Development and Application of Spacing Chart for Simultaneous Operations (SIMOPs) in Unconventional Shale Gas Fields

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Abstract

There has been a boom in development of North America's unconventional shale gas in recent years. Due to heavy reliance on equipment-intensive operations such as hydraulic fracturing, and an increasing desire to minimize surface disturbance and footprint, well site equipment spacing and layout is becoming a more complex issue for unconventional gas projects, particularly when there are simultaneous operations (SIMOPs) at the same well pad location. The Technical Safety Engineering team in Shell Exploration & Production Company developed a spacing chart for SIMOPS to help field supervisors and personnel make decisions about equipment layout for SIMOPs including drilling, completion, flowback, production, and construction.
Development of the chart employed a method using consequence modeling, which studies the physical effects of flammable gas dispersion upon release, and heat radiation from jet fire or pool fire. Release scenarios were identified for SIMOPs equipment from which release and ignition of flammable hydrocarbon may occur. Scenarios and minimum spacing distances were selected according to the principle of Managing Risk in Shell's [1] HSSE & SP Control Framework. The development process provides an opportunity to check through onsite hydrocarbon release and fire hazards in a systematic way for various well site operations.
The chart is used at Shell's unconventional shale gas facilities in the United States and is integrated into Shell's overall risk management system for SIMOPs. The aim is to use the spacing chart as a practical tool to manage the risk of fire hazards at well sites. Engagement with leadership of the various parties responsible for well site operations is necessary for successful chart usage in the field and establishment of a feedback channel for further improvements to the chart. Delivery of the chart to the field also enhances awareness of fire risks through communication and onsite training.

[1] Each Shell Oil Company subsidiary or affiliated company in the United States is a separate legal entity. In this document the term "Shell" refers to the subsidiary or affiliated company of Shell Oil Company that owns, operates, or provides services with respect to the assets and operations discussed.

Note: Do not add page numbers. Do not refer to page numbers when referencing different portions of the paper

1. Introduction and Background

Along with the recent boom in North America's shale gas development, Shell has expanded its onshore unconventional gas portfolio in the United States. Tight shale gas development operations involve different procedures and technologies than traditional onshore well operations. In particular, tight shale gas development depends heavily on hydraulic fracturing, which is an equipment-intensive procedure (Figure 1). In addition to increased complexity in field operations, more Simultaneous Operations (SIMOPs) are being carried out in the field. SIMOPs are scenarios in which two or more operations occur at the same time on the same well pad facility. SIMOPs include drilling, completion, workover, well intervention, flowback, and production. Besides well operations, the concept of SIMOPs also includes construction, commissioning, modifications, and maintenance. Examples of SIMOPs include the following [1]:

- In phased field development, production is started early while construction is still ongoing to add more production trains on the same well pad.
- The drilling crew works on a new well concurrently with production operations from existing wells.
- Modification to the production unit for debottlenecking, expansion, or regulatory compliance occurs without shutting down production operations in other trains on the same well pad.

Figure 1 Development Operations on a Typical Multi-well Pad in Shell Pinedale Shale Gas Field

Companies face significant challenges with unconventional shale gas projects to achieve their business goals while remaining focused on safety and minimizing impacts to the environment. Unlike continuous production from wells, many SIMOPs activities are temporary in nature and therefore bring an additional dimension of risk. Various simultaneously ongoing activities may place large numbers of personnel in close proximity to operating equipment in use for other activities. Activities such as construction or hydraulic fracturing may introduce a large number of ignition sources into the onsite area. It is therefore crucial to develop a comprehensive strategy to manage the SIMOPs.

Equipment layout and spacing is a fundamental aspect of risk management [2]. Proper siting and equipment layout is necessary to separate potential sources of fires, explosions, or toxic incidents from neighboring areas that could be involved in such events and protect people and assets from harm due to the events' potential consequences. In Canada, various provincial requirements or recommendations specify spacing for well site equipment, although the equipment is not specified for specific SIMOPs [3, 4]. In the United States, state regulations specify minimum spacing of permanent well site equipment from offsite facilities such as residential housing, public buildings, roads, and highways. However, to our best knowledge, there is no existing federal or state regulation for spacing and layout of temporary SIMOPs equipment on well sites in the United States.

