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A Systematic Approach to Relief and Flare Systems Evaluation

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The process industries are primarily concerned with the reliability, availability, auditability, and maintainability of relief and flare systems data. These data are critical component of process safety information and its lifecycle must be properly managed to ensure sound process safety management and loss prevention programs.

For most large facilities, the process of managing the lifecycle of relief and flare systems data are complex and fraught with challenges and risks, whether the work is performed internally or contracted out. For existing large facilities, the process of relief and flare systems evaluations require mechanical and process data collection, field verification, up to date heat and material balances, information about process safeguards, scenario identification, establishing relief requirements, identification and risk ranking of deficiencies, and managing the corrective actions process for addressing deficiencies where applicable.

Reliability is influenced by many technical and human factors including the quality of data, adequacy of tools used for analysis, the qualifications of the relief systems engineers performing the scenario identification, and relief and flare systems evaluations.

Availability primarily deals with how quickly can one access accurate and up to date relief and flare systems data. This is especially challenging since relief systems data are not all "structured" data and are interconnected with other engineering data systems.

Auditability involves version control and the management of revisions and/or modifications of relief and flare systems that typically result from plant/process modifications, process hazard analysis, incident investigations, etc.

Maintainability requires keeping the relief and flare systems data forever green and enabling efficient reviews and revisions.

This article describes a systematic web-based workflow methodology for managing the lifecycle of relief and flare systems data for a single site or at a corporate level. The workflow methodology breaks the flare and relief systems data lifecycle into discrete components and activities, with built-in review, approval, quality management, and reporting. Built-in business and engineering rules ensure that all activities can only progress when specific quality criteria are met.

This system was developed based on our experience with the execution of many such large scale projects for refineries, chemical, and petrochemical facilities. Process Saf Prog 32: 230–238, 2013

Keywords: relief systems; flare systems; emergency relief systems; workflow; reaction systems; depressuring systems

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INTRODUCTION AND RELIEF SYSTEMS REGULATORY REQUIREMENTS IN THE UNITED STATES

Any process dealing with relief systems design and/or evaluation has to comply with regulatory requirements and good engineering practice. In the United States, the process safety information (PSI) element of the Occupational Safety and Health Administration (OSHA) process safety management (PSM) regulation requires a PSM covered facility to demonstrate that:

- relief systems comply with recognized and generally accepted good engineering practice (RAGAGEP) 29 CFR 1910.119 (d)(3)(ii), and
- the relief systems design and design basis information is properly documented 29 CFR 1910.119 (d)(3)(i)(D).

Under section 29 CFR 1910.119 (d)(3)(iii): "For existing equipment designed and constructed in accordance with codes, standards, or practices that are no longer in general use, the employer shall determine and document that the equipment is designed, maintained, inspected, tested, and operating in a safe manner." This is especially important for older facilities that were constructed well before the PSM regulation was enacted.

OSHA's definition of equipment is broad as defined in the mechanical integrity (MI) element and includes relief and vent systems and devices. This also creates additional requirements for relief and flare systems testing and inspection such as under (j)(4) as well as the requirement to address MI deficiencies in a timely manner:

- CFR 1910.119 (j)(4)(ii): "Inspection and testing procedures shall follow recognized and generally accepted good engineering practices."

The PSM requirements needed to be satisfied by May 26, 1997.

Corporate standards, policies, best practices, and procedures qualify as in-house RAGAGEP for company facilities worldwide, especially, where the corporate standard is more restrictive. Whether the facilities have their own procedures or follow corporate procedures or both, it is clear that OSHA expects that the facility will comply ("*do what they have* *committed to do*") with these procedures to satisfy PSM requirements regardless of how they are classified. More importantly, most corporate standards include by reference other standards and codes that they designate as RAGAGEP.

The term RAGAGEP encompasses a wide body of industry codes and standards. Moreover, RAGAGEP defines the standard of care expected of companies by regulatory agencies, government, and society in operating chemical manufacturing (and other) businesses [1].

RAGAGEPs will change with time as new standards are developed and existing standards are updated. This allows the PSM standard to stay current with RAGAGEPs without necessitating a change in the regulation. In many cases, the OSHA PSM standard has in fact resulted in many RAGAGEP s to be developed or updated.

Considerable effort is required to stay in compliance with a performance-oriented standard like the OSHA PSM regulation. Compliance requires (1) a good understanding of the RAGAGEPs that apply to the facility, (2) that the PSM program procedures incorporate these requirements, (3) constant vigilance to stay up to date on changes to RAGAGEPs since many industry standards are reissued every few years, (4) and most importantly an effective compliance audit program to verify that procedures include all applicable RAGAGEPs and that the procedures are being implemented as written.

