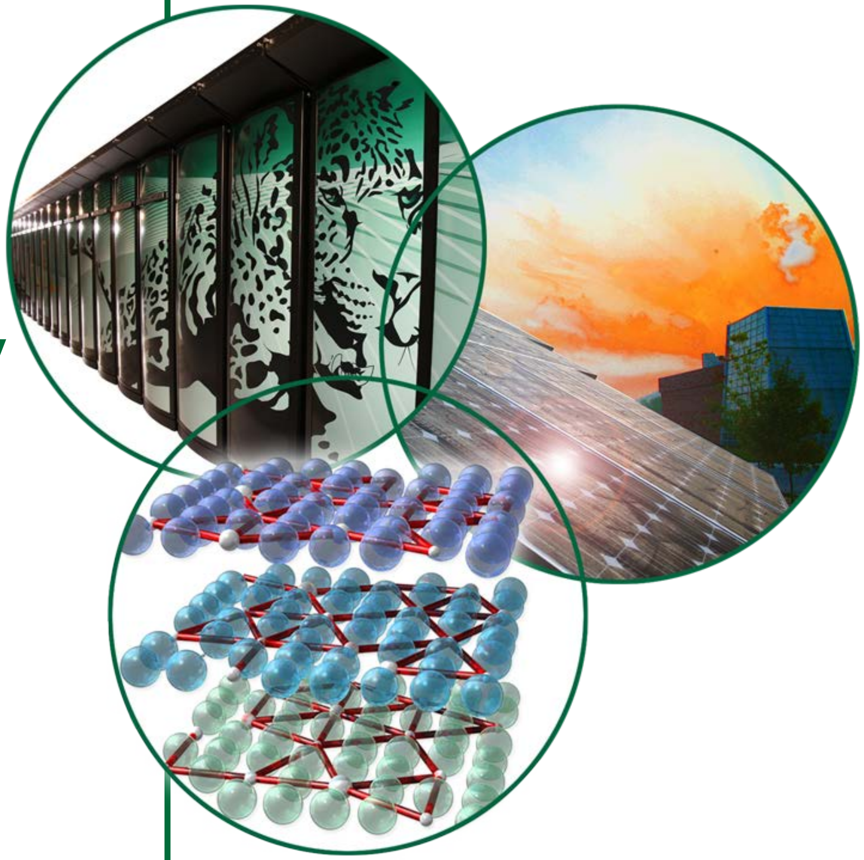
Studies for the Requirements of Automatic and Remotely Controlled Shutoff Valves on Hazardous Liquid and Natural Gas Pipelines with Respect to Public and Environmental Safety



Simon D. Rose, C. Barry Oland, Herb L. Grant, Mark D. Lower, Mark A. Spann, John R. Kirkpatrick, and C. David Sulfredge

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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Webinar Topics

- Introduction
- Results Summary
- Risk Analysis
- Natural Gas Pipeline Releases
- Hazardous Liquid Pipeline Releases
- Fire Science and Potential Consequences
- Assessment Methodologies
  - Natural Gas Pipeline Releases with Ignition
  - Hazardous Liquid Pipeline with Ignition
  - Hazardous Liquid Pipeline without Ignition
- Feasibility Evaluations
- Potential Consequence Reduction Strategies
- Questions

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Introduction

- In March 2012, PHMSA requested assistance from ORNL in preparing a report titled:

  Studies for the Requirements of Automatic and Remotely Controlled Shutoff Valves on Hazardous Liquids and Natural Gas Pipelines with Respect to Public and Environmental Safety

- Studies apply to natural gas and hazardous liquid transmission lines and addresses:

  1. Requirements of the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Section 4 – Automatic/Remote-Controlled Shut-off Valves
  2. Recommendations on Automatic Shutoff Valves (ASVs) and Remote Control Valves (RCVs) from NTSB Investigation of 2010 San Bruno natural gas pipeline accident

Introduction

- Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Section 4:

  U.S. Department of Transportation (DOT) to require by regulation the use of automatic or remotely controlled shutoff valves, or equivalent technology, where it is economically, technically, and operationally feasible on hazardous liquid and natural gas transmission pipeline facilities constructed or entirely replaced . . .

- NTSB Recommendation P-11-11 (San Bruno):

  Amend Title 49 Code of Federal Regulations Section 192.935(c) to directly require that automatic shutoff valves (ASV) or remote control valves (RCV) be installed in high consequence areas and in Class 3 and 4 locations and spaced at intervals that consider population factors listed in regulations.

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Work Summary

- Studies assess the effectiveness of block valve closure swiftness in mitigating the consequences of natural gas and hazardous liquid pipeline releases on public and environmental safety.

- Studies also evaluate the technical, operational, and economic feasibility and potential cost benefits of installing ASVs and RCVs in newly constructed and fully replaced pipelines.

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Scope and Activities

- Study the ability of transmission pipeline facility operators to respond to a hazardous liquid or gas release from a pipeline segment located in high consequence areas (HCAs), Class 3 and 4 areas for natural gas transmission.
- Study the economic, technical, and operational feasibility of requiring the installation of ACVs or RCVs on newly constructed or entirely replaced facilities.
- Analyze the requirements of valve spacing and the effects of requiring a more stringent minimum spacing of ASVs or RCVs.
- Evaluate fire science behind initial accident rupture and response time provided by ASVs and RCVs by developing models that could demonstrate potential benefits of rapid response time.
- Conduct cost, risk, and benefit analysis of installing ASVs and RCVs in HCAs, Class 3 and 4 areas.

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Analysis Approach

- Risk analyses of hypothetical pipeline releases: worst-case guillotine-type break (design basis accident) to assess:

  (1) Fire damage to buildings/property in Class 1, 2, 3 and 4 HCAs from natural gas pipeline releases and subsequent ignition of released gas

  (2) Fire damage to buildings/property in HCAs designated high population areas/other populated areas from hazardous liquid pipeline releases and subsequent ignition of released propane.

  (3) Socioeconomic and environmental damage in HCAs caused by hazardous liquid pipeline releases of crude oil.

- Analysis approach:
  – Uses engineering principles/fire science practices to characterize thermal radiation effects on buildings/humans, quantify damage cost.
  – Consistent with risk assessment standards developed by industry/incorporated into Federal gas pipeline safety regulations.

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Federal Pipeline Safety Regulations

- Requirements for pipeline facilities and the transportation of gas are defined in 49 CFR 192.
- Requirements for pipeline facilities used in the transportation of hazardous liquids or carbon dioxide are defined in 49 CFR 195.
- Requirements for oil spill response plans to reduce the environmental impact of oil discharged from onshore oil pipelines are defined in 49 CFR 194.

Parameters and Boundaries

- Studies evaluated the following potential effects of unintended releases from natural gas and hazardous liquid pipelines:
  - ✓ Human impacts including personal injuries and fatalities
  - ✓ Property damage
  - ✓ Environmental impacts
  - ✓ Supply losses and business interruptions

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Parameters and Boundaries (cont'd)

- Studies did not evaluate the following potential effects on humans, property, and the environment:
  - ✓ Blast
  - ✓ Overpressure
  - ✓ Earthquake-like
  - ✓ Shrapnel
- These effects occur immediately after the break.
- RCVs and ASVs, which typically require several minutes to close, cannot mitigate these hazards.

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Results Summary: ASVs/RCVs Installation Feasible with Case-by-Case Consideration

- Hypothetical pipeline releases studied show ASVs/RCVs installation in newly constructed/fully replaced gas and liquid transmission lines are technically, operationally, and economically feasible (positive cost benefit).

- This may not apply to all newly constructed/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 these studies.

- Consequently, technical, operational, economic feasibility (and potential cost benefits) of installing ASVs/RCVs needs evaluation on case-by-case basis.

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Results Summary: Benefits of Swift Block Valve Closure

- Decreasing the total volume of released product reduces overall impacts on public and environmental safety. Installing ASVs/RCVs can potentially be an effective strategy to mitigate consequences of unintended pipeline releases.
- Block valve closure has no effect on preventing pipeline failure or preventing remaining product inside isolated pipeline segments escaping into environment by blow-down or drain-down.
- Block valve closure swiftness is most effective in mitigating damage resulting from a pipeline release (and subsequent fire) when damaged pipeline segment is isolated and thermal radiation produced by fire declines in time to enable emergency responders to safely start fire fighting activities immediately upon arrival.

