Auditing Relief Systems Design Basis – Best Practices

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Prepared for Presentation at
American Institute of Chemical Engineers
2015 Spring Meeting
11th Global Congress on Process Safety
Austin, Texas
April 27-29, 2015

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Keywords: Auditing, Relief Systems, Pressure Relief

Abstract

Ever since OSHA implemented their National Emphasis Program in 2007, facility's pressure relief systems design basis have come under increasing scrutiny. Recognizing that they may not be fully compliant, many companies are conducting audits of their relief systems design basis to determine their current state, identify gaps, and establish a path forward for compliance. ioMosaic Corporation is often called upon to conduct these audits, and in doing so, has developed a successful methodology to do this efficiently and effectively. This paper outlines how companies can conduct audits of their relief systems in a successful way.

1. Background

The explosion at BP's Texas City Refinery on March 23, 2005 triggered an industry-wide increase in focus on pressure relief systems design basis. Relevant codes and standards, such as API Standard 520 **[1]**, **[2]** and 521 **[3]** were updated and expanded. At the same time, OSHA implemented CPL-03-00-004 (Petroleum Refinery Process Safety Management National Emphasis Program) in 2007, followed by CPL-03-00-014 (PSM Covered Chemical Facilities National Emphasis Program) in 2011. Both of these programs involved onsite auditing activities, with pressure relief systems being one area of particular focus. Since then, there is still a continued awareness of the benefit and need to audit pressure relief systems.

Additionally, Section O of the OSHA PSM standard requires that compliance audits be conducted every three years. Since a facility's relief systems design and design basis is part of its Process Safety Information (PSI), this information should be audited every three years, and revalidated every five years.

The main purpose of auditing relief systems design basis is threefold:

- Ensuring a design basis exists for every relief system
- Ensuring accuracy of existing relief system design basis
- Ensuring adequacy of existing relief systems design basis documentation

Only by conducting all three of these activities can a company develop a complete understanding of their existing relief systems design basis. Additional benefits and reasons for auditing relief systems design basis include:

- Ensuring regulatory compliance
- Maintaining up-to-date process safety information
- Identifying non-conformities, or areas of improvement
- Promotion of industry best practices and Recognized and Generally Accepted Good Engineering Practices (RAGAGEP)

2. Audit Preparation

Preparation is a key part to conducting any audit, including one that is focusing on relief systems design basis. An audit plan should be developed which establishes the scope and schedule of the audit. This plan will take into account that audits are usually time and resource limited, and should aim to focus resources on the areas with highest priority. Scope definition determines whether the audit may be facility-wide, unit-wide, or limited to a specific area of focus. An audit protocol is also a key part of the preparation. The term "protocol" means the checklist used by the relief systems auditor as the guide for conducting the audit activities. The audit protocol considers the following for each item in the scope of the audit:

- Scope Item - what is being evaluated and how is it being measured
- Performance Criteria - what is the item being measured against
- Review Depth - how much need to be measured
- Audit Technique - how is the item being measured

The audit protocol will be based on the appropriate codes and standards that are being considered, and may also be used to define which audit techniques that should be utilized. For example, use of questionnaires, interviews, documentation review, calculation checking, or field verification. A combination of various techniques may be applied. A successful audit protocol should ensure that a consistent approach is followed by each auditor involved.

The preparation stage prior to conducting an audit should also include establishing data requirements for the audit. The analysis of pressure relief systems requires 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 audit, a full range of supporting process safety documentation should be available, such as that shown in Table 1. Additionally, the auditor should consider field verification of piping isometrics, relief devices and vessel design parameters, and piping and instrument drawings (P&IDs) to ensure an accurate evaluation. In addition, there are many gray areas in the current state of the art for relief systems evaluation that complicate relief systems design basis. These may need to be considered during development of the audit protocol. Technical issues that are currently the subject of debate and some controversy amongst relief systems experts include, but are not limited to:

- Use of actual (best estimate) flow vs. required flow for (a) inlet pressure loss, (b) backpressure, (c) sub-header/ flare header hydraulics, and (d) effluent handling equipment (knockout drums, flare tips) design
- Use of 3 % inlet pressure loss requirement vs. 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
- 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

Table 1. 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

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**
Vessels	Liquid levels	1. Operating procedures 2. P&IDs 3. Equipment design drawings 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,	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**
	Volumetric efficiency	
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

3. Codes and Standards

It is important to be aware of the relevant codes and standards that are either directly or indirectly related to a relief systems design basis audit. The audit team should have these documents at their disposal, and should be aware of the content of each. The main codes and standards that should be considered include:

- API Standard 520 Part 1 (9th Edition). "Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries", 2014.
- API Recommended Practice 520 Part 2 (6th Editions). "Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries", 2015.
- API Standard 521 (6th Edition). "Guide for Pressure-relieving and Depressuring Systems", 2014.
- API Standard 526 (6th Edition). "Flanged Steel Pressure Relief Valves", 2009.
- API Standard 2000 (7th Edition). "Venting Atmospheric and Low-Pressure Storage Tanks: Non-refrigerated and Refrigerated", 2014.
- API Recommended Practice 576 (3rd Edition). "Inspection of Pressure-Relieving Devices", 2009.
- ASME BPVC Section VIII. "Boiler & Pressure Vessel Code (BPVC), Section VIII, Division 1: Rules for Construction of Pressure Vessels", 2013.
- ASME B31.3. "Process Piping (B31.1-2014) and Process Piping Design", 2014.
- OSHA 29 CFR 1910.119: "Process Safety Management of Highly Hazardous Chemicals".
- OSHA Emphasis Programs