On June 7, 2007 OSHA initiated a Petroleum Refinery PSM National Emphasis Program (NEP). The PSM covered Chemical facilities NEP program was effective on July 27, 2009. The NEP approach provided a particular set of requirements to be addressed during inspections including review of documents, interviews of employees, and verification of implementation for specific processes, equipment, and procedures.

The NEP program most frequently cited items included MI, PSI, operating procedures (OP), process hazard analysis (PHA), and management of change (MOC). The Petroleum Refinery NEP program focused heavily on relief and flare systems.

The OSHA NEP program citations statistics confirm that PSI compliance is lacking. Missing or incomplete PSI also cause deficiencies in MI and other PSM elements since PSI, MI, and MOC PSM compliance are highly interrelated. Significant components of PSI are relief and flare system design and design basis documentation.

RELIEF SYSTEMS PSI REQUIREMENTS

Relief systems are critical chemical process safeguards that protect from catastrophic vessel failures (bursts) due to overpressure and/or underpressure. They are often referred to as the "last line of defense" and are expected to function properly when all other safeguards fail to mitigate the scenarios causing overpressure or underpressure. Relief systems should not be the only line of defense or layer of safeguarding. Relief systems should be one of the protection layers, and preferably the last layer that will be called upon when all other layers fail to address deviations from normal operation.

A relief system includes both relief devices and vents containment/flare equipment. A relief system includes the relief device, the inlet line, the discharge line, the common header, the catch tank, etc.

A design basis is established by examining all possible scenarios (or contingencies) that can lead to overpressure and/or underpressure of the equipment protected by the relief system. The scenario that leads to the largest relief requirement is typically chosen as the "design basis." Proper scenario development and analysis for relief systems design requires substantial PSI as shown by Table 1. Establishing the design basis for one vessel protected by one or more relief devices is a similar exercise to performing a PHA on that one vessel.

The documentation of "design and design basis" has to include much of the information provided in Table 1 in addition to the calculation details in order to comply with numerous published RAGAGEP requirements by NFPA, ASME, API, CCPS, AIChE/DIERS, ISA, ANSI, etc. Note that justification needs to be provided for why scenarios apply or for why they do not apply.

CHALLENGES ASSOCIATED WITH DEVELOPING AND DOCUMENTING RELIEF AND FLARE SYSTEMS DESIGN AND DESIGN BASIS

Significant resources are required in order to properly establish compliance with RAGAGEP and to document the design and design basis for relief and flare systems. Compliance requires up to date information for all that is listed under the OSHA PSI element (d). For example, the P&ID data has to be provided and field verified as well as vessel design ratings.

The level of effort required for performing an analysis to establish/verify/document the design and design basis for one relief device/system will depend on the nature of the system and the state of the existing information required to perform the analysis. One has to also account for missing PSI data development or mitigation costs that would be required if deficiencies are discovered. For example, some systems will require the testing and development of chemical reaction information for undesired chemistry.

For plants constructed prior to 1992, it expected that up to 40% of relief device installations will not meet the OSHA requirements for compliance with RAGAGEP and/or for design and design basis documentation.

Experience indicates that most relief systems challenges are similar across a variety of industries. Typical issues encountered during relief and flare systems evaluation projects include but are not limited to:

- Outdated or nonexistent design basis and supporting calculations including vent containment and flare system design basis
- Noncompliance with new API-521/ISO/OSHA documentation recommendations
- Missing or outdated process and mechanical information such as material and energy balances, piping isometrics, vessel design data, and control system specifications
- Relief devices that discharge hazardous materials to atmosphere, or the counterpart: overloaded flare systems
- Ignorance of chemical reactivity and multiphase flow in existing relief calculations
- Pressure relief valve (PRV) installation inadequacies such as excessive inlet pressure drop and excessive backpressure
- Improperly designed depressuring systems, particularly with high-pressure operations—examples include cold temperatures downstream of pressure relief valve and wall temperatures/failure pressures under fire exposure

In addition, there are many gray areas in the current state of the art for relief systems evaluation that further exacerbate and complicate how compliance is achieved. Technical issues that are currently the subject of debate and some controversy amongst relief systems experts including but not limited to:

- Use of actual (best estimate) flow versus required flow for (a) inlet pressure loss, (b) backpressure, (c) subheader/flare header hydraulics, and (d) effluent handling equipment (knockout drums, flare tips) design
- Use of 3% inlet pressure loss requirement versus a more relaxed requirement for existing installations such as blowdown minus 2%
- Fire exposure and cold temperature development for depressuring systems, especially, for gas filled vessels

Table 1. Typical Process Safety Information Required for Establishing and Documenting Relief and Flare Systems Design and Design Basis [1].