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Results Summary: Benefits of Swift Block Valve Closure

- The benefits in terms of cost avoidance (gas and liquid with ignition) attributed to swiftness of block valve closure increase as the time to isolate damaged pipeline segment decreases.

- Similarly, avoided cost of socioeconomic and environmental damage for hazardous liquid pipeline releases (without ignition) increase as time required to isolate damaged pipeline segment decreases.

- Positive effects of rapid block valve closure are only realized through combined efforts of pipeline operators and emergency responders.

RISK ANALYSIS

Risk Analysis

- Risk analyses were:
  - ✓ Used to evaluate the effectiveness of block valve closure swiftness on mitigating the potential consequences of a release
  - ✓ Based on hypothetical release scenarios in HCAs
- Risk analysis approach for natural gas pipelines is consistent with risk assessment standards developed by industry (ASME B31.8S) and incorporated into Federal pipeline safety regulations.
- Risk analyses are based on engineering principles and fire science practices.

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Risk Analysis (cont'd)

- Risk analysis focused on consequence mitigation because block valve closure swiftness does not:
  - ✓ Prevent a rupture
  - ✓ Reduce the probability of rupture occurrence
- Risk analyses were used to:
  - ✓ Characterize thermal radiation effects on buildings and humans
  - ✓ Quantify the total damage cost of socioeconomic and environmental impacts

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Risk Analysis (cont'd)

- Potential consequences involved:
  - ✓ Fire damage to buildings, vehicles, and personal property
    - U.S. Census Bureau cost data for housing and vehicles
    - International Building, Fire, and Zoning Codes
  - ✓ Burn injuries to fire fighters and the public
    - heat flux intensity and exposure duration thresholds
    - NFPA, HUD, and other sources
  - ✓ Socioeconomic and environmental damage
    - EPA Basic Oil Spill Cost Estimation Model
    - Cleanup costs from recent spills
- Consequence modeling focused on case studies for hypothetical release scenarios with and without ignition.

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Risk Analysis for Releases with Ignition

- Potential fire consequences and thermal radiation effects resulting from unintended releases evaluated for:
  - ✓ Natural gas pipelines in HCAs and Class 3 and 4 areas
  - ✓ Hazardous liquid pipelines in HCAs – butane, gasoline, propane, and propylene
- Analysis only considered worst-case release scenarios.
  - ✓ Guillotine-type break
  - ✓ Immediate ignition
  - ✓ Consistent with the design basis accident used to develop the Potential Impact Radius (PIR) equation in 49 CFR 192.903.

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Potential Impact Radius (PIR)

- As discussed in 49 CFR 192.903, the term PIR means the radius of a circle within which the potential failure of a pipeline could have significant impact on people or property. The PIR is determined by:
- $PIR = 0.69(pd^2)^{1/2}$
  - *PIR is radius of a circular area in feet surrounding point of failure*
  - *p is maximum allowable operating pressure (MAOP) in the pipeline segment in psi*
  - *d is the nominal diameter of the pipeline (inches)*
  - A potential impact circle is a circle of radius equal to the PIR
- 0.69 is the factor for natural gas and will vary for other gases depending upon their heat of combustion

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Risk Analysis for Releases without Ignition

- Analysis of potential socioeconomic and environmental effects resulting from unintended releases of crude oil (spill) from guillotine-type breaks in hazardous liquid pipelines in HCAs.
  - ✓ Commercially navigable waterway
  - ✓ Unusually sensitive areas (USAs) – drinking water or ecological resource areas

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NATURAL GAS PIPELINE RELEASES

Natural Gas Pipeline Releases

- A natural gas pipeline release is subdivided into the following sequential phases:
  1. Detection
  2. Block Valve Closure
  3. Blowdown
- The total discharge volume equals the sum of the volumes released during each phase.
- Immediately following a guillotine-type break, the gas begins flowing rapidly through the break and into the surrounding atmosphere.

Natural Gas Pipeline Releases (cont'd)

- The escaping natural gas creates a highly turbulent mushroom shaped vapor cloud that increases in height above the release point due to the source momentum and buoyancy.
- For buried pipelines, the escaping natural gas ejects the overlying soil forming a crater of a size and shape which influences the behavior of the released gas.
- As the release continues, the natural gas jet feeds the vapor cloud and entrains air that may contain ejected soil particles. However, without an ignition source, the escaping gas disperses into the atmosphere.

Natural Gas Pipeline Releases (cont'd)

- If ignition of the released natural gas occurs immediately, or shortly after, the guillotine break, a transient fireball that typically lasts 30 seconds or less leaving a quasi steady-state fire that continues to burn until all of the escaping natural gas is consumed.
- The possibility of a significant flash fire resulting from delayed remote ignition of the released natural gas is extremely low due to the buoyant nature of the vapor which generally precludes the formation of a persistent flammable vapor cloud at ground level.

Natural Gas Pipeline Releases (cont'd)

- Consequently, the dominant hazard from a natural gas pipeline release is thermal radiation from a sustained jet fire.
- Fireballs and jet fires have the potential to injury humans, damage property, and impact the environment in the vicinity of the break.

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Natural Gas Pipeline Releases (cont'd)

- Flow through each line segment may vary depending on:
  - ✓ Location and closure status of block valves
  - ✓ Distance between the break and the block valves
  - ✓ Compressor stations and connections with other pipelines
- These boundary conditions determine whether the flow through the pipeline at the break decreases to zero, or transitions to a quasi steady-state condition.
- The size and intensity of a fire depends on the effective rate of gas release which is primarily influenced by the pressure differential and the size and shape of the break (guillotine-type break is considered worst case).

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Natural Gas Pipeline Releases (cont'd)

- For worst-case, guillotine-type breaks, where the effective hole size is equal to the line pipe diameter, the governing parameters are the:
  - ✓ Line pipe diameter
  - ✓ Internal operating pressure at the time of the break
- Analysis quantifies the impacts of these parameters on the affected area by characterizing time-dependent radiant thermal intensities at various separation distances from the break.

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HAZARDOUS LIQUID PIPELINE RELEASES

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Hazardous Liquid Pipeline Releases

- A hazardous liquid pipeline release is subdivided into the following sequential phases:
  1. Detection
  2. Continued Pumping
  3. Block Valve Closure
  4. Pipeline Drain Down
- The total discharge volume equals the sum of the volumes released during each phase.
- For worst-case, guillotine-type breaks, the effective hole size is equal to the line pipe diameter.

Hazardous Liquid Pipeline Releases (cont'd)

- The amount of material released following a hazardous liquid pipeline break is influenced by the following factors:
  - ✓ Type of liquid
  - ✓ Operating pressure of the pipeline
  - ✓ Size and position of the hole through which the liquid is released
  - ✓ Rate at which the liquid is being pumped through the pipeline
  - ✓ Response of the operator in terms of shutting off pumps and closing valves
  - ✓ Pipeline route and elevation profile
  - ✓ Location of the break relative to the pumps and block valves

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Hazardous Liquid Pipeline Releases (cont'd)

- Following a release, the liquid could:
  - ✓ Flash on release of pressure to form a vapor cloud containing a fine mist of residual liquid droplets
  - ✓ Accumulate in a pool on the ground surface near the pipeline break
  - ✓ Create a stream that flows away from the release point
  - ✓ Soak into the surrounding soil
- Hazard mitigation for this type of release requires rapid detection, pump shutdown, and block valve closure.

Hazardous Liquid Pipeline Releases (cont'd)

- However, some amount of liquid in the pipeline will drain out of the broken line segments.
- Without ignition, the escaping liquid could adversely affect HCAs – waterway navigation, surface and ground water quality, and other aspects of the human and natural environments.
- If the released liquid ignites following the break, it could result in a pool fire, a flash fire, or, under certain conditions, a vapor cloud explosion.

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Hazardous Liquid Pipeline Releases (cont'd)

- Pool fires can:
  - ✓ Spread out in all directions on level ground
  - ✓ Flow in a particular path depending on the terrain

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FIRE SCIENCE

Fire Science and Potential Fire Consequence Models

- Fire is a combustion or burning process accompanied by flame in which substances combine chemically with oxygen from the air and typically evolve bright light, heat, and smoke.
- A fuel is any substance that can undergo combustion.
- The time and energy required for ignition to occur is a function of the energy of the ignition source, the thermal inertia of the fuel, the minimum ignition energy, and the geometry of the fuel.

