Understanding Overpressure Scenarios and RAGAGEP

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Introduction to Using RAGAGEP for Overpressure Risk Mitigation

Process Hazard Analysis (PHA) is a key tool used by the chemical, oil, and gas industries to assist companies in identifying, implementing and managing the critical safeguards needed to achieve their risk tolerance criteria. The Process Hazard analysis for some sites may be regulatory driven (e.g., Occupational, Health and Safety Administration's (OSHA's) 29 CFR 1910.119 Process Safety Management of Highly Hazardous Chemicals (PSM), or the United States Environmental Protection Agency's (USEPA's) 40 CFR 68 Chemical Accident Prevention Provisions (RMP)).

During the PHA the team identifies consequences of concern arising from potential process deviations, identifies existing safeguards, or if LOPA (Layer of Protection Analysis) is required, the Independent Protection Layers (IPLs) available to reduce the likelihood of the consequence to a tolerable risk level. If the team identifies a gap between the potential event likelihood, severity and the minimum target set by the company, the team will propose recommendations to close the gap.

An overpressure scenario can be a significant contributor to the risk of a facility. Overpressure of pressure vessels, piping, and other equipment can result in loss of containment of flammable or toxic materials. This paper will develop guidance including related RAGAGEP (Recognized and Generally Accepted Good Engineering Practice) to help engineers and designers participate in the safety lifecycle for managing the risk of overpressure.

Role of the Control Systems Engineer (CSE) in PHA/ LOPA

CSE personnel are an important part of a PHA/ LOPA team. Specifically related to overpressure scenarios, the CSE will often be able to provide input to the following issues:

- develop overpressure scenarios related to failure of automatic controls
- assist team to understand dependence between automatic controls (for exclusion of double-jeopardy)
- understand the types of pressure relief hardware that is specified or installed (e.g. pilot operated vs. conventional relief)
- understand relief valve codes and practices
- assist the team with developing alternate gap closure solutions (e.g., “system design” (SIS), High Integrity Pressure Protective System (HIPPS), critical alarms, etc.)

If the process engineering representative to the PHA has not specifically worked in the discipline of pressure relief design, the CSE representative, if knowledgeable, can fill in most of this knowledge gap. The CSE may inherit recommendations or action items related to mitigating overpressure gaps, or may have responsibility for the maintenance and ongoing integrity related to overpressure mitigation. A solid understanding of the RAGAGEP related to managing the risk associated with overpressure scenarios is required in all of these cases.

Introduction to Codes and Recommended Practices related to Overpressure

The following RAGAGEP are used to manage the risk associated with overpressure.

ASME *Boiler and Pressure Vessel Code*, Section VIII - Pressure Vessels

The ASME *Boiler and Pressure Vessel Code*, Section VIII - Pressure Vessels (ASME Section VIII), is considered the authority for minimum safety and performance requirements of pressure relief devices. It is widely used in industry as a reference and base code. ASME Section VIII has been codified by many state and local regulatory authorities, meaning it is required by law [1].

API Standard 520, *Sizing, Selection, and Installation of Pressure-relieving Devices,* Parts 1 (Sizing) and 2 (Installation)

API Standard 520, *Sizing, Selection, and Installation of Pressure-relieving Devices* (API 520), supplements the material and information in ASME Section VIII, and “provides more complete information on relieving devices, including the determination of relief requirements, disposal systems, piping and installation practices, than was previously available from published sources” [1].

API Standard 521, *Pressure-relieving and Depressuring Systems*

API Standard 521, Pressure-relieving and Depressuring Systems (API 521), "Provides an additional source of knowledge and experience gained by the petroleum processing and related industries. It recommends economically sound and safe practices for pressure relief. This source considers the complex design and operation of modern processing plants and the vast amount of energy stored. It suggest analysis guides for determining capacity requirements and design concepts for discharge and disposal systems" [1].

NFPA 30, *Flammable and Combustible Liquids Code*

NFPA 30, *Flammable and Combustible Liquids Code*, closely parallels the information in API Standard 2000, Venting Atmospheric and Low Pressure Storage Tanks [1]. OSHA's Standard, 29 CFR 1910.106, Flammable Liquids, is its codified cousin.

ANSI/ISA-84.00.01-2004 Parts 1 (IEC 61511 Mod), *Functional Safety: Safety Instrumented Systems for the Process Industry Sector*

When ASME Section VIII UG-140 is used as the basis to protect a vessel from overpressure by "system design" (e.g., SIS) then the safety lifecycle in ANSI/ISA-84.00.01-2004 Parts 1 (IEC 61511 Mod), *Functional Safety: Safety Instrumented Systems for the Process Industry Sector* (S84) would be followed for the SIS design, installation, maintenance, and testing.