Process Design and Description	Piping and Instrumentation Diagrams (P&ID) Heat and Material Balances (H&MB) Process Flow Diagrams (PFD) Process Safety Flow Diagrams Process Descriptions/OP 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	
		Typical Data Source
Fluid and Mixture Properties	Thermo-physical properties	1. Properties Databases such as DIPPR and SuperChems 2. Company generated data 3. Estimates based on structure
	Chemical reactivity and reaction kinetics	1. MSDS (starting point) 2. Client **adiabatic** calorimetry data 3. Open literature data 4. 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. OP 2. P&IDs 3. Equipment design drawings 4. Level alarm set-points 5. Level-gauge tapping locations (from equipment design drawings)
	Elevation	1. Equipment elevation drawings 2. Equipment arrangements drawings
	Insulation type, thickness, fire proofing 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	1. Performance curves
	Suction Conditions	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
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

- Correct usage of two-phase discharge coefficient
- Estimation of two-phase density with slip
- Use of fire flux for dynamic simulations. Decreasing wetted surface area for all gas flow as well as use of total vessel wetted surface area for two-phase flow
- Level of documentation that is sufficient to meet the OSHA PSI requirements

In addition to the numerous technical complexities, the most significant challenge with relief and flare systems documentation is "Management of the Data Lifecycle" and how that integrates with overall PSM. In particular, the connectivity of nonstructured data becomes very important. A relief device design and design basis record might include spreadsheets, e-mails, sketches, articles, and references, in addition to structured information that may already exist in a database.

Lack of PSI, uncertainties in the actual relief systems evaluation process dealing with some of the topics above as well as the availability of competing and inconsistent RAGAGEP, make this process very challenging.

Reliability, availability, auditability, and maintainability of this critical information continue to be a challenge for most companies. The ioXpress™/SuperChems™ server-client platform was developed to easily address these four key requirements and to facilitate site-wide and large scale multisite relief systems studies.

RELIEF AND FLARE SYSTEMS INFORMATION RELIABILITY REQUIREMENTS

The quality of relief systems evaluations is heavily influenced by many technical and human elements. The qualification of engineers performing the analysis should be verified. While drafting of isometrics and data entry can be adequately performed by a nonrelief system expert, scenario identification, modeling of complex dynamics, and the assessment of corrective actions will require deep expertise in process safety and relief systems.

The quality of the end result of any process simulation or relief systems assessment will also depend on the quality of thermodynamic, transport, chemical reactivity, and kinetic data available for the calculations. Vapor-liquid equilibrium data in particular are very important, especially for reaction systems.

The evaluation process should use field verified equipment ratings, relief piping isometrics, and flare network data for existing systems. For new design, the initial evaluation should be revalidated after the construction drawings are issued and also audited for compliance after construction is complete and prior to startup. This is necessary as isometrics can be changed during construction without considerations of pressure loss, elevation changes, and other factors that can impact relief device stability and structural dynamics and integrity.

Scenario identification and development is best performed by experienced process safety and relief systems engineers. Once scenarios are developed, a formal scenario review with plant operations should be conducted in order to validate the scenarios. Operating personnel in facilities can provide a wealth of knowledge regarding scenarios that have occurred in the past or more importantly near misses as well as deep insight into the control systems.

Up to date and truly representative material and energy balance data are very important, especially, for relief systems scenarios that are dependent on the flow capacity of a plant or a particular unit within a plant. Note that many older plants in the United States have been debottlenecked and increases in capacities have pushed operating conditions much closer to the operating design limits.

Consideration for reaction forces and vibration risk developed during relief is often poorly addressed in many systems we have reviewed. In some unique cases, poorly supported and/or designed relief piping can exhibit resonance with other systems components and fail catastrophically.

There are many unique systems that require special expertise such as high pressure ethylene systems, where the pressure can be as high as 1500 bars during normal operations and pressure relief can lead to very large dynamic reaction forces as well as cold cryogenic temperatures downstream of the flow restricting devices. In general, it is very difficult to support structures that are exposed to more than 25,000 lbf of thrust during relief.

Reaction and multiphase flow systems also require special expertise. Unlike non-reaction systems, where small uncertainties in PVT data and/or other design variables such as fire flux can be tolerated, reaction systems are very unforgiving. Reactions rates will typically double every 10 degrees. An erroneous estimate of the actual temperature at the relief device set point pressure can yield much faster reaction rates and ultimate failure due to inadequate relief. The vast majority of reaction systems will cause multiphase flow. Unlike single-phase flow, two-phase flow estimates are more uncertain and the reliability of designs involving two-phase flow are best validated by an expert [2].