Fire Science and Potential Fire Consequences (cont'd)

- For fuel to reach its ignition temperature, the heat source itself must have a temperature higher than the fuel's ignition temperature.
- Fire can spread either by direct flame impingement or by remote ignition of adjacent fuel packages through heat transfer by conduction, convection, or radiation.

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Fire Science and Potential Fire Consequences (cont'd)

- Key strategic considerations for fire fighters and other emergency responders to a pipeline release and fire are:
  - ✓ Life safety
  - ✓ Extinguishment
  - ✓ Property conservation
- Upon arrival at the scene, when resources are often limited, initial response typically focuses on life safety as the number one priority, followed by extinguishment and then property conservation.

Fire Science and Potential Fire Consequences (cont'd)

- Response time by fire fighters and emergency personnel involves the following sequential components:
  1. Ignition
  2. Combustion
  3. Discovery, call processing and dispatch time
  4. Turnout time
  5. Drive time
  6. Setup time
  7. Combat
  8. Extinguishment

Fire Science and Potential Fire Consequences (cont'd)

- Based on U.S. Fire Administration data from 2000 and 2001, response times were less than:
  - ✓ 5 min. nearly 50% of the time
  - ✓ 8 min. about 75% of the time
- Nationally, average response times were generally less than 8 min.
- The overall 90th percentile was less than 11 min.
- For these studies, fire fighters arrive on scene within 10 minutes after the break.

Fire Science and Potential Fire Consequences (cont'd)

- The *2008 Emergency Response Guidebook* published by DOT states that:
  - ✓ Natural gas pipeline fires should not be extinguished unless the leak can be stopped
  - ✓ Use of water spray when fighting a hazardous liquid pipeline fire may be ineffective for fires involving very low flash point materials such as gasoline
- The *Pipeline Emergency Response Guidelines* is published in 2011 by the Pipeline Association for Public Awareness (PAPA) for reference prior to and during a pipeline emergency.

Fire Science and Potential Fire Consequences (cont'd)

- This PAPA publication includes an incident response checklist that is subdivided into the following four action categories applicable to fire fighters and other emergency response personnel:

1. Assess the Situation
2. Protect People, Property, and the Environment
3. Call for Assistance of Trained Personnel
4. Work Together with the Pipeline Operator

Fire Science and Potential Fire Consequences (cont'd)

- This checklist includes the following additional guidance.

  "Pipeline operators will concentrate on shutting down pipeline facilities. Responders should focus on protecting the public and isolating or removing ignition sources."

- Appendix A recommends a minimum evacuation distance equal to 3.3 (PIR), e.g.:
  - ✓ 474 feet for 12-in. natural gas pipelines that operate at 300 psig
  - ✓ 3,709 feet for 42-in. pipelines that operate at 1,500 psig

Thermal Radiation Effects (cont'd)

- Thermal radiation is the primary mechanism for injury or damage from fire.
- Thermal radiation hazards from a hydrocarbon fire depend on:
  - ✓ Composition of the hydrocarbon
  - ✓ Size and shape of the fire
  - ✓ Duration of the fire
  - ✓ Proximity to the object at risk
  - ✓ Thermal characteristics of the object exposed to the fire

Thermal Radiation Effects (cont'd)

- Potential fire damage to buildings, fire fighting activities, and open spaces where people congregate were established based on the following heat flux thresholds:
  - ✓ Exposure to a heat flux of 1.4 kW/m^2 (450 $Btu/hr\ ft^2$) is considered acceptable for outdoor, unprotected facilities or open spaces where people congregate.
  - ✓ Exposure to a heat flux of 2.5 kW/m^2 (800 $Btu/hr\ ft^2$) is considered acceptable while conducting continuous fire fighting and emergency response activities.

Thermal Radiation Effects (cont'd)

- ✓ Exposure of a building to a heat flux of 15.8 kW/m^2 (5,000 Btu/hr ft^2) is considered acceptable for an extended period of time (30 minutes) without burning and the threshold for minor damage to buildings.
- ✓ Exposure of a building to a heat flux of 31.5 kW/m^2 (10,000 Btu/hr ft^2) is considered acceptable for an extended period of time (15 minutes) without burning and the threshold for moderate damage to buildings.
- ✓ Exposure to a heat flux of 40.0 kW/m^2 (12,700 Btu/hr ft^2) 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 PIR.

Thermal Radiation Effects on Humans

- When radiant heating raises the temperature of the skin, the higher the radiant flux, the faster damage will occur:
  - ✓ A heat flux of 2 kW/m^2 (635 $Btu/hr\ ft^2$) will not cause blisters
  - ✓ A heat flux of 10 kW/m^2 (3,175 $Btu/hr\ ft^2$) will blister in 12 seconds
  - ✓ A heat flux of 20 kW/m^2 (6,350 $Btu/hr\ ft^2$), typically associated with flashover, is sufficient to ignite clothing or cause severe burns or death by brief thermal exposure

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Thermal Radiation Effects on Humans (cont'd)

- NTSB defines *fatal injury* as any injury that results in death within 30 days of the accident.
- NTSB defines *serious injury* as an injury that:

(1) Requires hospitalization for more than 48 hours, commencing within 7 days of the date the injury was received;

(2) Results in a fracture of any bone (except simple fractures of fingers, toes, or nose);

(3) Causes severe hemorrhages or nerve or tendon damage;

(4) Involves any internal organ; or

(5) Involves second- or third-degree burns, or any burn affecting more than 5% of the body surface.

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Thermal Radiation Effects on Buildings and Construction Materials

- The following terms were used to classify structural damage to houses following the natural gas transmission pipeline rupture and fire in San Bruno, California on September 9, 2010:

  (1) Severe indicated that a house was not safe to occupy and most likely would need to be demolished or completely renovated prior to occupancy

  (2) Moderate indicated that a house had substantial damage and repairs would be necessary prior to occupancy

  (3) Minor indicated that a house had the least amount of damage and could be legally occupied while repairs were being made

ASSESSMENT METHODOLOGIES

NATURAL GAS PIPELINE RELEASES WITH IGNITION

Assessment Methodology and Results for Natural Gas Pipeline Releases

- Fluid mechanics and heat transfer principles were used to develop separation distance vs. time plots based on computed time-dependent heat flux data.
- The plots were used to:
  - ✓ Quantify fire damage to buildings and property resulting from hypothetical releases in Class 1 and 2 HCAs and Class 3 and 4 areas
  - ✓ Determine the effectiveness of block valve closure swiftness in mitigating fire damage

