The Importance of a Team-Based Approach to Overpressure Scenario Development

Neil Prophet / Principal Author
ioMosaic Corporation
93 Stiles Road | Salem, NH 03079
prophet.n.tx@iomosaic.com

Gene Gorski / Author
ioMosaic Corporation
93 Stiles Road | Salem, NH 03079
gorski.g.nh@iomosaic.com

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Neil Prophet / Principal Author
ioMosaic Corporation
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Gene Gorski / Author
ioMosaic Corporation
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gorski.g.nh@iomosaic.com

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Abstract

With the increased regulatory focus on pressure relief and flare systems (PRFS) design basis, many companies are in the process of updating their existing relief systems design documentation. A very important aspect of any relief systems analysis is the correct identification of overpressure scenarios, and one way to ensure successful and accurate overpressure scenario development is to conduct this process as a team. This approach is currently in effect at many major oil and petrochemical companies including BP, Shell, Chevron Phillips, Bayer, etc., even though current relief systems, recognized and generally accepted good engineering practice (RAGAGEP), does not call for this approach.

The benefits of a team-based approach to overpressure scenario development include participation and consensus from all affected disciplines: engineering, operations, instrumentation and control, maintenance, and process safety. Unique insights can be provided through operational experience, and there are opportunities to confirm correct operating and design conditions.

In the same way that a process hazard analysis (PHA) is conducted using a team approach; so should the relief systems rationale.

This paper outlines the basic steps involved in overpressure scenario identification, the way that a team approach can be implemented, and the benefits of a team-based approach to overpressure scenario development.

1. Background

The provision of overpressure protection is a typical requirement for any ASME code-stamped equipment. When considering overpressure protection, the primary regulatory drivers in the US are:

i. OSHA Standard 1910.119 Process Safety Management of Highly Hazardous Chemicals
ii. ASME Section VIII (Pressure Vessels)
iii. ASME Section I (Boilers)
iv. ASME B31.1 and B31.3 (Piping)

When designing overpressure protection systems, the established codes and practices that are commonly considered include:

i. API Standard 520 Part I[i]
ii. API Recommended Practice 520 Part II[ii]
iii. API Standard 521[iii]
iv. API Standard 526
v. API Standard 2000
vi. NFPA-30
vii. CCPS, '*Guidelines for Pressure Relief and Effluent Handling*' [iv]

It is interesting to note that while these documents are considered RAGAGEP, they do not discuss the need for a team approach for overpressure scenario identification and development.

When conducting design or evaluation studies of existing relief systems, there are a number of commonly established steps in any project:

- Define scope, basis, and project guidelines
- Gather project and process data
- Develop overpressure scenarios for each protected system
- Determine relief requirement for each applicable scenario
- Calculate relief device capacity for each applicable scenario
- Identify any relief system deficiencies and formulate mitigation options
- Generate report

For new relief systems, the last three steps listed above are substituted with the following steps:

- Determine the minimum relief area which will satisfy all applicable scenarios
- Select an appropriately-sized relief device with proper materials of construction
- Design relief system piping system to avoid temperature concerns, downstream collection system concerns, vibration concerns, (for relief valves: excessive inlet line pressure loss or discharge line built-up backpressure), discharge consequences.
- Generate PRFS design information (Process Safety Information)

This paper focuses on the "development of overpressure scenarios for each protected system" step. A thorough hazard identification is essential for the overall study to be successful.

As Trevor Kletz once stated "Are we sure that we have identified all the major hazards and all the ways they can occur? What has not been identified can neither be assessed nor mitigated". It is therefore imperative that the overpressure scenario development stage receives the attention it merits.

2. Overpressure Scenario Identification

When considering overpressure protection, prudent evaluation of pressure-relief systems involves much more than just relief devices.

A "Relief System" should include, but is not limited to:

- All interconnected vessels, equipment, and process lines in the system
- Relief device
- Relief device inlet line
- Relief device discharge line
- Relief header
- Vent containment system (cyclone, separator, catch tank, scrubber, stack)
- Flare knockout pot
- Flare and stack
- A variety of associated indicators, sensors, and alarms used to indicate whether the process equipment is functioning properly and whether the relief systems are functional or functioning as designed
- External factors such as human error, control systems failure, fire exposure
- A consideration of the area at and around the atmospheric release point

Depending on the extent of the study scope, each of these components should be considered during the overpressure scenario development stage.