Depressuring systems represent another area where special expertise is required and where poor designs have lead to accidents. For depressuring systems, we have to worry about both hot and cold temperatures during depressurization. Cold temperatures reached in vessel or downstream (especially if dew point is reached) can reach the embrittlement temperature of typical carbon steel. High superficial vapor velocities during depressuring that can cause liquid carryover and two-phase flow, excessive noise, and vibration risk [3, 4].

Condensing gas/two-phase flow downstream can lead to more liquid accumulation and cold temperatures. Condensation can lead to the formation of liquids at their associated dew point and can cause localized stress concentrations and embrittlement. Many offshore depressuring systems are suspect to hydrate formation as small amounts of water are present in the vessel hydrocarbon contents. Hydrate formation can cause plugging.

Even under fire exposure, large temperature differences at the vapor/liquid wall interface have been observed. This is where most failures are observed to initiate for two-phase vessels engulfed in a pool fire. A vessel under fire exposure that is rapidly depressurized can still be exposed to cryogenic temperatures because of the poor free convection heat transfer characteristics from the vessel wall to the vapor space during the first few minutes as the walls have not reached a sufficiently high temperature for radiation heat transfer to become dominant between the inner metal wall surface and the vapor/liquid contents. Localized flame jet heating on vessel walls (dry) and thermal heating from ignited PRV discharge are scenarios where protection by a relief device may not be possible or practical.

Software tools are a critical component of any relief systems design/evaluation. We often use a variety of tools including process simulators, spreadsheets, and commercially available specialized software tools such as SuperChems for DIERS (marketed by AIChE/DIERS). When selecting a software tool to evaluate relief and flare systems one needs to consider the pedigree of the software, how long it has been on the market, how many users are currently using the software, how the software is supported, how the software is updated, and how backward compatibility is addressed, whether the software has undergone industry wide benchmarking and review, etc. These calculation engines typically do not address data integrity requirements such version control, access history, encryption, etc. The web-based workflow system described in this article is based on the ioXpress/SuperChems server-client platform where the data management is centralized using ioXpress and the calculations are performed by clients using SuperChems Lite, for DIERS, or Expert as well as a variety of other tools.

RELIEF AND FLARE SYSTEMS INFORMATION AVAILABILITY REQUIREMENTS

"Availability" deals primarily with how quickly and easily one can access ALL relevant relief and flare systems data. This is a very challenging requirement since relief systems data are not all "structured data." Data access is required by the OSHA PSM regulation 29 CFR 1910.119 (c)(3) and (p)(1).

Relief systems data are often interconnected or embedded with other plant data systems and covers more than just a "specification" sheet for a relief device. This important data must be available and easily accessible to audit, incident investigation, PHA, and QRA teams.

The web-based workflow platform described later in this article addresses this requirement by providing the user with the ability to access all the interconnected relief systems data using a single point of access web form or by drilling down from a PFD and/or a PID.

RELIEF AND FLARE SYSTEMS INFORMATION AUDITABILITY REQUIREMENTS

The integrity of relief and flare systems information is enhanced by having a system with audit functions and features. "Auditability" deals primarily with version control and tracking of access, revisions, and modifications to all relief systems data and how modifications and updates influence and/or are influenced by MOC. Changes can result from field changes, overall process and equipment capacity changes, process changes, calculation revisions, incident investigations, revisions triggered by "MOC." Note that old versions should be maintained and accessible for the entire lifecycle of the plant.

The web-based platform described in this article incorporates version control as well as the ability to reverse changes that are rejected by the workflow in order to preserve the integrity of the data.

RELIEF AND FLARE SYSTEMS INFORMATION MAINTAINABILITY REQUIREMENTS

"Maintainability" deals primarily with keeping the relief and flare systems data forever green. Many operating companies have requirements for automatic periodic review/revisions, once every 5 years for example. Revisions may also be needed because of changes in RAGAGEP, corporate policies, regulatory requirements, for example blowdown systems or facility siting, PHA, Incident Investigation, or MOC driven revisions.

These revisions should be easily handled by the system and should not necessitate a complete rework of the relief systems data.

The ioXpress/SuperChems platform addresses this requirement by providing a robust and easy to use action assignment, tracking, and resolution engine. This web-based action tracking system is integrated with the workflow engine.