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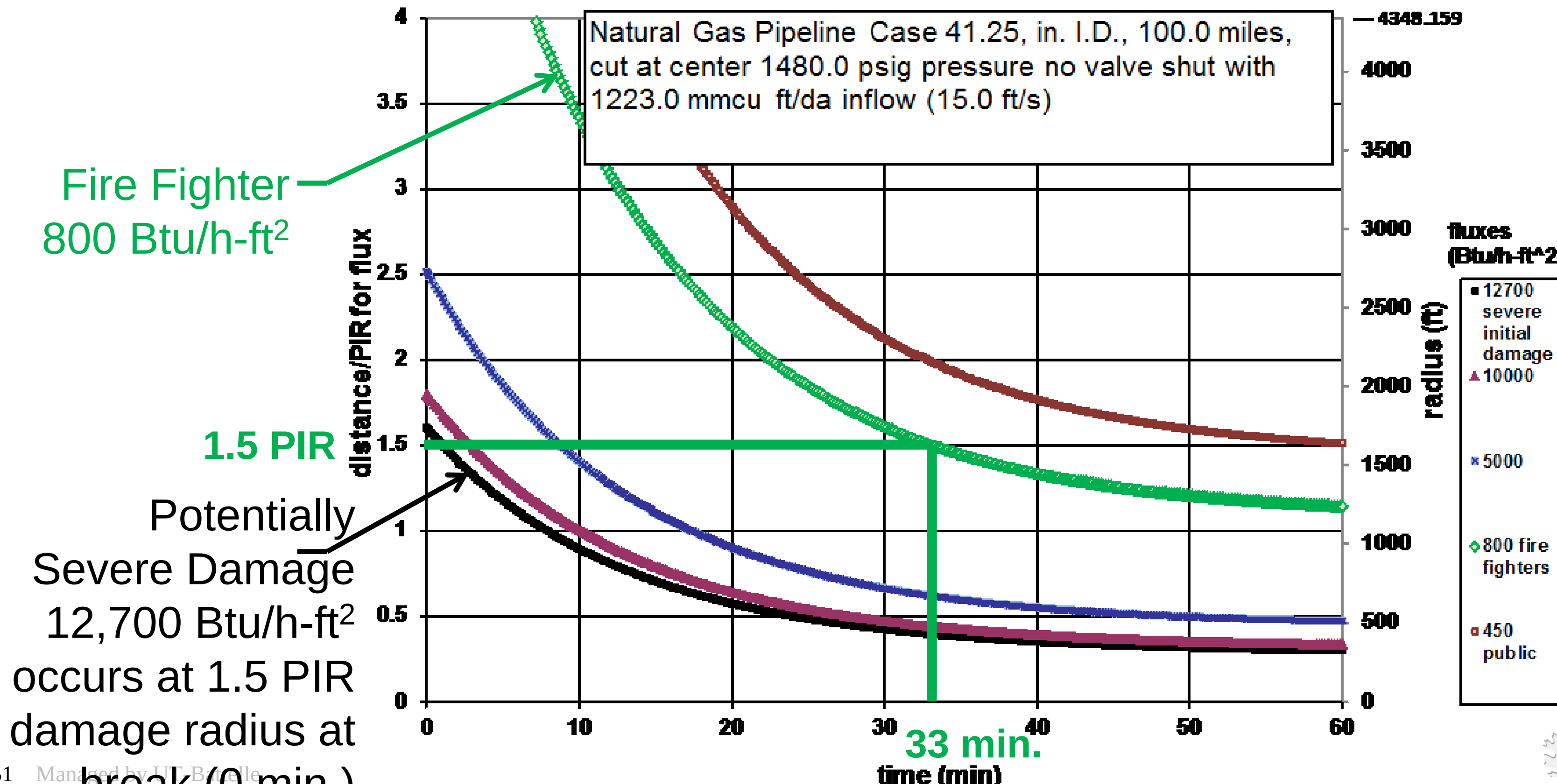
Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Plot for 42-in. natural gas pipeline release with MAOP = 1,480 psig & no block valve closure after break.



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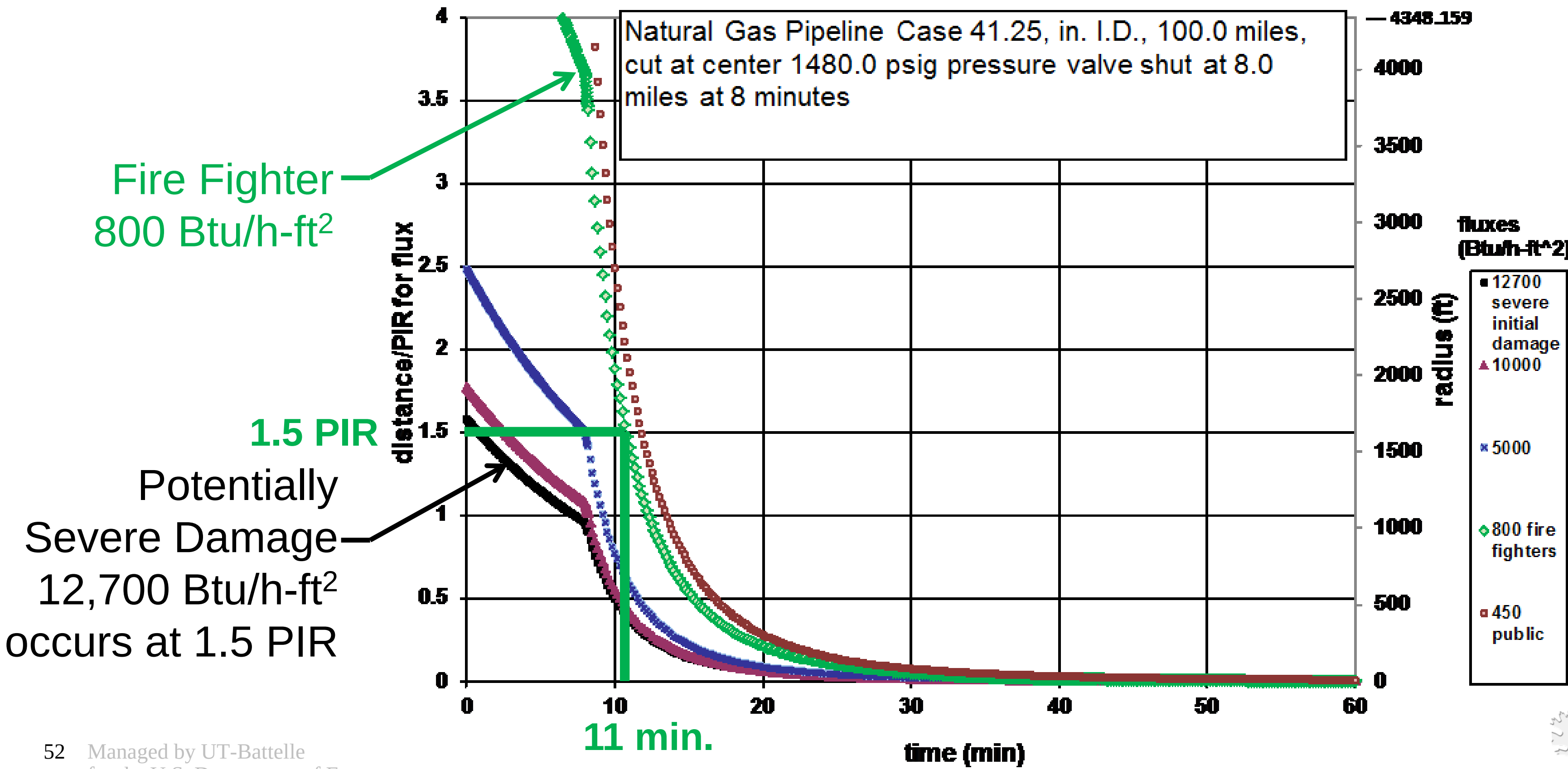
Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Plot for 42-in. natural gas pipeline release in Class 3 HCA with MAOP = 1,480 psig and block valve closure 8 min. after break.