Using a Pressure Relief Device as a Safeguard or IPL in PHA/ LOPA

One typical safeguard or IPL that is identified during a LOPA study is a pressure relief device. This type of IPL is identified by the team to manage the risk of an overpressure consequence to an acceptable level. A pressure relief device (i.e., a pressure-relief valve or rupture disk) is used as a consequence mitigation system to protect against hazards of overpressure resulting in loss of containment due to rupture or leak and potential exposure to a toxic release, fire or explosion. The reliance on the pressure-relief valve (PRV) (a generic term) as a safeguard depends on its proper design for the potential overpressure event, installation, and maintenance.

One of the requirements in 29 CFR 1910.119 [2] is "the employer shall complete a compilation of written process safety information before conducting any process hazard analysis required by the standard." Two categories called out as process safety information (PSI) in the standard are: 1) relief device design basis and calculations shall be documented, and 2) be designed in accordance with RAGAGEP.

This paper does not recommend that the team perform a detailed review of the pressure relief design calculations during the PHA. An underlying assumption of a PHA is the engineering calculations are correct (unless the team has knowledge they are not). Also because the team time to review a process node during a PHA session must be managed efficiently, an audit of the PSI is not feasible. However, PHA recommendations are routinely captured to address PSI deficiencies identified; such as the need to update P&IDs, update of operating procedures, update of safe operating limits, or the review of a PRV design basis and the associated sizing calculation to confirm it provides overpressure protection for a PHA/ LOPA scenario to which it is credited (in adherence to RAGAGEP).

The following are recommended questions to raise with the PHA team when performing the study to assess the health of the pressure relief management system. The sources of information available to answer these questions are typically the P&IDs, team member knowledge and experience and observations made during the walk-around tour of the process area. Note that these questions focus on pressure relief for pressure vessels and not for low-pressure or atmospheric tanks, though similar questions may be developed for those. Although pressure relief devices are used to protect pressure vessels and piping, the provision of pressure relief on piping is also not covered in this paper as requirements for piping overpressure protection are generally more specific for the material being handled and would be driven by application of the correct RAGAGEP for that industry (e.g., Cl2 Institute guidance on thermal expansion pressure relief of liquid chlorine trapped in pipe).

PRV/ Overpressure RAGAGEP Deviation Questions for PHA

The following potential deviations related to overpressure based on RAGAGEP will be addressed in detail in this section.

1. Is a pressure relief device required?
2. Is overpressure protection available through a connected vessel that has a pressure relief device?
3. Is the pressure relief device setpoint below the MAWP?
4. Is the vessel nozzle or inlet pipe to the PRV a smaller area than the inlet of the PRV?
5. Is the PRV mounted below the normal liquid level that is not adequate for non-compressible relief?
6. Are there any PSE/PRV combinations on the P&ID?
7. Is there a PRV installed on the shell or tube side of a heat exchanger?
8. Is the opening in the vessel designed to provide unobstructed flow between the vessel and the pressure relief device?
9. Does the PRV vent to a “safe” location?
10. Is the relief path kept free of accumulated liquid?
11. Is there a credible contingency for hydraulic overpressure?
12. Is double-jeopardy claimed for an overpressure scenario?

What the PHA team is looking for from these questions are potential deviations from RAGAGEP for pressure relief design (including basis), installation and maintenance. The question raised may be:

- Answered during the meeting if the appropriate PSI can be quickly accessed, as there is a limited time to search for information during the meeting session, (rapid access);
- Captured as a parking lot item to be researched and answered outside the meeting time but before the end of the meeting sessions (available from field or record review);

- Made into a recommendation to verify the design meets RAGAGEP and if not to initiate the development of the PSI or a design modification (e.g. prolonged record search, work order or study needed).

The following discussions of each question below include a reference to the applicable and supporting RAGAGEP(s). The information provided is intended to be useful to a facilitator in leading a hazard analysis. The codified requirements are also detailed in a table at the end of this paper.

1) Is a pressure relief device required?

ASME Section VIII requires that pressure vessels be protected by a pressure relief device. In most cases it is easy to identify a pressure vessel by inspection of the P&ID. In some cases it is not.

The following criteria will exclude a vessel as being considered an ASME Section VIII pressure vessel:

- Vessel rated for less than 15 psig (100 kPa)
- Vessel diameter is less than 6" (152 mm)

Source RAGAGEP: ASME Section VIII U-1 (h), U-1 (j)

Look at each pressure vessel identified in the node and on the P&ID. Look for the PRV and where it vents to during the field tour.

Are there any pressure vessels not protected by a pressure relief device? If, so inquire per the next section below.

2) Is overpressure protection available through a connected vessel that has a pressure relief device?