API Standard 521 provides very thorough guidance on overpressure contingency analysis, determination of relieving rates, and disposal systems. API Standard 521 lists the following upset conditions, which may result in overpressure:

- Closed outlets on vessels
- Inadvertent valve opening
- Check-valve leakage or failure
- Utility failure
- Electrical or mechanical failure
- Loss of fans
- Loss of heat
- Reflux failure
- Abnormal heat input from reboilers

- Heat exchanger tube failure
- Transient pressure surges
- Plant fires
- Process changes/chemical reactions

Using this list as a basis, it was possible to develop a matrix of overpressure scenario, cross-referenced to specific vessel types, as shown in Table 1:

Table 1. Common Contingencies Cross-Referenced to Type of Equipment

	Closed Outlets	Cooling Failure	Reflux Failure	Accumulation of Noncondensables	Mixing of Volatile and Hot Materials	Failure of Automatic Controls	Abnormal Heat or Vapor Input	Internal Explosions	Chemical Reaction	Hydraulic Thermal Expansion	Exposure to External Fire	Ruptured heat exchanger tube	Power / Utility Failure	Inadvertent Valve Opening	Transient Pressure Surges	Inbreathing/Outbreathing
Blower	☑												☑			
Boiler	☑										☑		☑			
Column - Packed	☑	☑	☑			☑	☑				☑		☑	☑		
Column - Trayed	☑	☑	☑			☑	☑				☑		☑	☑		
Compressor - Centrifugal	☑												☑			
Compressor - Positive Displacement	☑												☑			
Dryer	☑				☑	☑				☑	☑		☑	☑		
Filter	☑					☑				☑	☑		☑	☑		
Fired Heater	☑												☑			
Heat Exchanger - Aerial	☑					☑					☑		☑			
Heat Exchanger - Concentric Pipe	☑					☑				☑	☑		☑			
Heat Exchanger - Electric	☑					☑				☑	☑		☑			
Heat Exchanger - Other	☑					☑				☑	☑		☑			
Heat Exchanger - Plate and Frame	☑					☑				☑	☑		☑			
Heat Exchanger - Shell and Tube	☑					☑				☑	☑	☑	☑			
Pipe Segment	☑									☑			☑			
Pump - Centrifugal	☑												☑			
Pump - Positive Displacement	☑												☑			
Reactor	☑	☑				☑			☑		☑		☑	☑		
Storage Tank	☑					☑					☑		☑	☑		☑
Storage Vessel	☑					☑					☑		☑	☑		
Turbine	☑												☑			
Vessel	☑					☑					☑		☑	☑		

For each relevant scenario, a narrative should be developed stating whether a scenario is applicable or not, and the reasoning behind a decision. A standard overpressure scenario analysis form should be developed which addresses each of these scenarios, as well as listing the protected equipment, and overpressure protection, for each system.

It is common practice for designers of pressure-relief systems to require extensive process and equipment information. OSHA 1910.119 Section D outlines data that should be available to support a process hazard analysis study, and the requirements are similar for a relief systems design study. In order to fully conduct a relief systems design study, a full range of supporting process safety documentation should be available, such as that shown in Table 2. Additionally, piping isometrics, relief devices and vessel design parameters, and piping and instrument drawings (P&IDs) should be field verified to ensure an accurate evaluation.

Table 2. Typical Relief Systems Design Study Data Requirement

	General Data Requirements	
Process Design and Description	Piping and Instrumentation Diagrams (P&ID) Heat and Material Balances (H&MB) Process Flow Diagrams (PFD) Process Safety Flow Diagrams (PSFD) Process descriptions / operating procedures Plot plans / elevation plans	
Utility and Piping Design	Utility operating conditions (electrical, instrument air, cooling water, steam, etc.) Electrical one-line diagrams Piping designations and ratings Insulation designations and ratings	
	Data Requirements	
	Required Information	**Data Source Hierarchy**
Fluid and Mixture Properties	Thermophysical properties	1. DIPPr database using modified PR EOS 2. Company generated data 3. Estimates based on structure
	Reaction kinetic models	1. Company provided adiabatic calorimetry data 2. Open literature data 3. Externally generated adiabatic calorimetry data
Pressure Relief Devices	Manufacturer / model number Inlet / outlet / discharge area sizes Opening pressure and temperatures	Relief Device Information: 1. Maintenance records 2. Relief device specification sheets 3. Original design basis 4. P&ID 5. Valve Tag Inlet / Outlet Piping Details: 1. Existing isometric drawings 2. Field sketches
Fixed Process Equipment (General)	MAWP, MAWT, and vacuum rating Design conditions Equipment Dimensions	1. U-1A forms 2. Mechanical drawings 3. Equipment specification sheets 4. Operating Manuals 5. P&IDs 6. Nameplate
Vessels	Liquid levels	1. Operating procedures 2. P&IDs 3. Equipment design drawings