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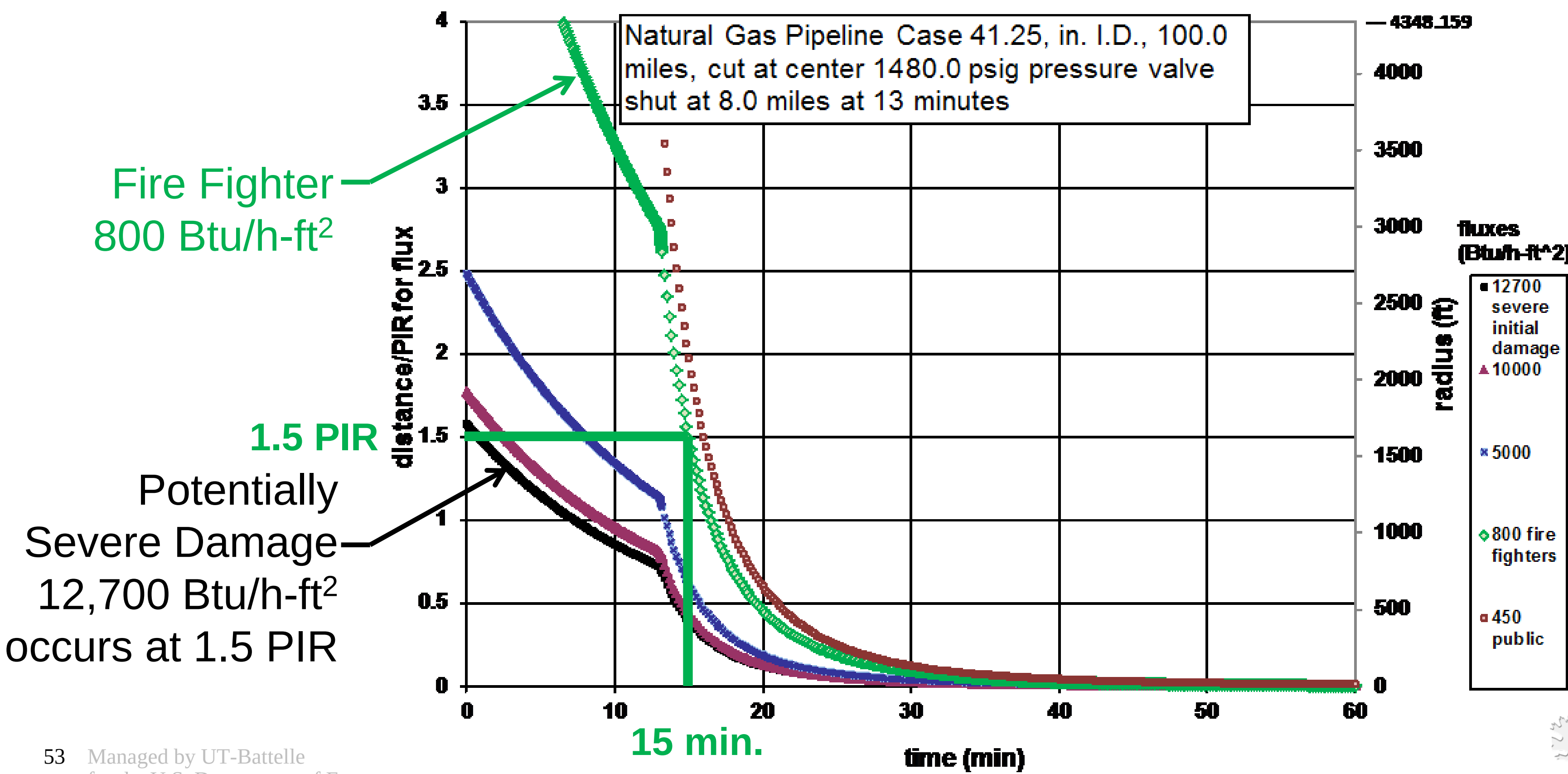
Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Plot for 42-in. natural gas pipeline release in Class 3 HCA with MAOP = 1,480 psig and block valve closure 13 min. after break.



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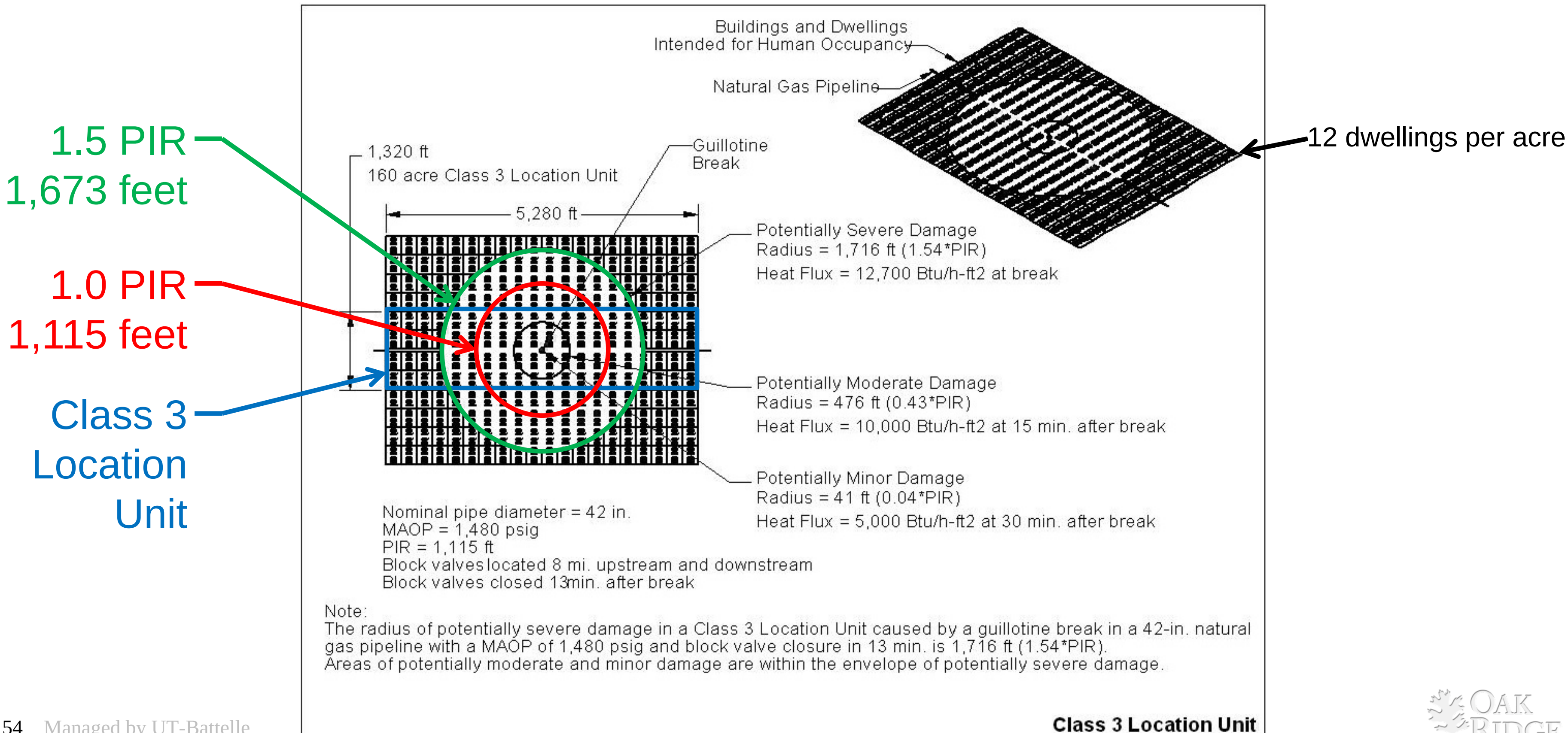
Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Potentially severe damage radius for 42-in. natural gas pipeline release in Class 3 HCA with MAOP = 1,480 psig and block valve closure 13 min. after break.



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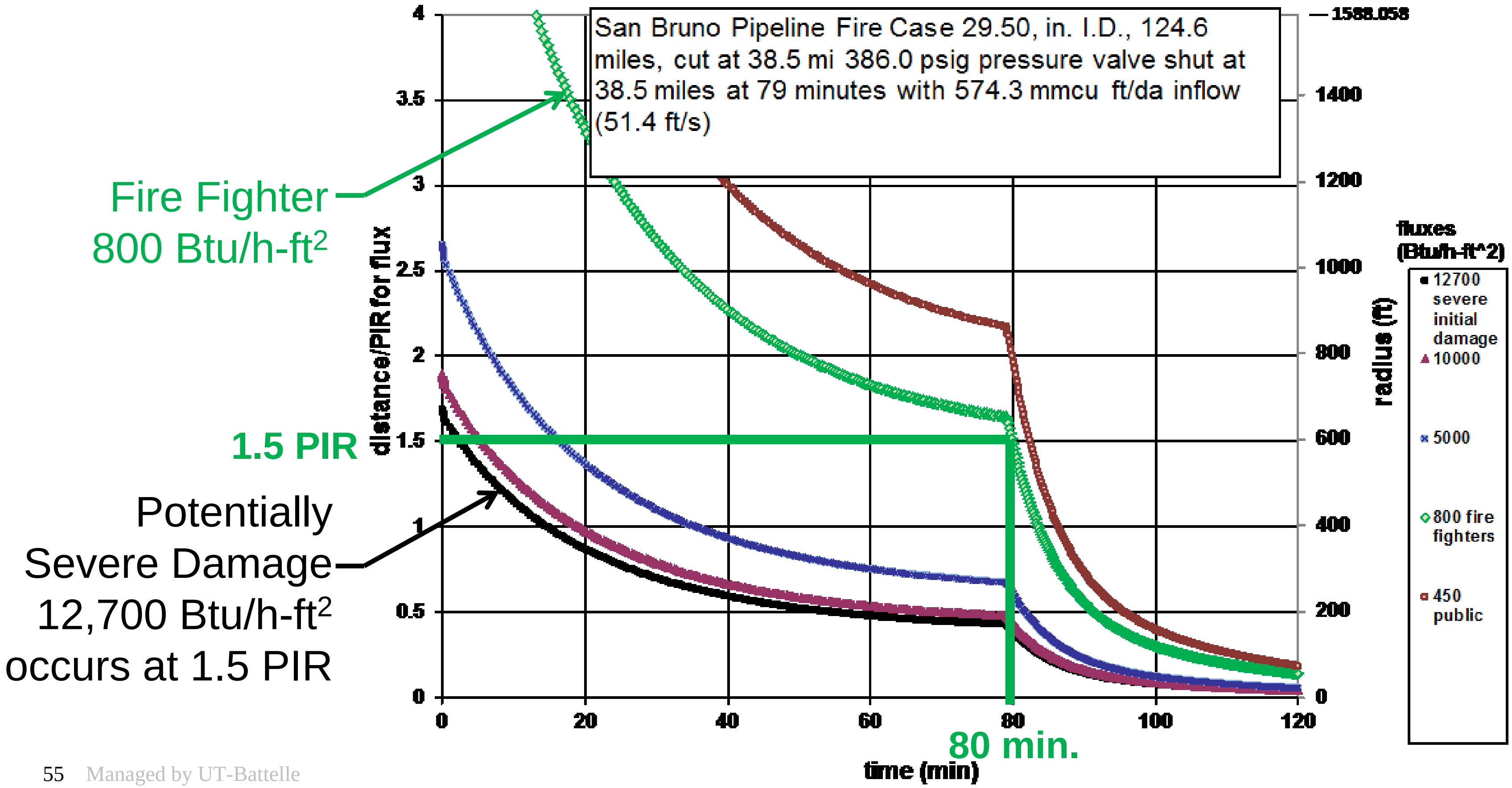
Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Plot for 30-in. natural gas pipeline release in San Bruno with MAOP = 386 psig and block valve closure 79 min. after break.