ASME Section VIII allows a vessel that is open to a connected vessel to be protected by that vessel's PRV. In this case, ensure the design basis contained in the relief valve folder includes the connected vessel in its scope.

Does the relief design basis include the connected vessel in its scope?

Source RAGAGEP: ASME Section VIII UG-133 (c), Appendix M M-5

2.1) What if there is no path to a pressure relief (no pressure relief device)?

Verify if the vessel involved has been evaluated per ASME Section VIII UG-140 to not need overpressure protection. This could be the case if the system pressure is self-limiting (the source of pressure cannot exceed the MAWP of the pressure vessel) and there is no credible fire-case (such as when a pressure vessel is elevated). If no documentation exists to support application of ASME Section VIII UG-140, propose a recommendation to perform a study and initiate modification as needed to provide adequate overpressure protection.

A HIPPS may be used in lieu of a pressure relief device. This is also governed by ASME Section VIII UG-140, which requires making the likelihood of an overpressure of a vessel protected by a HIPPS to be non-credible. Consequence criteria is not taken into consideration. Mitigating to non-credible implies the use of a “SIL 3” HIPPS which is best available technology. SIS documentation should be reviewed to confirm the HIPPS is designed and maintained to this level of integrity.

UG-140 applies to new projects or new pressure vessels.

When using a HIPPS in lieu of a PRV (or no PRV is required) inform the vessel manufacturer in writing (filling out manufacturer’s data sheet for UG-140) and the vessel should be stamped for UG-140 etc.

Source RAGAGEP:

- ASME Section VIII UG-140 (formerly Code Case 2211)
- Guidance note for UG-140 is WRC bulletin 498. A “how-to” apply guide for UG-140.

2.2) What if the existing pressure relief device is not sized for a specific relief contingency?

A PHA team may find that a vessel overpressure scenario being considered is not protected by an existing pressure relief device (but otherwise the vessel has a pressure relief device that is properly sized for other scenarios, e.g., a fire case). In these cases the PHA team could (if mechanical relief protection for the specific contingency were impractical) recommend the use of a HIPPS to mitigate the risk of overpressure for the specific contingency.

If a HIPPS is used to eliminate a relieving scenario (but the vessel otherwise has a PRV) you only need a risk basis documented (LOPA) for that scenario. It is not subject to ASME Section VIII UG-140.

As long as there is a properly designed, installed, and maintained PRV on the vessel sized for some scenario, UG-140 does not apply (this allows less than SIL 3 for a HIPPS). API 521 is the applicable RAGAGEP. This is an interpretation of code and should be verified independently by each end-user.

API 521 supports the use of a risk analysis using LOPA and allows the “consequence” to be taken into consideration when mitigating with a HIPPS (ASME Section VIII does not). This is why the design basis for the HIPPS may be SIL 1 or 2.

2.3) Are there maintenance valves (or control valves) in the flow path between the vessel and the pressure relief device or its downstream vent point?

Valves (manual or automatic) in the flow path with a pressure relief device should be reviewed carefully with the PHA team. They potentially can defeat the safeguard or IPL.

ASME Section I (for fired equipment, e.g., boilers) does not allow valves in the relief path.

ASME Section VIII (unfired pressure vessels) allows valves in the path of a relief device, however they must be managed open.

Do valves in flow path through PRV on P&ID show car seal open (CSO) or chain locked open (CLO)?

Source RAGAGEP: ASME Section VIII UG-135 (d)(1), (d)(2) and Appendix M.

3) Is the pressure relief device setpoint below the MAWP?

The P&ID should show the design rating for a vessel (i.e., pressure and temperature). Either the vessel design pressure or the MAWP (Maximum Allowable Working Pressure) may be shown. The design pressure is set by the process requirements. The MAWP is what the vessel is built to withstand by the manufacturer. The MAWP should be equal to or higher than the design pressure. The set pressure for at least one PRV on a vessel shall not exceed the MAWP of the vessel.

If the vessel design pressure is shown on the P&ID (but not the MAWP), investigate the MAWP because this may lower the overpressure ratio if the vessel was fabricated with a higher MAWP.

The P&ID may show multiple PRVs protecting a single vessel. The PHA team should understand why there are multiple PRVs. Are the PRVs protecting the same relief contingency, or are they protecting different contingencies. In any case, it is common to stagger the (multiple) relief valve set-points to ensure proper performance of each relief device (e.g., to avoid chattering).

Compare set-point of PRV with the MAWP of all the equipment it is protecting against the RAGAGEP criteria.

Source RAGAGEP: ASME Section VIII UG-134 (a) "When a single pressure relief device is used, the set pressure shall not exceed the maximum allowable working pressure of the vessel. When the required capacity is provided in more than one pressure relief device, only one pressure relief device need be set at or below the maximum allowable working pressure, and the additional pressure relief devices may be set to open at the higher pressures but in no case at a pressure higher than 105% of the maximum allowable working pressure, except as provided in (b) below" [3].