THE NEED FOR WORKFLOW

The execution and quality assurance/quality control (QA/QC) of large, and complex site-wide flare relief and flare systems projects can be substantially enhanced and improved by using visual workflow to manage all aspects of a relief systems project:

- Visually represent complex engineering and/or business processes
- Associate one or more data forms with each workflow node
- Associate one or more business/engineering rules with each workflow node
- Associate subworkflows with each workflow node
- Implement notifications, approvals, rejections, delegation of authority, etc.
- Implement tracking and reporting
- Implement alerts and subscriptions
- Management oversight

The workflow requirements described in the previous sections form the foundation of the automated ioXpress/SuperChems workflow process illustrated in Figure 1. Each workflow block controls the flow of data, approvals, and QA.

A relief systems project in the workflow shown in Figure 1 can be initiated for a variety of reasons including:

- Establishing a baseline or a new design
- Revalidation of relief system design basis
- PHA review item
- MOC review item
- Corrective action
- Effluent handling evaluation

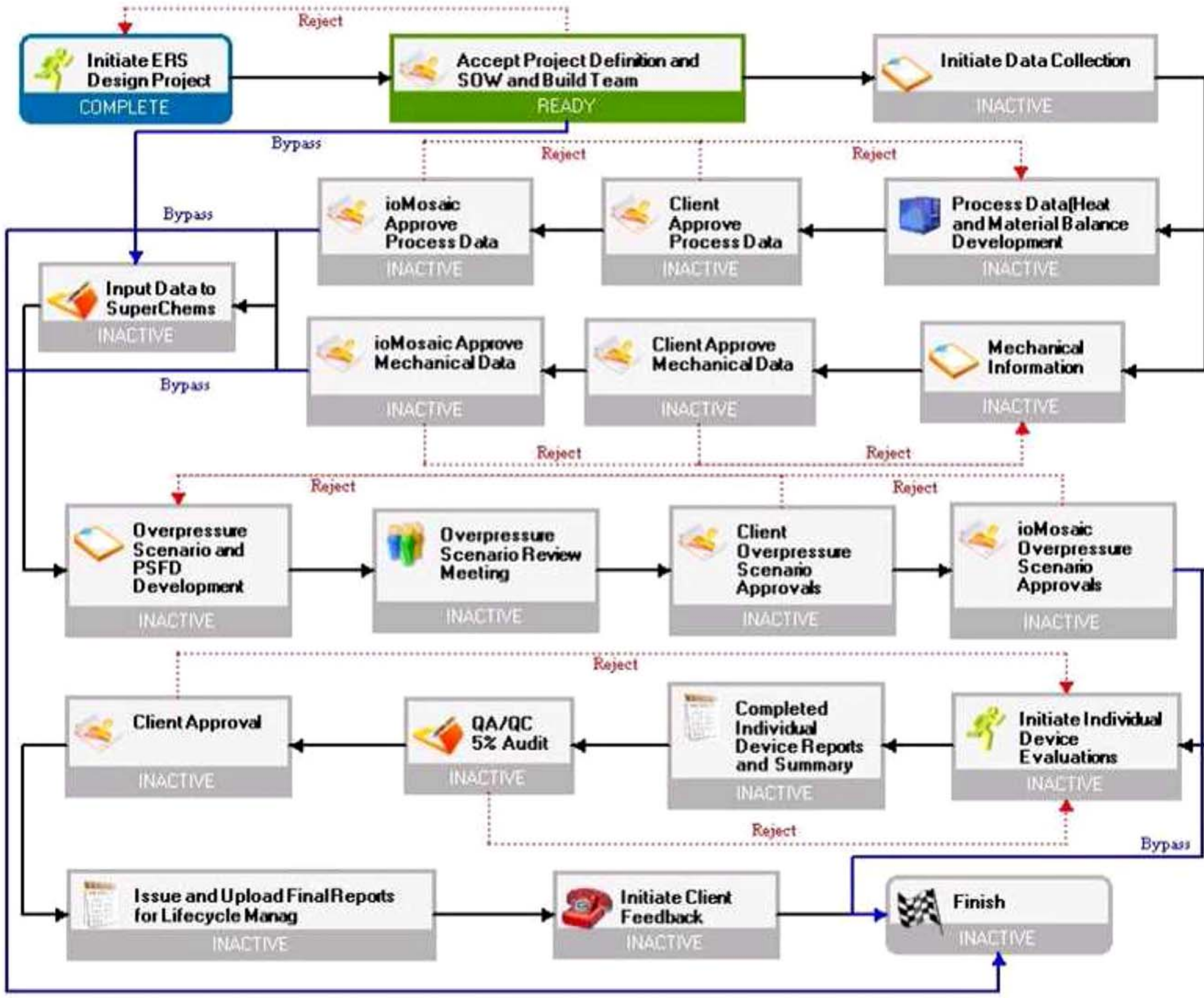

Figure 1. The ioXpress/SuperChems visual workflow process for site-wide relief and flare systems data. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**].