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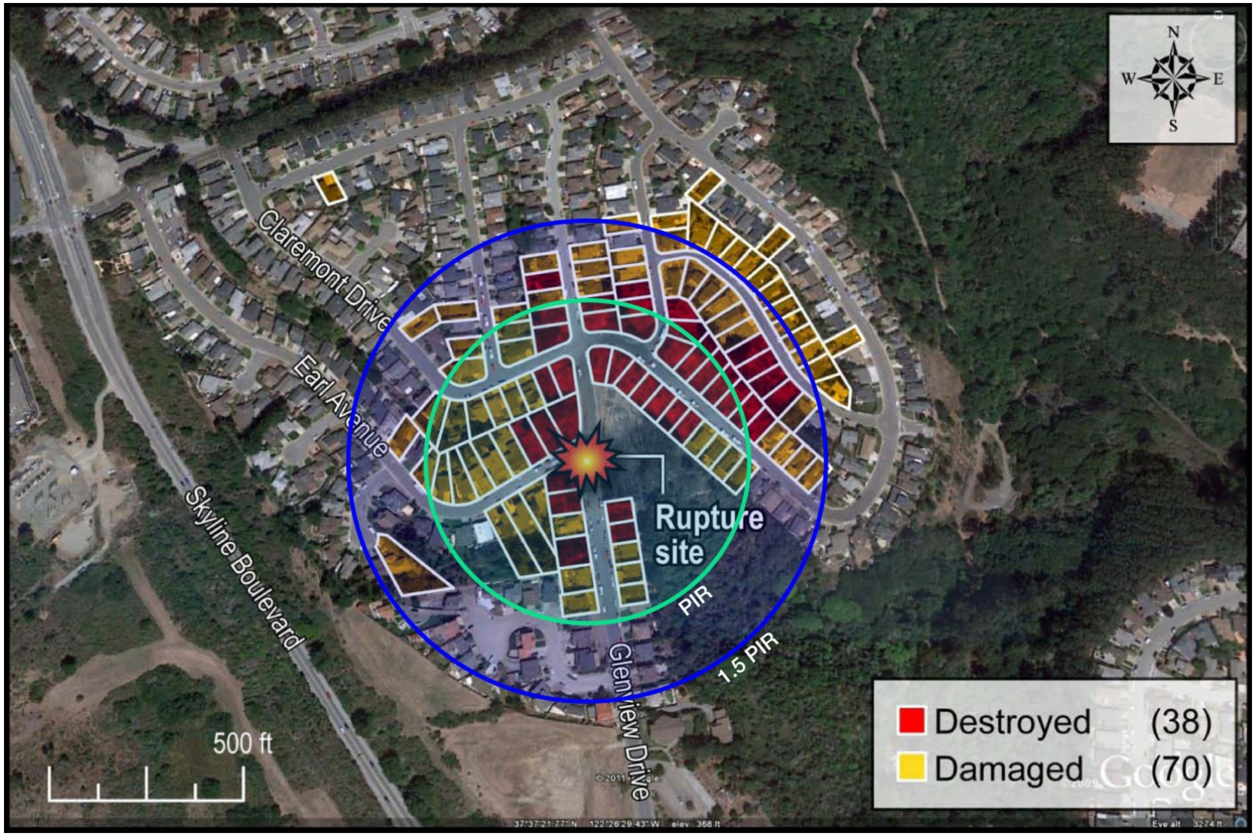
Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Potentially severe damage radius for 30-in. natural gas pipeline release in San Bruno with MAOP = 386 psig and block valve closure 79 min. after break.



PIR = 407 ft.
1.5 PIR = 610 ft.

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Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Without fire fighter intervention, the swiftness of block valve closure has no effect on mitigating potential fire damage to buildings and property in Class 1 and 2 HCAs and Class 3 and 4 areas because:
  - ✓ Immediately following the break, the heat flux at 1.5 PIR exceeds the potentially severe damage threshold of 40.0 kW/m^2 (12,700 $Btu/hr\ ft^2$)
  - ✓ Potentially severe damage occurs before block valves can isolate the damaged pipeline segment

Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- The benefit in terms of cost avoidance is based on the ability of fire fighters to mitigate fire damage to buildings and personal property located within a distance of approximately 1.5 PIR by conducting fire fighting activities as soon as possible upon arrival at the scene – 10 minutes after the break.
- The ability of fire fighters to conduct fire fighting activities within a distance of approximately 1.5 PIR is only possible if the heat flux at this distance is below 2.5 kW/m^2 (800 $Btu/hr\ ft^2$) and fire hydrants are available at locations where needed.

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Assessment Methodology and Results for Natural Gas Pipeline Releases (cont'd)

- Block valve closure within 8 minutes after the break can result in a potential cost avoidance of at least $2M for 12-in. pipelines and $8M for 42-in. pipelines depending on the configuration of buildings within the Class 3 HCA.
- Delaying block valve closure by an additional 5 minutes reduces the cost avoidance by approx. 50%.
- Block valve closure in 8 minutes for 42-in. pipelines increases the time fire fighters can conduct fire fighting operations at 1.5 PIR by approx. 22 minutes.

ASSESSMENT METHODOLOGIES

HAZARDOUS LIQUID PIPELINE RELEASES WITH IGNITION

Assessment Methodology for Hazardous Liquid Pipeline Releases with Ignition

- Fluid mechanics and heat transfer principles were used to develop separation distance vs. time plots based on computed time-dependent heat flux data for a propane pool fire.
- The plots were used to:
  - ✓ Quantify fire damage to buildings and property resulting from hypothetical releases in HCAs – Highly Populated Areas and Other Populated Areas
  - ✓ Determine the effectiveness of block valve closure swiftness in mitigating fire damage