4) Is the vessel nozzle or inlet pipe to the PRV a smaller area than the inlet of the PRV?

The proper design of a PRV installation must consider and limit the pressure drop on the inlet line to a PRV and the back-pressure developed on the discharge line of a PRV, both of which may reduce the capacity of the PRV and cause performance issues (e.g., chattering). Does the P&ID show a nozzle or pipe with a smaller diameter than the opening of the PRV on the P&ID or observed during a tour?

Source RAGAGEP: ASME Section VIII UG-135 (b) (1)

5) Is the PRV mounted below the normal liquid level that is not adequate for non-compressible relief?

The PHA team may be aware of issues related to a PRV installation, or it might become apparent during the tour of the unit. For example, in one facility, a group of PRVs were installed below the centerline of the flare header where the PRVs discharged to.

Verify with the PHA team if a PRV mounted below a normal liquid level is specified as per compressible fluid. Potential issues that should be identified by the team include; operating level changes, repurposed vessel, inadequate nozzle selection (design), or bad installation, etc.

Source RAGAGEP: ASME Section VIII UG135 (a)

6) Are there PSE/PSV combinations on the P&ID?

If a PSE (rupture disk) is installed in series with a PRV, there must be a way to monitor pressure in the interstitial space. If the rupture disk were to leak, pressure could build up in the space between the PSE and PRV, putting back-pressure on the PSE, effectively raising the bursting pressure of the PSE. A tell-tale pressure indication should be installed to measure pressure in the interstitial space. In addition, an inherently safer design solution is to vent the interstitial space to the flare header (thus preventing build-up of pressure) at the same time monitoring for blown rupture disk.

Is there a tell-tale to monitor the space between the rupture disk and PRV?

How is it monitored: checklist, SOP, DCS alarm?

At a minimum the tell-tale should be monitored by periodic operator rounds to inspect the read-out (although the tell-tale may not be a gauge, e.g. a try cock). During the PHA there may be an opportunity to record and review the procedure that documents the monitoring requirements of these indications, e.g. how are device inspections documented, frequency of monitoring, and requirement for corrective action.

Source RAGAGEP: ASME Section VIII UG-127 (b) (4): "The space between a rupture disk device and a pressure relief valve shall be provided with a pressure gage, a try cock, free vent, or suitable telltale indicator. This arrangement permits detection of disk rupture or leakage53."

7) Is there a PRV installed on the shell or tube side of a heat exchanger?

In older plants it is common to find one or more heat exchangers not protected for the tube rupture contingency. Tube rupture may overpressure the shell side of the exchanger, or pressure may develop on the exchanger heads (from the shell side) and overpressure that way. In any case, always verify from the P&ID design spec information for the heat exchanger the ratio of design pressure of high side to low side. If the ratio exceeds 1.3 (10/13ths rule), then look for pressure protection (a PRD) on the low side. For example, if the pressure rating of the tube side is 375 psig, and the pressure rating of the shell side is 100 psig, the ratio is 3.75. For this example, verify a PRD device is protecting the shell side. If the shell side is rated for 375 psig, and the tube side is rated for 100 psig, then look for a PRD protecting the tube side (the exchanger heads).

Is there a pressure relief device protecting the shell or tube side? If pressure relief is provided by connected equipment, is it documented and is the path to that relief managed open?

Source RAGAGEP: ASME Section VIII UG-133 (d)

8) Is the opening in the vessel designed to provide unobstructed flow between the vessel and the pressure relief device?

This is the "open communication rule." The path between a vessel and the PRD protecting it shall be open. By open it is meant that no manual valves or control valves, or other process equipment (e.g., exchangers, filters, etc) that could block flow, reduce flow or create backpressure to an unacceptable degree between the vessel and its PRD. This is especially important to look for when a vessel is being protected by a relief valve not fitted directly to the vessel but instead is located on another vessel or pipe. For the case of manual valves, if they are locked open (CLO) this is considered acceptable to maintain open communication. Be aware, that if closure of the valve (control or manual) or pluggage of the filter is the cause of high pressure, but at the same time isolates the vessel from high pressure, then this is not an overpressure concern for that vessel.

Open communication in the path of the PRV discharge to its destination (e.g., atmosphere, flare header, etc.) must be unobstructed as well.

Source RAGAGEP: ASME Section VIII UG-135

9) Does the PRV vent to safe location?

A challenge placed on a PRD to prevent overpressure will create a second scenario for consideration. Where does the relieved fluid vent to? If a PRV discharges to flare, at a minimum there could be a potential environmental impact cause by non-permitted flaring.