- Incident investigation
- Consequence analysis and/or QRA

OVERALL DESCRIPTION OF THE ACTUAL WORK PROCESS

A systematic work process for relief and flare systems evaluation was developed and implemented with the aid of electronic workflow in order the address the data quality and compliance challenges discussed above. Overall, the work process is divided into distinct phases:

Step I – Develop Overall Evaluation Guidelines and Quality Management

These guidelines are developed before any project work is started. They govern all aspects of performing the relief systems evaluation and data requirements. More importantly, they declare and summarize the applicable (RAGAGEP) to follow as well as what specific scenarios will be considered for different types of equipment and what the data hierarchy will be for performing the evaluations.

Step II – Data Collection

For existing facilities, the relief and flare systems evaluation begin with data collection, that is, obtaining a copy of all the available data listed in Table 1. During this phase of the project, a team of engineers will go to the actual site to collect the data required for performing the relief systems evaluations. The team will field verify critical data and will draw the actual relief system isometrics for protected equipment. Prior to the data collection trip, a list of relief devices and their associated P&IDs are developed/reviewed and an understanding of the process is obtained from a process description. After the data collection is complete, data gaps are identified and missing data are developed from original or alternate/new sources.

Step III – Scenario Identification

Once all the data are obtained, vetted, and approved by all the stakeholders, the next project phase will involve scenario identification. This is a critical aspect of the relief systems evaluation. A team of senior engineers will evaluate scenarios that can cause temperature and pressure deviations for specific pieces of equipment. When the scenario development is complete, a formal scenario review is scheduled with the end user to go over the identified scenarios. The scenario list is finalized and agreed upon before the actual evaluation of relief requirements proceeds in the next step.

Step IV – Preliminary Evaluation of Relief Requirements

Using the guidelines, QA procedures, site and plant data, and scenarios developed earlier, steady state and dynamic calculations of relief requirements are performed. Preliminary evaluation reports are developed. Where deficiencies exist, they are identified and recommendations for improvement are provided. These preliminary evaluations are discussed with the end user to agree upon the most practical solutions.

Step V – Final Evaluation of Relief Requirements

Final evaluations are provided based on step IV and these reports become the actual PSM relief systems design and design basis documentation.

Step VI – Evaluate Vent Containment and Flare Systems

If vent containment or flare systems are involved, specific scenarios considered and evaluated earlier are consolidated into global scenarios and the adequacy of the vent containment and/or flare system is evaluated. If the vent containment system is found to be deficient, recommendations for improvement are provided.

THE IMPORTANCE OF QA/QUALITY CONTROL

The ioXpress/SuperChems platform described in this article places strong emphasis on QA and QC as evident from the various levels of approval gates and requirements shown in the workflow in Figure 1.

For large scale pressure relief and effluent handling systems analyses, the steps outlined below are executed using the ioXpress/SuperChems platform. Utilizing the electronic workflow requires the steps outlined below to be completed prior to advancing the workflow. This automatically ensures version and revision control in ioXpress.

1. **Dedicated Project Lead and Supervision:** Each project has a dedicated project lead to provide ongoing supervision and review during the execution of the project. The project lead has to sign off on all work products prior to submission for a final audit (step 6) after ensuring that the QA/QC procedures outlined below have been followed and implemented correctly.
2. **Formal Scenario Reviews:** Prior to commencement of any calculations or report generation, these reviews will be conducted with one or more operations process knowledgeable engineers to ensure that the correct equipment, piping, and process data are used and that all scenarios of concern have been selected and discussed [5].
3. **Automated Audit Alert SuperChems Scripts:** These scripts check the accuracy and consistency of a report against the requirements established earlier and are executed by the project design engineer to assist with validating the evaluation data prior to completing the checklist (step 4). These scripts look for missing comments, inconsistent discharge coefficients for selected devices and/or flow type, missing calculations, values being within expected normal limits, etc. The scripts ensure adherence to both client and industry standards and practices.
4. **Relief Systems Checklist:** This is a checklist that guides the design and evaluation of each relief system to ensure that no detail has been overlooked. The design engineer utilizes the checklist prior to submitting the evaluated relief device package for independent reviewer signoff.
5. **Independent Reviewer Signoff:** Each completed package will be checked and approved by a senior process safety or relief systems specialist confirming that the report is accurate and that it meets the requirements. This review focuses on completeness, accuracy, and methodology.
6. **Independent Audit of a 5% Sample:** For each project, a 5% sample will be selected at random (but has to represent different types of equipment or operations) for detailed audit review. The process is intended to ensure that no systemic issues exist and is repeated until no further issues can be identified or until the entire pool of reports is exhausted.
7. **Electronic Version and Revision Control:** This is an automated feature of ioXpress that ensures version and revision control for all relief systems data and project files. It provides an auditable trail of all changes and revisions.
8. **Client Feedback:** Consistent with our internal quality control systems, we routinely seek and learn from client feedback. Results from the feedback are integrated in the next revisions of requirements as applicable in order to ensure continuous improvements are achieved.