Engineers in Shell's Technical Safety Engineering Team assisted Shell's unconventional gas projects and operations with identifying risks in the unconventional gas production business related to handling of flammable hydrocarbons and implementing effective measures to control the risks. In recent years, the Technical Safety Engineering Team has been helping various project and asset teams on fire hazard assessment for spacing and layout of SIMOPs equipment. The team recognized the need for a spacing guideline designed specifically to address the spacing problem associated with SIMOPs on shale gas facilities. In 2011, Technical Safety Engineering Team teamed up with Shell's unconventional gas business and Shell's Projects & Technology group to develop a new SIMOPs spacing chart that applies to all Shell unconventional shale gas well site locations in the United States. The purpose is to create a standard solution to a standard problem, to create more consistency in operations and elevate the bar for safety performance in Shell.

2. Project Overview

The project objective is to produce a set of recommended minimum spacing distances between SIMOPs equipment to prevent harm to people and damage to equipment from potential fire hazard due to hydrocarbon release. The chart is based on the minimum distances between flammable hydrocarbon sources and ignition sources. The chart will be applied in Shell unconventional gas development and production facilities in the United States.

Figure 2 depicts the three stages in this project:

1. Development
2. Review and Approval
3. Implementation

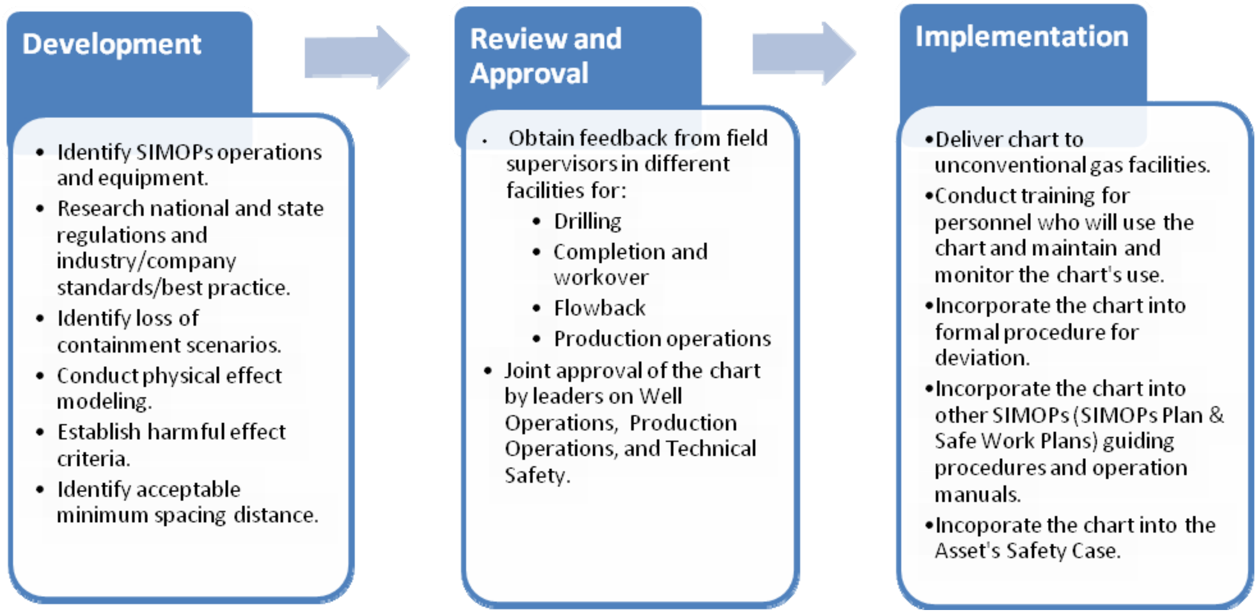

Figure 2 Project Road Map for Producing the New SIMOPs Spacing Chart

In the Development stage, the chart took its shape by following steps as listed in Figure 2. In the Review and Approval stage, the chart gained buy-in from its future users through the review and feedback process. In the Implementation stage, the chart was delivered and put into practice. Details of the stages are introduced in Section 3.