Other items to consider are:

- Will discharge rain down liquid to an occupied area?
- Is there history of inadequate liquid knock- out (disengagement) prior to venting?
- Is liquid overfill credible but not part of the relief design or discharge design?
- Can the PRD discharge create human risk of exposure to flammable vapor or toxic vapor in occupied areas?
- What is the elevation of the PRD vent discharge relative to elevated working surfaces?
- What is the direction of the PRD discharge (vertical or horizontal)?
- Is the discharge aimed at an occupied area, working areas, steps, etc?

Source RAGAGEP: API 521 6.3 and ASME Section VIII UG-135

9.1 Are any toxic or flammable reliefs discharging inside a building?

Source RAGAGEP: NFPA 30 2.3.4.6.1, 29 CFR1910.106

10) Is the relief path kept free of accumulated liquid?

Are there traps in the path of a PRV discharge to the KO drum/flare header? In one facility the PRV discharge header was run underground and then back up to flare. Accumulated liquid on the discharge of a PRV will increase backpressure and reduce relieving capacity.

Source RAGAGEP: ASME Section VIII UG-135 (f)

11) Is there a credible contingency for hydraulic overpressure?

In addition to a high level deviation in a vessel, the PHA team should review the potential for overpressure caused by high level – hydraulic overpressure. This is especially important as many PRV studies will deem the liquid overfill case as not-credible based on favorable Operator response allowed in API 521. The PHA team should independently verify this is so.

High pressure develops when the liquid rate cannot flow out of a vessel faster than it is put in. This could result in an overpressure up to the source deadhead pressure (i.e. pump, compressor, upstream line pressure, nitrogen header, etc.)

Source RAGAGEP: API 521 4.2.5 and 4.4.7

12) Is double-jeopardy claimed for an overpressure scenario?

Double-jeopardy is used in pressure relief valve design to exclude multiple independent failures as a basis for design. Do not let a PHA team easily claim “double-jeopardy.” The folder for a specific PRV may indicate a scenario is “double-jeopardy.” The PHA team does not have to agree with that assessment. For high severity consequences that result from double-jeopardy, LOPA allows an easy and conservative means to evaluate the scenario.

Failures may be related to equipment, human error, or external events. Follow these guidelines [4]:

- Any single failure is credible.
- Two or more simultaneous failures are credible if related by common cause.
- Two events in sequence are credible (one latent failure followed by another failure).
- Three or more events in sequence may be credible (if latent failures are not detected).

Source RAGAGEP: API 521 4.2.3

Taking Overpressure Scenarios to a Layer of Protection Analysis

In accordance with a company's risk analysis procedures, if the consequence severity is high enough, overpressure scenarios identified in a PHA may be further assessed in a Layer of Protection Analysis (LOPA). LOPA, in conjunction with the PHA, has become a routine tool used by the chemical, oil, and gas industries to assist companies in identifying, implementing and managing the critical safeguards needed to achieve their risk tolerance targets. LOPA is used to identify the number of Independent Protection Layers (IPLs) and their integrity needed to reduce the likelihood to an acceptably low frequency that an initiating cause will progress to an undesired consequence. LOPA quantifies if there is a gap between the existing Mitigated Event Likelihood (MEL) and the Target Mitigated Event Likelihood (TMEL) established and is reflective of a company's risk tolerance requirements. If the LOPA finds a gap where the undesired consequence is more frequent than the company's risk targets (TMELs), the team will propose additional IPLs to close the risk gap or suggest design changes to reduce the credible consequence severity.

Pressure Relief Devices used as an IPL

IPLs can be categorized as preventive or consequence mitigation systems. A pressure relief device acts as a consequence mitigation IPL as it does not prevent the overpressure, but it minimizes the consequence by controlling and directing the loss of containment to a "safe" location (as covered earlier). If the pressure relief device is to be treated as an IPL, it must meet the following criteria for acceptance as an IPL per CCPS RAGAGEP.

Specificity: The IPL by itself can prevent the cause from progressing to the undesired consequence. Verify the relief design basis (found in the PRV folder) includes the deviation that results in this overpressure case.

Independence: This IPL is independent from the initiating cause and other IPLs in that LOPA scenario. Verify that common failures do not defeat the PRV protection (e.g., undesirable reaction putting demand on PRV at same time creates a material that plugs the PRV).

Dependability: The IPL can be relied on to function with an expected probability to successfully prevent the undesired consequence when placed in demand. Refer to company specific IPL credit tables for specific guidance.

Auditability: The IPL can be and is routinely tested through the process lifecycle to maintain its' dependability. This is typically supported by testing and inspection in conformance with API RP 576, Inspection of Pressure-relieving Devices. A good question to ask the PHA team is "How often are PRVs removed from service for testing?"