	General Data Requirements	
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Utility and Piping Design	Utility operating conditions (electrical, instrument air, cooling water, steam, etc.) Electrical one-line diagrams Piping designations and ratings Insulation designations and ratings	
	Data Requirements	
	Required Information	**Data Source Hierarchy**
		4. Level alarm set-points 5. Level-gauge tapping locations (from equipment design drawings)
	Elevation	1. P&ID 2. Equipment design drawing
	Insulation type, thickness, firegrade status	1. Maintenance records 2. Equipment design specification 3. P&IDs
Heat Exchangers	Design type Rated and normal duty Tube ID / length	1. U-1A forms 2. Heat exchanger specification sheets 3. P&ID 4. Nameplate
Heaters / Steam boilers	Tube Design Pressures Furnace design duty Boiler dimensions and design duty	1. Heater / Boiler specification sheets 2. U-1 Forms 3. P&ID 4. Nameplate
Rotating Process Equipment (General)	MAWP, MAWT Design conditions	1. Equipment specification sheets 2. P&ID 3. Equipment nameplate
Centrifugal Pumps	Pump capacity curve, rated capacity, and installed impeller size Suction Conditions	1. Performance curves 2. Pump specification sheets 3. Maintenance records (installed impeller and corresponding curve) 4. P&ID 5. Nameplate
Centrifugal Compressors	Compressor capacity curve and rated capacity Suction conditions Isentropic or polytropic efficiencies	1. Performance curves 2. Compressor specification sheet 3. Original design data 4. P&ID 5. Nameplate
Positive Displacement Pumps	Pump casing MAWP / MAWT, design conditions Rated capacity	1. Pump specification sheets 2. P&ID 3. Nameplate
Reciprocating Compressors	Compressor manufacturer/model Cylinder type (double acting, etc.), diameter Stroke length, Rod diameter, Piston displacement, Engine speed, Volumetric efficiency	1. Compressor specification sheets 2. Original design specification 3. P&ID 4. Nameplate

General Data Requirements		
Process Design and Description	Piping and Instrumentation Diagrams (P&ID) Heat and Material Balances (H&MB) Process Flow Diagrams (PFD) Process Safety Flow Diagrams (PSFD) Process descriptions / operating procedures Plot plans / elevation plans	
Utility and Piping Design	Utility operating conditions (electrical, instrument air, cooling water, steam, etc.) Electrical one-line diagrams Piping designations and ratings Insulation designations and ratings	
Data Requirements		
	Required Information	**Data Source Hierarchy**
Turbines	Exhaust casing MAWP / MAWT, design conditions, Steam throughput	1. Turbine specification sheets 2. P&ID 3. Nameplate
Control Valves	Sizes (inlet / outlet / port) Manufacturer and model number Fail safe position	1. Control valve data sheets 2. Vendor data 3. Nameplate

Of particular importance at the overpressure scenario development stage is the following information:

- Piping & Information Diagrams
- Process Flow Diagrams
- Heat & Material Balance
- Equipment design pressures, operating pressures, and elevations
- Relief systems set pressures and specifications