3. Development of SIMOPs Spacing Chart

3.1 Identify SIMOPs and related equipment

The first step in the chart development process is identifying the SIMOPs in Shell's shale gas well pad facilities. A cross functional project team that includes people from various backgrounds with knowledge and experience in SIMOPs is formed. The project team works together with operations superintendents, field supervisors, and wells engineers to identify a list of operations with associated equipment (Table 1) that will be covered by the SIMOPs spacing chart.

Table 1: SIMOP Equipment and Operations

Operations	Equipment
Drilling (excluding rig move-up and rig up operations) • Drill into reservoir, assessing composition of fluids in the rock for assessment of formation • Run various strings of casing • Cement to isolate different wellbore sections	Drilling well (including drilling rig) Drilling mud pits, shale shaker Diesel/oil-based mud storage tank Drilling rig boiler Mud de-gasser and atmospheric separator
Completions and Workover • Hydraulic fracturing: mix fresh or salty water with chemicals, add sand in blender, and pump fracturing fluid into well • Well intervention: perforating, wireline, snubbing, and coiled-tubing • Workover: stimulation of an existing production well to restore or enhance well production	Well under completion Completion high pressure equipment (including flow line, chokes, and trash catcher) Workover well (including service rig) Completion earthen pit
Flowback • Rig up well to temporary production equipment • Flow fluid in the well after a treatment to clean up the well and return the well to production	Flowback well Flowback separators and temporary piping Frac tank Flowback open top tank Temporary emergency flare tower, with engineered ignition source.
Production • Continuous flow of gas, with a certain amount of liquid (oil, condensate, or water) from well into surface equipment • Indirect heating through line heater • Three phase separation • Gas dehydration and compression • Chemical Injection • Liquid storage and loadout • Gathering and combustion of tank emissions • Inspection and maintenance work on production equipment	Producing well Flow line Production package (including indirect heaters, separators, dehydration, and metering) Instrument gas system Oil/condensate/produced water tanks Oil/condensate/water load-out tanker Chemical tanks Emergency relief systems Utilities (including heat medium reboilers)
Common • Operations that involve equipment which can be used in various phases of operations • Transportation on the well site • Construction: land preparation and vessel installation	Site offices and accommodation Fired equipment with/without flame arrestor Diesel/gasoline engines Hot oiler (propane fired) Flare tower Propane tanker for camp fuel delivery Well site LNG fuel supply and vaporizing equipment Designated smoking area Safe muster area

The SIMOPs equipment is further divided into two groups: potential release source of flammable hydrocarbons and ignition source.

Potential release source of flammable hydrocarbons

Equipment that contains flammable hydrocarbons is considered a potential release source. When loss of containment (LOC) occurs from such equipment, hydrocarbon is released into surrounding environment. Depending on properties of the released material and release conditions, there may be gas, liquid, or two-phase release. This document considers the following two forms of releases:

- Vapor release: gas dispersion and jet fire upon ignition.
- Liquid pool: formation of a liquid pool and pool fire upon ignition.

This document does not consider the scenario of pressurized liquid release and formation of liquid spray.

Ignition source

Equipment that may produce energy sufficient to initiate combustion in a flammable cloud is considered an ignition source. Ignition sources can be internal combustion engines, non-classified electrical equipment, or any fired equipment.

Based on this categorization, SIMOPs equipment is listed in the SIMOPs spacing chart, with equipment that is a potential release source of flammable hydrocarbons listed in the left column and equipment that is a potential ignition source listed on the top row. The distance in the block at the intersection of a row and column is the recommended minimum spacing for that pair of equipment (Figure 3).