Access Security: Changes to the PSV design (including inlet and discharge piping) are managed under Management of Change (MOC).

Risk Reduction Credits for Overpressure Scenario

The following ranges of risk reduction credit (1 credit = 1 IPL credited with a Risk Reduction Factor (RRF) of 10) are typically used during a LOPA, and are reported in the literature as noted.

Open Pipe: Typically considered an inherently safe solution as long as the vent capacity of the pipe is sufficient for the scenario and pluggage is not credible. Often inventoried as a pressure relief stream in process safety information.

Single PRV: Typically 2-3 credits, depending on the data cited [6]. Choose the low end if using managed block valve fitted beneath the PRV.

Multiple PRVs (each sized for full load): One additional credit beyond a single PRV [6].

Multiple PRVs (each not sized for full load): Same as a single PRV credit.

Plugging (or other fouling) Service: Reduction of one credit unless designed out (by installation, PRV type, etc.). If designed out, the installation should be monitored (flushes, freeze protection, tell-tale, etc.).

Rupture Disk Installed Beneath PRV: A rupture disk (or “bursting disc”) may be installed beneath a PRV to protect the PRV from the service conditions. Performance data for a stand-alone rupture disk is sparse. This is likely because legacy interpretations of the regulatory codes (ASME, etc.) discouraged their use, and therefore the installed base to gather data was lean. One industry source [5] indicates that a bursting “diaphragm” is worthy of 2 credits. In any case, more recent guidance from CCPS [6] gives 2 credits for a rupture disk in tandem with a PRV.

Pilot operated PRV: “The pilot-operated relief valve is particularly useful for operation close to the set pressure. Positive opening and closing actions avoid the simmering and chattering characteristics of conventional and balanced valves. Product losses are reduced, and maintenance costs to repair damaged seats are considerably lower” [1]. The disadvantage of a pilot relief valve is “more parts that can give trouble” [1]. Specific mention is made of the pilot lines which may plug or become crimped thus making the pilot relief valve inoperative. PERD data [7] show a pilot-operated relief valve to be less reliable than a conventional spring-loaded relief valve, by an order-of-magnitude higher PFD (probability to fail on demand). It may be useful to raise these issues with the PHA team if relevant to the context of the study. Use of 2 credits for a pilot relief valve is likely acceptable because the failure data reported in PERD, even though higher than a conventional relief valve, is still good enough for 2 credits.

Restoration of a Block Valve Fitted Under a PRV: Restoration is defined as “to return equipment to its normal status for production mode after the completion of maintenance, testing, calibration, etc.” [8]. A PRV may be removed from on-line service for bench testing and maintenance. It is necessary then to restore the PRV to service which would include re-opening the block valves that isolate the PRV from the process and flare header (if provided). There are several ‘tools’ that can increase the likelihood of successful restoration activities, such as use of restoration procedures, a robust tagging system (e.g. CLO/CSO program), and a culture that promotes use of administrative controls. Even when these systems are in place, performance of a PRV (or other IPL) to protect may be limited by human factors. It may be useful to raise these issues with the PHA team if relevant to the context of the study.

Using an SIS in lieu of a PRV: To what level of reliability should the SIS be designed? T.A. Kletz suggests, "Because of the uncertainties in the figures and differences in the mode of failure (a relief valve that fails to operate at set-pressure may open at a higher pressure, but this is not true of a trip), I suggest that a trip system used instead of a relief valve should have a reliability 10 times greater" [13]. If a standard credit for a single PRV of 2 is assumed, a trip used instead should be worthy of 3 credits (SIL 3). This is only a suggestion. Some end-users may choose to apply the risk based approach mentioned earlier.

Overpressure IPL solutions other than PRV (and any concerns)

A situation that may occur in a PHA/ LOPA is when the gap of a high-hazard overpressure scenario cannot be closed by a properly designed and installed PRV. In this case alternate solutions to close the gap are necessary. As long as independence is met, some options include:

- Quantitative Risk Analysis ("sharpen the pencil" to verify risk)
- Lining up Spare PRV for extra IPL credit (multiple 100% PRVs)
- High pressure alarm (or high level alarm for contingency of hydraulic overpressure)
- Interlocks to initiate shutdown of equipment or process

QRA could include consequence modelling be performed outside the PHA as a recommendation or parking lot item. Dispersion modeling software could be used to model the effects of fire, explosion, or toxic effects. Probit models could be used to further refine probability of impact to personnel. QRA could also include likelihood determination using fault tree analysis or human reliability analysis for estimating more precise (less conservative) initiating cause frequencies.