2.1 Overpressure Scenario Development Preparation

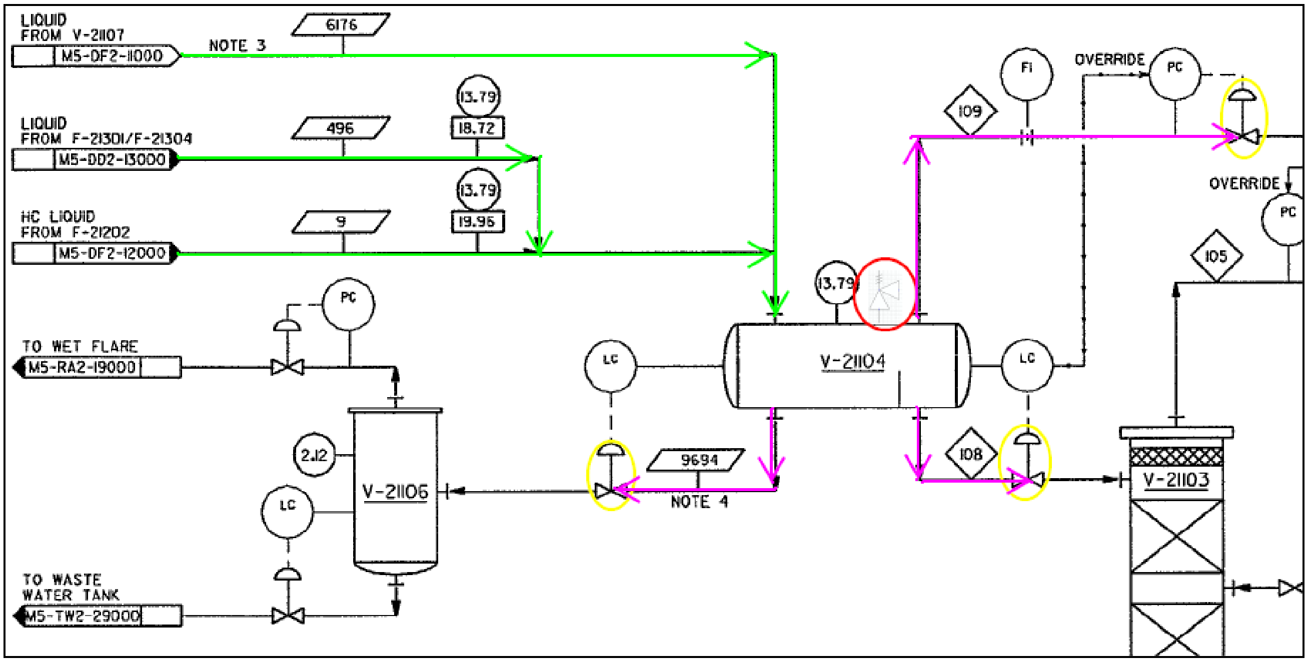
Unlike conducting a PHA, it is most efficient for an individual engineer to develop a set of narratives prior to conducting the team meeting. These draft overpressure scenario analysis forms (narratives), developed by the engineer should be considered as a ‘strawman’ for discussion, based on the information available to the engineer. The intent of the team-based meetings is then to ratify, or amend, these forms, to gain consensus on which overpressure scenarios are applicable, and which are not.

In addition to the draft overpressure scenario analysis forms, a visual representation of each protected system should be developed. An example is shown in Figure 1. This visual aid should show the protected equipment, equipment connectivity, pressure sources, pressure-limiting devices, process and utility lines leading into and out of the (evaluated) protected equipment. The visual aid will help to expedite the team-based overpressure scenario review meeting, which occurs upon completion of the individual draft work.

The visual aid can be created by using a portion of the PFD, one or more P&IDs, and / or a hand sketch. Color-coding can further enhance the effectiveness of these visual aids. For example, the following color scheme can be used for highlighting lines and valves:

- Red - PSV’s
- Green - Feed lines to vessels or equipment
- Purple - Discharge lines
- Yellow - Control valves
- Blue - water, steam, air, or nitrogen (utility lines)

Figure 1. Visual Aid for Each Protected System



2.2 Team-Based Overpressure Scenario Review Meeting

The team-based overpressure scenario review meeting should be conducted similarly to that of a process hazard analysis. Participants should include:

- Facilitator
- Scribe
- Pressure Safety Specialist
- Process Knowledgeable Person
- Plant Operator
- Plant Process Engineer
- Project Engineer

(At a minimum, the team must include a pressure safety specialist and a process knowledgeable person to be effective.)

In addition to the main participants, other participants are likely to be required on a less-than-full-time basis, with one participant potentially providing more than one type of expertise. These "as needed participants" typically include:

- Controls and Instrumentation
- Electrical, Mechanical
- Maintenance
- Process Safety

Attendance should be taken at the start and end of each morning and afternoon session, noting full-time and part-time participants, the date and the session. The Scribe is responsible for keeping accurate attendance lists and matching the attendance lists with evaluated equipment.

Team-based overpressure scenario review meetings should assess each equipment item within the scope, and aim to cover a specific section of plant. At the start of the scenario analysis for a unit, the process knowledgeable person should briefly describe the unit's design intent and modes of operation.

Meeting progress can be expedited by sharing the draft overpressure scenario development forms (narratives) with meeting participants for their review prior to the meeting. Team members should be provided with both the relevant draft overpressure scenario development forms, and the visual aid that was assembled to help facilitate discussion.

Providing team members with a copy of the project guidelines used would also be very useful. A good project guidelines document addresses the following concepts:

- Document the relief systems evaluation and design philosophy
- Address gaps and inconsistencies in existing design methodology, guidelines or standards
- Serve as a condensed design guide/best practices document addressing all relevant codes and standards
- Identify the form, layout, and content of all project reports and deliverables

The facilitator should lead the team-based overpressure scenario review meeting, one piece of equipment (or protected system) at a time. The facilitator should use the draft overpressure scenario development forms and visual aids to lead the meeting participants through the review to determine if all credible scenarios have been identified and if the identified scenarios are correctly considered credible. A good facilitator keeps the review moving (limiting side discussions) and keeps the participants engaged. The facilitator decides when discussions should be tabled, rescheduled for a smaller group, or expanded to include one or more of the additional attendees.