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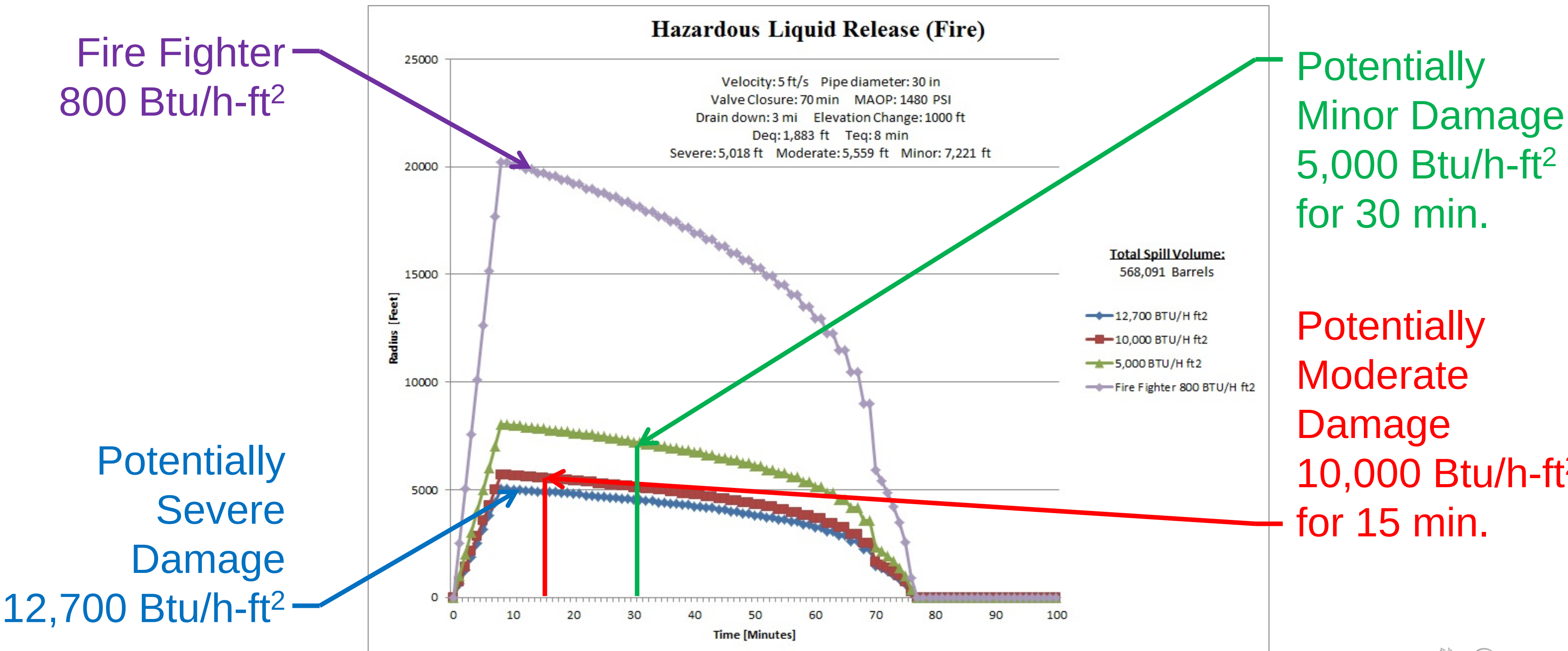
Results for Hazardous Liquid Pipeline Releases with Ignition

- Plot for 30-in. hazardous liquid pipeline release in HCA with MAOP = 1,480 psig, 1,000 ft elevation change, and block valve closure 70 min. after break.



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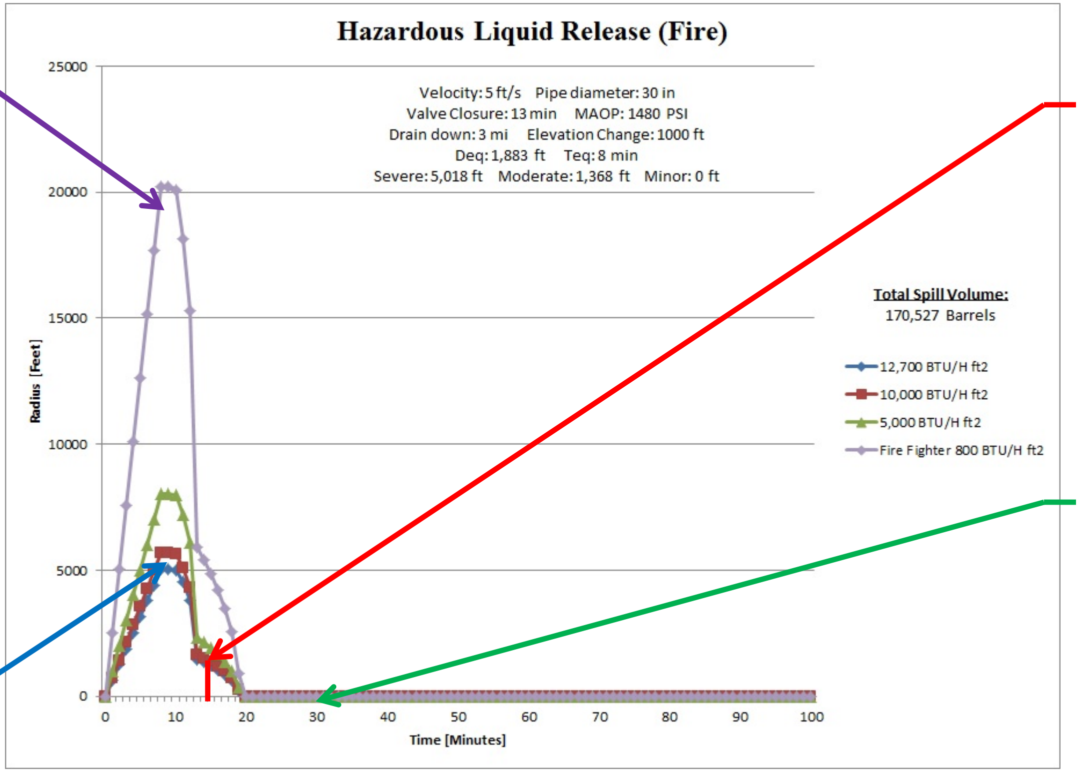
Results for Hazardous Liquid Pipeline Releases with Ignition (cont'd)

- Plot for 30-in. hazardous liquid pipeline release in HCA with MAOP = 1,480 psig, 1,000 ft elevation change, and block valve closure 13 min. after break.

Fire Fighter 800 Btu/h-ft^2

Potentially Severe Damage 12,700 Btu/h-ft^2



Potentially Moderate Damage 10,000 Btu/h-ft^2 for 15 min.

Potentially Minor Damage 5,000 Btu/h-ft^2 for 30 min.

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Results for Hazardous Liquid Pipeline Releases with Ignition (cont'd)

- D_{eq} is defined as the maximum equilibrium diameter where release rate equals regression (burn) rate.
- The potentially severe damage radius equals 2.6 D_{eq} because the heat flux within this area exceeds the severe damage threshold (12,700 Btu/hr ft^2).
- Areas of potentially moderate and minor damage are reduced or eliminated as the block valves closure time decreases.

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Results for Hazardous Liquid Pipeline Releases with Ignition (cont'd)

- The swiftness of block valve closure has a significant effect on mitigating potential fire damage resulting from liquid propane pipeline releases in HCAs.
- The benefit in terms of cost avoidance increases as the duration of the block valve shutdown phase decreases.

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Results for Hazardous Liquid Pipeline Releases with Ignition (cont'd)

- Risk analysis results for a hypothetical 30-in. hazardous liquid pipeline release of propane in a HCA show that the estimated avoided cost of moderate building and property damage resulting from block valve closure in 13 minutes rather than 70 minutes after the break is over $300M.

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ASSESSMENT METHODOLOGIES

HAZARDOUS LIQUID PIPELINE RELEASES WITHOUT IGNITION

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Assessment Methodology for Hazardous Liquid Pipeline Releases without Ignition

- Fluid mechanics principles were used to:
  - ✓ Compute time-dependent discharge from hazardous liquid pipelines following a guillotine-type break
  - ✓ Determine the effects that detection, continued pumping, and block valve closure duration have on a worst-case discharge (design basis accident)

Assessment Methodology for Hazardous Liquid Pipeline Releases without Ignition (cont'd)

- Worst-case discharge is defined in 49 CFR 194 as:

  maximum release time plus maximum shutdown response time

  multiplied by

  maximum flow rate

  plus

  largest line drainage volume after shutdown

- Flow rate remains constant through the detection, continued pumping, and block valve closure phases.
- Flow rate during the pipeline drain down phase is a function of the elevation profile of the pipeline.