If a small gap exists for an overpressure scenario the PHA/ LOPA team may be tempted to recommend lining up a spare PRV to service to gain an extra credit (multiple 100% PRVs). The drawbacks associated with this are documented in [9] and should be looked at carefully.

High pressure alarms typically do not give enough operator response time. Process safety time to overpressure shall be estimated by calculation. High level alarm response time is more likely to be sufficient and should be verified by calculation.

Sometimes the only solution to close a high pressure gap is to initiate a trip of equipment or the process to remove the source of overpressure. This is typically not desired, and the trip system should be designed with reliability in mind.

Conclusion

This paper has presented guidance on the use of RAGAGEP for overpressure scenarios and their associated protective devices in the context of PHA and LOPA. Deviation questions related to overpressure and the governing RAGAGEP were reviewed. Protective devices used as IPLs in LOPA were reviewed for requirements and typical credits. Gap closure solutions were presented. CSE personnel should become familiar with this RAGAGEP and associated protective devices to be able to support overpressure risk mitigation in the safety lifecycle.

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10. API STD 521. Pressure-Relieving and Depressuring Systems. American Petroleum Institute.
11. 29 CFR 1910.106. Flammable Liquids.
12. NFPA 30. Flammable and Combustible Liquids Code.
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Table 1 of RAGAGEP Excerpts

RAGAGEP [3] [10] [11] [12]	Extract
ASME Section VIII U-1 (h)	Excluded from ASME VIII if (h) … (1) vessels having an internal or external pressure not exceeding 15 psi (100 kPa) (i) vessels having an inside diameter, width, height, or cross section diagonal not exceeding 6 in. (152 mm), with no limitation on length of vessel or pressure;
ASME Section VIII U-1 (j)	Exempted from Inspection if U-1(j) Pressure … that **do not exceed** the following volume and pressure limits may be exempted from inspection by Inspectors, … (j)(1) 5 cu ft (0.14 m3) in volume and 250 psi (1.7 MPa) design pressure; or U-1(j)(2) 3 cu ft (0.08 m3) in volume and 350 psi (2.4 MPa) design pressure; U-1(j)(3) 1½ cu ft (0.04 m3) in volume and 600 psi (4.1 MPa) design pressure. Note: The exclusion of relief device for these vessels should be verified per local jurisdiction.
ASME Section VIII UG-133 (c), Appendix M M-5	*(c)* Vessels connected together by a system of adequate piping not containing valves which can isolate any vessel, and those containing valves in compliance with Appendix M, M-5, may be considered as one unit in figuring the required relieving capacity of pressure relief devices to be furnished Is there a connected vessel that may provide pressure relief
ASME Section VIII UG-140	(a) A pressure vessel does not require a pressure relief device if the pressure is self-limiting (e.g., the maximum discharge pressure of a pump or compressor), and this pressure is less than or equal to the MAWP of the vessel at the coincident temperature and the following conditions are met: (1) The decision to limit the pressure by system design is the responsibility of the user. The user shall request that the Manufacturer's data report state that over- pressure protection is provided by system design per UG-140(a). (2) The user shall conduct a detailed analysis to identify and examine all potential overpressure scenarios. The "Causes of Overpressure" described in ANSI/API Standard 521, Pressure-Relieving and Depressuring Systems, shall be considered. Other standards or recommended practices that are more appropriate to the specific application may also be considered. A multidisciplinary team experienced in methods such as hazards and operability analysis (Hazop); failure modes, effects, and criticality analysis (FMECA); "what-if" analysis; or other equivalent methodology shall establish that there are no sources of pressure that can exceed the MAWP at the coincident temperature. (3) The results of the analysis shall be documented and signed by the individual in responsible charge of

RAGAGEP [3] [10] [11] [12]	Extract
	the management of the operation of the vessel. This documentation shall include as a minimum the following: a. a. detailed process and instrument flow diagrams (P&IDs), showing all pertinent elements of the system associated with the vessel b. a description of all operating and upset scenarios, including scenarios involving fire and those that result from operator error, and equipment and/or instrumentation malfunctions c. an analysis showing the maximum coincident pressure and temperature that can result from each of the scenarios listed in item UG-140(a)(3)(b) above does not exceed the MAWP at that temperature (b) If the pressure is not self-limiting, a pressure vessel may be protected from overpressure by system design or by a combination of overpressure by system design and pressure relief devices, if the following conditions are met. The rules below are NOT intended to allow for normal operation above the MAWP at the coincident temperature. (1) The vessel is not exclusively in air, water, or steam service unless these services are critical to preventing the release of fluids that may result in safety or environmental concerns. (2) The decision to limit the overpressure by system design is the responsibility of the user. The user shall request that the Manufacturer's data report state that over- pressure protection is provided by system design per UG-140(b) if no pressure relief device is to be installed. If no pressure relief device is to be installed, acceptance of the jurisdiction may be required. (3) The user shall conduct a detailed analysis to identify and examine all scenarios that could result in an over- pressure condition and magnitude of the overpressure. The "Causes of Overpressure" as described in ANSI/API Standard 521, Pressure-Relieving and Depressuring Systems, shall be considered. Other standards or recommended practices that are more appropriate to the specific application may also be considered. A multidisciplinary team experienced in methods such as hazards and operability analysis (Hazop); failure modes, effects, and criticality analysis (FMECA); "what-if" analysis; or other equivalent methodology shall conduct the analysis. (4) The overpressure scenario shall be readily apparent so that operators or protective instrumentation will take corrective action to prevent operation above the MAWP at the coincident temperature.