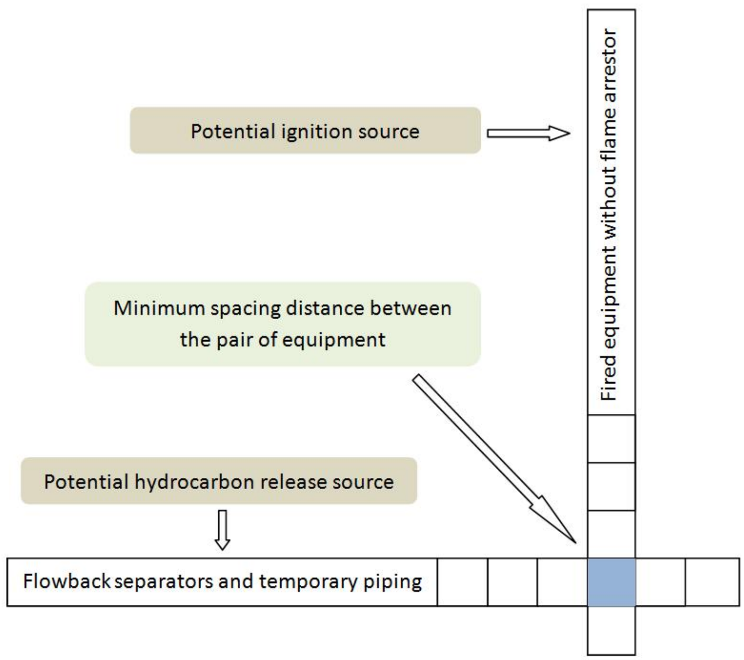

Figure 3 Minimum Spacing for Equipment Listed in SIMOPs Spacing Chart

3.2 Identify Loss of Containment scenarios

After the SIMOPs equipment is identified, the next step is identifying scenarios for how hydrocarbon leaks can occur and the consequences of such leaks. Identifying these release scenarios is a team workshop effort conducted using brainstorming to identify possible LOC scenarios for each type of SIMOPs equipment. Identified scenarios are classified into three categories: Major LOC, Most Likely LOC, and Credible Worst-case LOC.

Major LOC (M-LOC)

M-LOC is the worst-case possible release scenario that may happen. M-LOC involves the release of inventory in a large amount or an escape through a very large opening, which essentially establishes the metrics for the furthest extent for a flammable cloud or damaging fire heat flux. All M-LOCs are unintentional and undesired. Generally, an M-LOC is considered unlikely, and therefore is not usually applied as a design basis for SIMOPs spacing distances. Examples of M-LOCs include the following:

- Release from a full-bore ruptured pipe or a hole with a diameter of 150 mm or larger on a vessel.
- Release of gas from rupture or opening on a producing wellhead during loss of well control.
- Release of the entire liquid inventory from a condensate tank and ignition of vapor above the liquid pool.

Most Likely LOC (ML-LOC)

ML–LOCs are less severe release cases than M-LOCs. However, ML–LOCs are more likely to happen than M-LOCs. Examples of ML-LOCs include the following:

- Release of natural gas from a hole with a diameter up to 6 mm on high-pressure production equipment.
- Local minor release of natural gas from low-pressure or atmospheric systems.
- Local minor release of liquid hydrocarbons within bund area.

Credible Worst Case LOC (CWC-LOC)

CWC-LOCs are release cases that are less severe than worst-case M-LOC scenarios, but more severe than ML-LOCs. CWC–LOCs are usually based on the ML-LOCs, but with worse release conditions and more severe consequences, which are reviewed for conservative purposes.

- An example CWC-LOC scenario is natural gas release from a hole with a diameter up to 20 mm on flowback separator and associated piping. A maximum 20-mm-diameter hole size is adopted instead of a 6-mm hole for ML-LOC, because the temporary tubing on flowback equipment is considered more likely to have leaks than the permanent equipment for production.
- Another example is a case in which a loss of well control occurs after the fracturing operation, flow of gas from well was diverted to a temporary emergency flare tower, resulting in heat radiation from flaring.

Table 2 lists identified release scenarios using flowback equipment as an example.