GENERAL RECOMMENDATIONS FOR RELIEF SYSTEMS ENGINEERS

Before attempting to perform relief and flare systems evaluation and design, one should have a thorough understanding of the process and all available layers of protection. Chemical systems involving reactions tend to be complex and require an assessment of both desired and undesired chemistries. Systems with supercritical fluids, depressuring systems, high pressure/low pressure interfaces, and fractionators and distillation towers will require more experience than other simpler systems. Review of OP, batch records, PHA, risk assessment, and accident investigation reports can provide a lot of insight.

Develop and document all possible scenarios the can lead to overpressure, underpressure, and temperature excursions. Develop a “Protected Equipment Envelope” and identify the weakest system link. Indentify all available “Protection Systems”—Note that relief devices can fail too! It is very useful to draw a process safety flow diagram which shows all the available layers of protection including the relief system. Understand common mode and cascading failures and develop preferred and consistent methods for modeling specific scenarios.

Always perform a formal scenario review with plant operations and process knowledgeable engineers and/or chemists. Getting by-in from operations is always wise, especially, if the evaluations reveal deficiencies that need to be corrected. Confirm potential operation deviations with plant operations before embarking on lengthy and expensive dynamic calculations. Confirm that the material and energy balance data are representative of current operating conditions. Establish and confirm all data required to model specific scenarios before modeling the scenarios.

Always field verify the data used for relief and flare systems evaluation for existing systems. This includes P&IDs, piping isometrics, equipment ratings, and relief device information.

Before attempting any calculations make sure you understand all relevant standards, laws, and RAGAGEP. Watch out for gray areas and develop philosophy documents that govern the overall evaluation efforts in order to ensure consistency. Develop standardized approaches and methods for modeling specific scenarios. If dealing with unique systems, obtain relief systems training from those who have expertise in such systems. Be prudent but not paranoid—There are always inherent risks in all kinds of technologies.

Establish relief requirements and actual flow capacities. Watch out for reaction systems, high pressure, and depressuring systems. Look for computational tools that have a large installed user base and that are updated on a regular basis. Look for computational tools that can address both reactive and nonreactive chemicals and can address steady state and dynamic estimates as well as high pressure systems (as applicable). Do not use methods that are not compliant with RAGAGEP and always retain an archive copy of the actual software used to produce the evaluation.

If you identify deficiencies, risk rank the deficiencies and mitigate (where necessary) high risk contributors first. Always ensure that the final corrective action design matches field installations and/or modifications.

It is recommended that you split your documentation into three parts (see Figures 2 and 3) and connect the data using a system such as the ioXpress/SuperChems system:

Part I – Automated Data and Calculations	Part II – Supporting Data	Part III – Reference Data
Approval Sheet	E-mail correspondence	MFD Legends
Specification Sheet(s)	QA/QC Checklists	Piping Specifications
Scenario Summaries	Other calculations (Excel, MathCAD)	PRD Vendor Information
Project Notes	Isometric Sketch	Company Guidance Documents
Equipment Data	Photos	Reaction Models Papers
Piping Isometrics	P&IDs, PFDs	E-mail Correspondence
Process Safety Diagram	H&MB	Copies of Reference Documents
Mixtures / Chemicals	Operating Procedures	Old PRD Calculations
Chemical Reactions	Process Information	International Standards
Streams	Equipment specs / fabrication and installation drawings / U-1A forms	RAGAGEP Papers
Scenario Applicability	Insulation specifications	
Scenario Calculations	Control Valve Data	
Scenario Notes	Pump Data	
Author Data	PRD Inspection Report	
	PRD field survey data	
	Prior PRD specification	

Figure 2. Suggested general content of relief systems design and design basis documentation.