RAGAGEP [3] [10] [11] [12]	Extract
	(5) There shall be no credible overpressure scenario in which the pressure exceeds 116% of the MAWP times the ratio of the allowable stress value at the temperature of the overpressure scenario to the allowable stress value at the design temperature. The overpressure limit shall not exceed the test pressure. Credible events or scenario analysis as described in WRC Bulletin 498 “Guidance on the Application of Code Case 2211 — Overpressure Protection by Systems Design” shall be considered. (6) The results of the analysis shall be documented and signed by the individual in responsible charge of the management of the operation of the vessel. This documentation shall include as a minimum the following: (a) detailed process and instrument flow diagrams (P&IDs), showing all pertinent elements of the system associated with the vessel (b) a description of all operating and upset scenarios, including those involving fire and those that result from operator error, and equipment and/or instrumentation malfunctions (c) a detailed description of any safety critical instrumentation used to limit the system pressure, including the identification of all truly independent redundancies and a reliability evaluation (qualitative or quantitative) of the overall safety system (d) an analysis showing the maximum pressure that can result from each of the scenarios
ASME Section VIII UG-135 (d)(1), (d)(2) and Appendix M	There shall be no intervening stop valves between vessel and its pressure relief device or devices, or between the pressure relief device or devices and the point it discharge, except: (1) when these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure relieving capacity provided by the unaffected pressure relief devices below the required relieving capacity or (2) under conditions set forth in Appendix M.
ASME Section VIII UG-135 (b) (1)	(b)(1) The opening through all pipe, fittings, and non-reclosing pressure relief devices (if installed) between a pressure vessel and its pressure relief valve shall have at least the area of the pressure relief valve inlet. The characteristics of this upstream system shall be such that the pressure drop will not reduce the relieving capacity below that required or adversely affect the proper operation of the pressure relief valve.
ASME Section VIII UG135 (a)	(a)Pressure relief devices intended for relief of compressible fluids shall be connected to the vessel in the vapor space above any contained liquid or to piping connected to the vapor space in the vessel which is to be protected. Pressure relief devices intended for relief of liquids shall be connected below the liquid level Alternative connection locations are permitted, depending on the potential vessel overpressure scenarios and the type of relief device selected, provided the requirements of UG-125(a)(2) and UG-125(c) are met.

RAGAGEP [3] [10] [11] [12]	Extract
ASME Section VIII UG-127 (b) (4)	(4) the space between a rupture disk device and a pressure relief valve shall be provided with a pressure gage, a try cock, free vent, or suitable telltale indicator. This arrangement permits detectionof disk rupture or leakage.
API 521 6.3	6.3 Atmospheric discharge …. The decision to discharge hydrocarbons or other flammable or hazardous vapors to the atmosphere requires careful attention to ensure that disposal can be accomplished without creating a potential hazard or causing other problems, such as the formation of flammable mixtures at grade level or on elevated structures, exposure of personnel to toxic vapors or corrosive chemicals, ignition of relief streams at the point of emission, excessive noise levels and air pollution
ASME Section VIII UG-135 (f)	*(f)* Discharge lines from pressure relief devices shall be designed to facilitate shall be fitted with drains to prevent liquid form lodging on the discharge of the pressure relief device and such lines shall lead to a safe place of discharge.
29 CFR 1910.106(b)(4)(ii)	"Vents." Vents for tanks inside of buildings shall be as provided in subparagraphs (2) (iv), (v), (vi)(b), and (3)(iv) of this paragraph, except that emergency venting by the use of weak roof seams on tanks shall not be permitted. Vents shall discharge vapors outside the buildings.
NFPA 30 2.3.4.6.1	2.3.4.6.1 Vents for tanks inside tank buildings shall be designed to ensure that vapors are not released inside the building.
ASME Section VIII UG-133 (d)	(d) Heat exchangers and similar vessels shall be protected with a pressure relief device of sufficient capacity to avoid overpressure in case of an internal failure.
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