Table 2 Examples of LOC Scenarios for SIMOPs Equipment

Equipment	Scenario type and description
Flowback equipment, separator, and production pack (including temporary flow lines and sales lines)	ML-LOC Scenario A gas leak occurs on temporary production equipment for flowback, such as the manifold, sand trap, fracturing stack, fracturing pipe, trash catcher, and temporary flow lines. A 10-mm diameter hole on a typical 3/8-in. pipe is assumed under 1440 psi pressure in the pipe.
	CWC-LOC Scenario A gas leak occurs on temporary production equipment for flowback, such as the manifold, sand trap, SCUD, fracturing stack, fracturing pipe, trash catcher, and temporary flow lines. Considering that leaks are more likely to occur on temporary pipes for the flowback, a larger hole size of 20-mm diameter is assumed for conservative purposes, under 1440 psi pressure in the pipe.
	M-LOC Scenario A full-bore rupture of the temporary tubing occurs due to pipe connection failure. The flow line carries mainly gas and flow rate is limited by the maximum output from the well based on a conservative estimate.

3.3 Select design-basis scenarios

The project team identified possible scenarios for each piece of equipment which contains hydrocarbon. Then among the scenarios for each piece of equipment, the project team selected one scenario as the design-basis case. Results of consequence modeling on the design-basis case will be used to determine the minimum spacing distance for the equipment.
Selection of the design-basis scenarios follows the general principle of Managing Risk in the Shell HSSE & SP Control Framework. According to the Shell HSSE & SP Control Framework, HSSE hazards in Shell businesses need to be identified and risks of the identified hazards need to be assessed using the Shell Risk Assessment Matrix (RAM; Figure 4). For hazardous scenarios classified as yellow and red cases on the RAM according to their severity and likelihood ranking, controls and recovery measures need to be identified and implemented to prevent the events from happening. The project team assessed each identified scenario with the RAM and identified corresponding controls and recovery measures by consulting field supervisors in Shell assets.
Following the principle, the CWC-LOC scenarios were selected as the design cases for the majority of the SIMOPs equipment.

SEVERITY	CONSEQUENCES				INCREASING LIKELIHOOD				
	People	Assets	Environment	Reputation	A	B	C	D	E
					Never heard of in the Industry	Heard of in the Industry	Has happened in the Organisation or more than once per year in the Industry	Has happened at the Location or more than once per year in the Organisation	Has happened more than once per year at the Location
0	No injury or health effect	No damage	No effect	No impact					
1	Slight injury or health effect	Slight damage	Slight effect	Slight impact					
2	Minor injury or health effect	Minor damage	Minor effect	Minor impact					
3	Major injury or health effect	Moderate damage	Moderate effect	Moderate impact					
4	PTD or up to 3 fatalities	Major damage	Major effect	Major impact					
5	More than 3 fatalities	Massive damage	Massive effect	Massive impact					

Figure 4 Risk Assessment Matrix (RAM)

Although the likelihood of occurrence is lower for incidents with more severe consequences, detailed analyses on probabilities of the identified scenarios were not conducted during this project due to lack of release frequency data for onshore operations. Although risk-based methods are becoming more popular, the success of a risk-based analysis depends on a reliable and applicable database on probability of various release events. Accumulation of operational records and data in recent years means that leak frequency data are becoming more available and reliable for offshore operations. However, for onshore unconventional operations (especially the new shale gas development activities), available information is limited, making it difficult to conduct detailed probabilistic analyses for various events happening at onshore facilities.

3.4 Consequence modeling and selection of spacing distances

Physical effects from identified release scenarios in Section 3.2 were studied using a Shell proprietary software package for modeling the consequences, including flammable gas dispersion and fire heat radiation.

Based on the gas dispersion contour, a distance from the release source to gas concentration of lower flammability limit (LFL) is identified. The distance is used as the minimum spacing to prevent ignition of released gas. Based on the fire heat radiation contour, several distances are identified according to levels of the heat flux, each with different potentials to harm people or damage equipment. The heat flux levels are based on relevant Shell standards and industry guidelines. A distance from the release source to a heat flux level of 37.5 kW/m^2 is used as the minimum distance to avoid damage to equipment in a short-term period. A distance to 6.3 kW/m^2 is used to avoid injury to properly trained personnel during short-term exposure.