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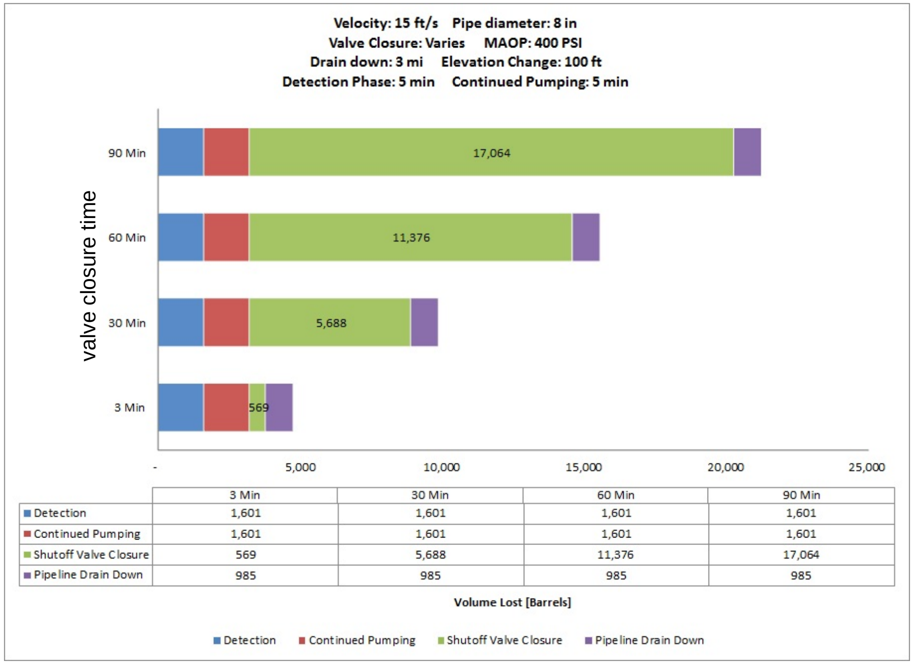
Results for Hazardous Liquid Pipeline Releases without Ignition

- Discharge volumes for hypothetical 8-in. hazardous liquid pipeline releases of crude oil in HCAs with MAOP = 400 psig, 100 ft elevation change, and block valve closure 13 min. to 100 min. after break*.

Estimated Socioeconomic and Environmental Damage Cost is $36,653/barrel



	3 Min	30 Min	60 Min	90 Min
Detection	1,601	1,601	1,601	1,601
Continued Pumping	1,601	1,601	1,601	1,601
Shutoff Valve Closure	569	5,688	11,376	17,064
Pipeline Drain Down	985	985	985	985

Damage Cost	(Time after break)
$779M	(100 min.)
$570M	(70 min.)
$362M	(40 min.)
$174M	(13 min.)

*100 min. time after break = 5 min. detection + 5 min. pump shutdown + 90 min. valve closure
70 min. time after break = 5 min. detection + 5 min. pump shutdown + 60 min. valve closure
40 min. time after break = 5 min. detection + 5 min. pump shutdown + 30 min. valve closure
13 min. time after break = 5 min. detection + 5 min. pump shutdown + 3 min. valve closure

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Assessment Methodology and Results for Hazardous Liquid Pipeline Releases without Ignition (cont'd)

- Potential consequences and effects on the human and natural environments resulting from a hazardous liquid pipeline release generally involve socioeconomic and environmental impacts.
- The amount of oil spilled can have a profound effect on the cleanup costs – the more oil spilled, the more oil there is to remove or disperse, and the more expensive the cleanup operation.

Assessment Methodology and Results for Hazardous Liquid Pipeline Releases without Ignition (cont'd)

- However, cleanup costs on a per-unit basis decrease significantly with increasing amounts of oil spilled.
- Smaller spills are often more expensive on a per-unit basis than larger spills because of the costs associated with setting up the cleanup response, bringing in the equipment and labor, as well as bringing in the experts to evaluate the situation.
- The unit cleanup cost for Enbridge Line 6B release in 2010 (~20,000 barrels) was ~$38,000 per barrel.

Results for Hazardous Liquid Pipeline Releases without Ignition (cont'd)

- Avoided damage costs for 8-in. crude oil pipeline release with MAOP = 400 psig and 100 ft elevation change in an environmentally sensitive HCA.

Block Valve Closure Time after Break, min.	Actual Damage Cost, $M	Avoided Damage Cost, $M
13	174	605
40	362	417
70	570	209
100	779	0

- A 30-minute delay in block valve closure increases damage cost by ~$200M.

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FEASIBILITY EVALUATIONS

Feasibility Evaluations

- Study results show that installing ASVs and RCVs in newly constructed and fully replaced natural gas and hazardous liquid pipelines is
  - ✓ Technically feasible
  - ✓ Operationally feasible
  - ✓ Economically feasible
- However, these conclusions do not apply to all newly constructed and fully replaced pipelines.

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Feasibility Evaluations (cont'd)

- 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.
- 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.

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Feasibility Evaluations (cont'd)

- Technical feasibility depends primarily on physical space limitations at the valve installation location.
- Sufficient space must be available for the:
  - ✓ Valve body
  - ✓ Actuators
  - ✓ Power source, sensors, and related electronic equipment
  - ✓ Personnel required to install and maintain the valve
  - ✓ Communications equipment that links the site to the control room (RCVs)

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Feasibility Evaluations (cont'd)

- Field evaluations by Texas Eastern Transmission Corporation show that RCVs are technically feasible because they:
  - ✓ Perform reliably
  - ✓ Perform as intended

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Feasibility Evaluations (cont'd)

- Installing of ASVs and RCVs in newly constructed or fully replaced pipelines is considered operationally feasible provided:
  - ✓ Communication links between RCV site and control room are continuous and reliable
  - ✓ Inadvertent and sudden block valve does not occur, since this could:
    - Disrupt service to critical customers
    - Cause damage to equipment from a pressure surge
- Operational feasibility evaluations may also need to consider workplace hazards for maintenance and repair activities.

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Feasibility Evaluations (cont'd)

- Operational feasibility evaluations also need to consider factors such as:
  - ✓ Remoteness and accessibility of the valve location
  - ✓ Effects of service disruptions for valve maintenance, repair, and testing
  - ✓ Possible travel delays caused by severe weather or traffic congestion
- Operators must consider downstream system demands when scheduling shutdowns for maintenance and repair.

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Feasibility Evaluations (cont'd)

- Meaningful economic feasibility evaluations and cost benefit analyses for specific pipeline segments need to be based on avoided damage costs and valve automation costs that reflect the actual pipeline design features and operating conditions.
- Consideration of site-specific variables is essential in determining whether:
  - ✓ Cost benefit is positive or negative
  - ✓ Installation of ASVs or RCVs in newly constructed or fully replaced pipelines is economically feasible

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POTENTIAL CONSEQUENCE REDUCTION STRATEGIES

Potential Consequence Reduction Strategies

- Installation of ASVs and RCVs in newly constructed and fully replaced pipelines can reduce overall impacts by decreasing the total volume of the release.
- However, block valve closure has no effect on preventing pipeline failure or stopping product that remains inside the isolated pipeline segments from escaping into the environment.
- Positive effects from rapid block valve closure are only realized through the combined efforts of pipeline operators and emergency responders.

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Potential Consequence Reduction Strategies (cont'd)

- For natural gas pipelines, installation of ASVs and RCVs can be effective provided all of the following conditions are satisfied.
  - ✓ The damaged pipeline segment is isolated within 10 minutes or less after the break
  - ✓ Fire fighters arrive on scene within 10 minutes or less after the break
  - ✓ Fire hydrants are accessible
  - ✓ Block valves close in time to reduce the heat flux at the potentially severe damage radius (1.5 PIR) to 2.5 kW/m^2 (800 $Btu/hr\ ft^2$) or less within 10 to 20 minutes after the break

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Potential Consequence Reduction Strategies (cont'd)

- For hazardous liquid pipelines with ignition, installing ASVs and RCVs can be effective provided the leak is detected and the appropriate ASVs and RCVs close completely so that the damaged pipeline segment is isolated within 15 minutes after the break.
- After continuous exposure to a heat flux of 31.5 kW/m^2 (10,000 Btu/hr ft^2) for 15 minutes, buildings located with the potentially moderate damage radius may begin burning.

Potential Consequence Reduction Strategies (cont'd)

- For hazardous liquid pipelines without ignition, installation of ASVs and RCVs can be effective in reducing socioeconomic and environmental damage.
- Block valve closure swiftness affects the amount of product released following a break.
- Cost effectiveness increases as the time required to isolate a damage pipeline segment decreases.

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QUESTIONS?