damage radius, positive cost benefits attributed to block valve closure swiftness may be realized when all of the following conditions are satisfied.

- **Fire fighters arrive on the scene and are ready to begin fire fighting activities within 10 minutes after the break.**
- **Fire hydrants are accessible and uniformly spaced around the perimeter of the potentially severe damage circle.**
- **Block valves close in time to reduce the heat flux at the potentially severe damage radius to 2.5 kW/m2 (800 Btu/hr ft2) within 20 minutes or less after the break.**

31. Comment: *"Significant Over Conservativeness in the Benefit Determination"* **INGAA**

Response from contractor: The worst case scenarios considered in this study are based on immediate ignition following the guillotine-type break of the natural gas pipeline. The analysis considered worst case release scenarios for areas with a maximum housing density based on International Zoning Code criteria. The building densities and construction features used in the study match the High Consequence Areas (HCAs) in Class 1, 2, 3, and 4 locations. For natural gas pipeline releases, the impact to buildings and property are based on applicable fire science practices described in the report. Release scenarios based on less conservative assumptions that reflect actual site-specific conditions need to be considered when (1) performing risk analyses for particular pipeline segments and (2) evaluating technical, operational, and economic feasibility

32. Comment: *"Underestimation of Valve Costs"* **INGAA**

Response from contractor: Cost values provided in the October 26, 2012 comments by INGAA include costs for (1) installing a new valve and (2) automating the new valve. Table 4.1 of the report only provides estimated costs for adding automatic closure capability to block valves that are installed in newly constructed or fully replaced pipelines. The cost for installing a new valve was not included in Table 4.1 because the study applies to newly constructed or fully replaced pipelines in which block valves must be installed in accordance with valve spacing requirements in 49 CFR192. Consequently, the cost benefit analysis discussed in Section 5.1.1 only considers costs for automating block valves because block valves (with or without automation) must be installed. Valve automation costs in Table 4.1 reflect the cost data in both INGAA 2012 and AGA 2011 publications. Consideration of site-specific variables including actual valve automaton costs in the risk analysis is essential in determining whether the cost benefit is positive or negative and whether automating valves in newly constructed or fully replaced pipelines is economically feasible.

Consequently, the technical, operational, and economic feasibility and potential cost benefits of automating valves in newly constructed or fully replaced pipelines need to be evaluated on a case-by-case basis.