For each equipment, selection of minimum spacing distance depends on the objective of protection by spacing. Usually, spacing is intended to avoid ignition in the first place to avoid harm to people and damage to equipment. Therefore, the distance to LFL is used for most cases. For certain equipment, the distance to 37.5 kW/m^2 was used for conservative purpose (this is necessary for equipment whose failure may result in loss of critical functions and escalation of events during emergency situations, such as loss of well control). For certain equipment, protection of personnel from fire heat injury is necessary because operators need to work continuously in areas around the equipment. So the more conservative distance to 6.3 kW/m^2 heat flux level was used to allow personnel to escape from the fire. When selection of the distances is finished for all the SIMOPs equipment, the distances are entered into the spacing chart.

4. Implementation of SIMOPs Spacing Chart

4.1 Implementation across the organization

Success in any project cannot be achieved until the deliverable is effectively implemented. To successfully implement the new SIMOPs spacing chart, involvement of personnel in various levels of Shell organizations for unconventional shale gas projects at various locations is the most crucial part of the work. The people who were involved in chart development and who use the chart in their daily jobs are summarized below.

Wells Delivery Manager and Operations Manager

The Wells Delivery Manager is in charge of overall projects to deliver wells in a Shell unconventional shale gas field. The Wells Delivery Manager oversees operations, from drilling, completion, and hydraulic fracturing to later workover and well intervention jobs. The Operations Manager is in charge of producing activities in a field after wells have been completed. The Operations Manager oversees operations from initial flowback to bring the well online to daily production and maintenance, as well as later modifications to the existing facility, including abandonment. The Wells Delivery Manager and Operations Manager are the leaders who are accountable for safe operations in their assets. They need to be aware of the HSSE & SP risks associated with their business activities and how the risks are managed.

At the early stage of developing the new SIMOPs spacing chart, managers whose assets will use the chart were informed of the project, including the scope of the chart and form of deliverable. The asset managers understand the value of the chart as an effective risk management tool in the field and demonstrate their commitment to the project by assigning their field leaders and personnel to provide support and feedback.

Superintendents of drilling, completion, flowback, operation, and construction

Superintendents of drilling, completion, flowback, operation, and construction are responsible for specific operations in the field. For example, a drilling superintendent is in charge of all drilling activities at an asset. Superintendents are often the most experienced personnel in their areas of charged operations. Their knowledge and input are very valuable to the SIMOPs spacing chart, particularly when problems in the project cannot be solved by relying only on engineering calculations and industrial history and incident statistics on shale gas are limited.

During development of the chart, a team of superintendents from various assets was formed to discuss issues including equipment used in each operation, how things may go wrong, and potential hazardous scenarios. The continuous discussion helps establish the building blocks for the new SIMOPs spacing chart as described in the previous Section 3. Although it is difficult to achieve consensus on all the issues due to varied personal experience and understanding of relevant risks, the team aims to create a process in which everybody has a chance to provide opinions for the work, and the team gains understanding of how and why a specific scenario was selected and a distance used.

Field personnel (supervisors, operators, HSE technicians, engineers, and foremen)

Field personnel are the main users of the SIMOPs spacing chart. For example, field supervisors need to consult the chart when reviewing or approving activities in advance of work. They need to make sure that the available onsite area is capable of accommodating the equipment in such a way that equipment spacing requirements will be followed, particularly when SIMOPs are occurring on the same pad.

Field engineers, operators and foremen need to consult the chart when there are changes in the work environment due to SIMOPs. They need to be aware of any change in equipment layout, identify any spacing issues that cause concerns for the safety of workers and facilities, use the chart to assess the conditions, and raise issues to supervisors. Field HSE technicians need to make sure that a copy of the chart is available to onsite personnel and is followed constantly.

4.2 Integration with overall SIMOPs risk control system

The SIMOPs spacing chart is a tool designed to prevent ignition of hydrocarbons from potential fixed and temporary ignition sources. When using the chart, it is important to recognize that there are many other hazards besides flammable hydrocarbon and fire, such as physical exposure from high pressure in temporary piping, dropped object, and collision. There are also many other Shell risk mitigation measures and tools to manage risks in SIMOPs. These measures constitute a system within which the new SIMOPs spacing chart should be used. These measures are briefly introduced below.

Manual of Permitted Operations (MOPO)

MOPO is a visual tool developed by Shell Technical Safety Engineering Team in coordination with relevant Shell organizations [5]. MOPO brings together a collection of field activities and situations into a matrix sheet and provides information about whether certain combinations of SIMOPs activities can add risks to safe operations.