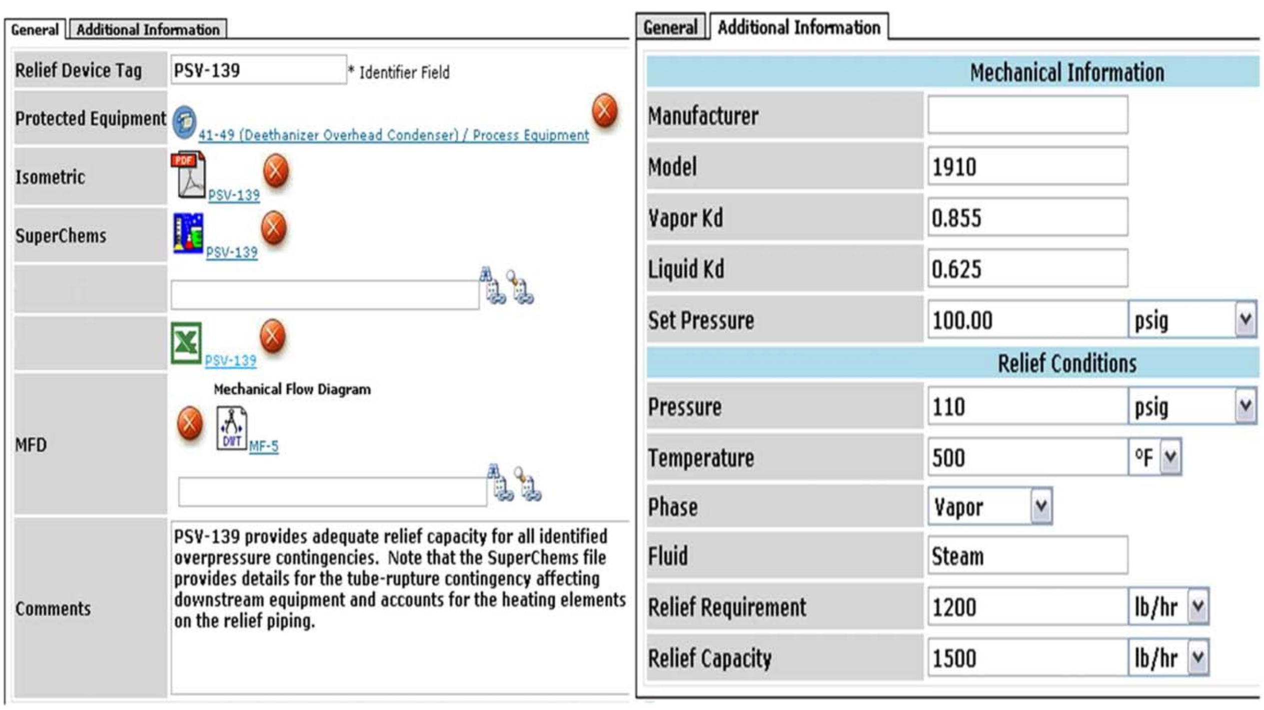

Figure 3. A sample ioXpress/SuperChems platform dynamic form connecting structured and nonstructured relief systems data/information. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**].

- Part I—where most changes in documentation are likely to occur
- Part II—data used for part I including isometrics and that is not likely to change as often
- Part III—reference data, old calculations, and all other data that is not going to change

CONCLUSION

We provided in this article a summary of a workflow system that we developed for the execution of large scale/site-wide relief systems studies as well as a general description of the work processes covered by the workflow. Benefits of this system include (a) compliance assurance and standardization, (b) enhanced change management, process operations, and loss avoidance, (c) easy integration of legacy/existing documentation and supporting calculations regardless of what calculation method, format, or tool is or was used, (d) easy, quick, and secure web-based access (internet or intranet) to the right information when needed, (e) single point access to different data formats, (f) cost efficient reviews, and most importantly (g) information life cycle management.

LITERATURE CITED

1. G.A. Melhem, Relief system's last line of defense, only line of defense? Process Saf Prog, 25 (2006), 290–297.
2. G.A. Melhem and P. Howell, Designing emergency relief systems for runaway reactions, Chem Eng Prog (2005), 23–28.
3. G.A. Melhem, Fire and Ice—How to Properly Model Depressuring Systems, DIERS Users Group Meeting, Kansas City, May 2012.
4. G.A. Melhem, Assess Piping Vibration Risk with Experience Based Methods, DIERS Users Group Meeting, Kansas City, May 2012.
5. N. Prophet and G. Gorski, The Importance of a Team-Based Approach to Overpressure Scenario Development, CCPS 9th Global Congress on Process Safety, San Antonio, April 2013.