As the review of each piece of equipment proceeds, the scribe should update the draft overpressure scenario development form based on team member comments and team consensus. The scribe should keep a record of all issues that require resolution, or tabled discussions that require follow-up action. Specific input from operations, or process engineering, can help resolve previously identified data discrepancies, and should be noted on the forms.

2.3 Improving Meeting Efficiency

Any meeting involving multiple participants for extend periods of time can be expensive, and difficult to organize. It is therefore in the team's interests to ensure that the team-based overpressure scenario development meeting runs as smoothly and efficiently as possible.

This can be achieved in a number of ways:

Availability of accurate process and mechanical data: it is essential that the engineer developing the draft overpressure scenario development forms has access to accurate data. If not, the process of identifying overpressure scenarios will be hindered prior to the team meeting, as well as during the team meeting. Throughout the overpressure protection study, a consistent design basis should be used.

Accurate draft overpressure scenario development forms: The progress of the team-based overpressure scenario development review meeting will be directly influenced by how little or how much revisions are required to the draft overpressure scenarios development forms. It is therefore beneficial that the engineers developing these draft forms spends as much time as is required to generate an accurate set of overpressure scenarios. Common errors include not analyzing every single control valve affecting a system, failing to trace the source of pressure far enough upstream, and not considering every equipment item in a 'protected' system.

Effective use of audio-visual equipment: As with a PHA, where the PHA worksheets can be projected using a data projector for all the participants to see, so can the draft overpressure scenario development forms. This will ensure the entire team can follow the meeting progress, and ensures agreement on conclusions reached. An adept scribe can even utilize two computers and two data projectors, where the draft overpressure scenario development form is shown on one, and the visual aid is displayed on the other.

Advanced preparation from all team members: If time permits, the draft overpressure scenario development forms should be shared with team members in advance of the team-based overpressure scenario review meeting. This will enable team members to review and develop comments and questions prior to the meeting. In addition, if time permits, it is useful to have an "example session" with all team members in advance of the team-based overpressure scenario review meeting. This will familiarize team members that have not previously participated in the review process so that they can better self-prepare for the future meeting.

Provision of P&IDs: During the entirety of the meeting, sets of P&IDs and visual aids should be available to each team member.

Grouping of similar or identical equipment: In facilities where similar or identical systems are present, and one system has already been reviewed in entirety, the team may elect to consider similar or identical systems 'by difference', thereby increasing the pace of the review meeting.

Pace of meeting: A simple system can be reviewed within a matter of minutes by an experienced team, whereas a complex system may take two or three hours. It is important that the team does not set too ambitious progress goals, so that the review meeting is not rushed. Additionally, the facilitator should recognize the need for frequent breaks in order to help the team stay focused.

2.4 Finished Product

The outcome of the team-based overpressure scenario development meetings will be a finalized set of overpressure scenario development forms (narratives). These forms will be part of the facility's relief systems design basis and, just like finalized PHA worksheets they should not be edited without consensus from the review team.

It should be realized that the finalized overpressure scenario development forms are only part of the relief systems design basis. Calculations are still required to determine required relief rates and flow capacities for each applicable overpressure scenario identified.

2.5 Conclusions

There is increased regulatory focus on pressure relief and flare systems design basis, and many companies are in the process of updating their existing relief systems design documentation.

Those companies that adopt a team-based approach to overpressure scenario development exhibit a proactive commitment to following recognized and generally accepted good engineering practices. In addition, they will have increased confidence in the quality of their relief systems design documentation, and the overpressure protection process will have increased understanding and acceptance from multiple plant disciplines.

While this step in a relief systems study is not identified as RAGAGEP, in current relief systems documentation, it is only matter of time before this process is identified as such.

3. References

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[i] "Sizing, Selection, and Installation of Pressure Relief Devices in Refineries" 8th Edition, API Standard 520 Part I (2008).

[ii] "Sizing, Selection, and Installation of Pressure Relief Devices in Refineries" 5th Edition, API Recommended Practice 520 Part II (2003).

[iii] "Pressure-relieving and Depressuring Systems" 5th Edition, ANSI/API Standard 521 (ISO 23241) (2007).

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Additional References not cited:

[v] "Guidelines for Hazard Evaluation Procedures", 3rd Edition, AIChE/CCPS (2008).