MOPO originated from findings by work planners and supervisors when they were reviewing work permits offshore. It is a valuable tool in providing a means to assist with consistently applying risk management controls to the various SIMOPs activities occurring on a daily basis in offshore platforms. Shell started to implement MOPO to its offshore installations in the Gulf of Mexico in 2007. Based on the successes in the Gulf of Mexico, MOPO for onshore business was developed and has been applied in onshore field production facilities, gas plants, and in-situ oil production in Canada and the United States since 2009.

MOPO uses a traffic light chart format to indicate when SIMOPs activities should not proceed (red), proceed with caution (yellow), or proceed without special restriction (green). For the activity combinations marked with yellow, SIMOPs should be carried out when certain restrictions are complied with. Among the 12 listed restrictions, 2 refer to the spacing chart:

- Restriction #1: as long as activity is not close to other activity, judgment of Person in Charge (PIC)/Supervisor/Spacing Chart.
- Restriction #4: wells within vicinity to be temporarily shut in, judgment of PIC/Spacing Chart.

Field supervisors must use the new SIMOPs spacing chart together with MOPO to assess and approve SIMOPs subject to the restrictions on equipment spacing.

Wells Worksite Instruction Manual (WWIM)

WWIM contains a summary of key company standards that are deemed the most critical for safe and efficient delivery of well operations. WWIM identifies 10 areas for which the mandatory requirements are laid out, including Permit to Work, Lifting and Hoisting, Dropped Object Prevention Scheme, temporary pipe work, and emergency preparedness. Among the requirements are that personnel exclusion zones shall be established, properly barricaded, and access-controlled to prevent physical pressure hazards and dropped objects. Because certain SIMOPs equipment must be continuously manned or constantly checked on, it is important to consider the necessary personnel exclusion zone or extra spacing distance when planning spacing of the equipment, besides using the SIMOPs spacing chart for prevention of fire hazards.

Sour Gas Protection

Unconventional shale gas reservoirs may contain high concentration of hydrogen sulfide (H_2S or sour gas). As an acute toxic substance, H_2S has caused fatalities in the oil and gas industry, including the Chuandongbei gas well blowout in China in 2003, which killed 243 people and injured more than 9000 people. In Shell, managing risks due to exposure to H_2S is listed as a Process Safety Basic Requirement (PSBR) in the HSSE & SP Control Framework, which requires assessment of safety risks in H_2S operations, particularly for concurrent operations or SIMOPs.

Shell International Exploration and Production developed a special concept called Time to Protect as a layout methodology for SIMOPs in high-pressure and high-H_2S-concentration facilities [1]. According to the Time-to-Protect methodology, when SIMOPs activities are ongoing in areas nearby a facility where H_2S is present, a safe separation distance must be established to allow safe evacuation of personnel upon early detection of an H_2S release. Therefore, larger equipment spacing might be needed based on this methodology.

Because the SIMOPs spacing chart is designed for “standard” or sweet gas facilities, facilities where H_2S is present must follow relevant Shell procedures to assess layout and equipment spacing to take H_2S presence into account, such as using dispersion models to determine the dimensions of the 300-ppm H_2S plume from credible release events and locating the SIMOPs work area outside of the plume’s footprint.

5. Summary

A spacing chart for SIMOPs was prepared for unconventional shale gas development and production fields in Shell in the United States. Development of the chart provides an opportunity to check through onsite risks in a systematic way by identifying various scenarios that can result in flammable hydrocarbon leak and fire. Valuable experience and knowledge on field operations and risk management is gained during the process. The chart’s implementation process enhances awareness of onsite risks through communication and training across Shell organizations and locations. The SIMOPs spacing chart is an important part of the overall system to manage risks from SIMOPs in Shell’s unconventional onshore assets in the United States.

6. Acknowledgement

Certain key people enabled success in this project. Support from the Operations and Wells Delivery Managers in Shell Exploration and Production Company is appreciated, especially because any changes and improvements in safety can only be realized with demonstrated leadership.

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Finally, we thank all the field personnel, superintendents, and operators for their support and guidance during this project.

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