In addition, any company-specific guideline documents should be considered within the audit. Other codes and standards which may be relevant depending on the process being evaluated include:

- ASHRAE Standard 15. “Safety Standard for Refrigeration Systems and Designation and Classification of Refrigerants”, 2013.
- OSHA 29 CFR 1910.110. “Storage and Handling of Liquefied Petroleum Gases”.
- OSHA 29 CFR 1910.111. “Storage and Handling of Anhydrous Ammonia”.
- NFPA 30. “Flammable and Combustible Liquids Code”, 2015.

4. Conducting the Audit

The scope of the audit will have been defined during the audit preparation. Having developed the audit protocol, determined what data is required, what standards are being measured against, the auditor can proceed with conducting the audit.

4.1 Sample Selection

For the purposes of the audit, it is necessary to select a subset of the scope for further, detailed analysis. This representative sample should be carried forward to the audit steps that include:

- Ensuring accuracy of existing relief system design basis
- Ensuring adequacy of existing relief systems design basis documentation

It is therefore important to select a sample which is a good cross-representation of all relief devices within the scope, and to ensure that various design criteria are addressed. Various sampling techniques exist for conducting audits, which may be considered for a relief systems design basis audit:

- Random - selection purely by chance
- Block - selection based on clusters of information
- Stratification - selection based on subjective decisions of higher risk categories
- Interval - selection based on every n^{th} item in a list

Regardless of sampling technique used, the sample selection should aim to ensure that the criteria shown in Table 2 are covered:

Table 2. Relief System Criteria

Criteria	**Scope**
Valve Type	Conventional, Balanced Bellows, Pilot, Rupture Disk
Equipment Type	Column, Vessel, Heat Exchanger, Pump, Compressor, Reactor
Discharge Location	Flare Header, Atmosphere, Process
Flow Regime	Vapor, Liquid, Two-Phase

It is typically possible to meet all the desired criteria, with some systems able to meet several criteria at the same time, e.g. a bellows device protecting a column, relieving to flare, which could experience vapor, liquid or two-phase flow. The CCPS book "Guidelines for Auditing Process Safety Management Systems" **[4]**, typically recommends a sample size of between 10 and 20% for detailed auditing. However, depending on schedule and resource availability, this size may be increased or decreased.

4.2 Ensuring a Design Basis Exists for Every Relief System

While it sounds fairly obvious to ensure a design basis exists for every relief system, it is not uncommon for unprotected equipment to be identified during a relief systems design basis audit. This activity is typically conducted through detailed review of Piping and Instrumentation Diagrams (P&IDs). As the P&IDs are being reviewed, the auditor should be compiling a list of relief devices and protected equipment. While a relief device list may already exist for the facility, it is important for the auditor to independently compile this list. This list should cross-reference which relief devices protect each piece of equipment within the audit scope.

Therefore, the following issues may be uncovered in conducting this P&ID review:

- Potentially unprotected equipment
- Potential obstructions in relief path: Block valves which should be locked open, check valves, control valves
- Incorrect set pressures
- Relief piping issues: The nominal size of the inlet piping must be the same as or larger than the nominal size of the pressure relief valve inlet flange connection
- Atmospheric relief: potential for relieving toxic or flammable fluid to the atmosphere

Another benefit of developing a list of relief devices and protected equipment comes when verifying if a design basis exists for every system. The list compiled by the auditor can be compared with the number of records currently being maintained by the facility. The comparison should yield identical results - if this is not the case, there could be relief devices which do not have any documentation, or which may not be on the facility's inspection and testing schedule.

4.3 Field Verification

Having reviewed the facility P&IDs, identified potential areas of concern, and selected an audit sample; it is very useful to conduct field verification. As well as getting a general feel for the facility and the housekeeping standards that are in place, the field verification includes some specific activities of benefit to the relief systems audit:

- Confirming relief device tags are present and correct
- Comparison of relief device installation with that shown on P&ID:
  - Set pressure, relief device size, piping size, fittings, etc.
- Check block valves in relief piping to confirm if car-seal program is in effect
- Identify any areas of pocketing in relief piping
- Evaluate potential for atmospheric relief devices for toxic or flammable discharges:
  - Ensure no liquid scenarios can relieve to atmosphere
  - Ensure flammable releases have at least 50 feet horizontal separation
  - Check if consequence modeling has been performed for toxic or flammable releases
- Conduct field sketching for relief devices that are selected for the audit sample

4.4 Ensuring Accuracy of Existing Relief System Design Basis

The relief systems audit should also aim to ensure the accuracy of the existing relief systems design basis. This can be achieved by conducting a revalidation of the audit sample - in other words, a complete redo of the design calculations for all the relief devices selected in the audit sample. The main steps involved in a relief systems design basis study include:

- Define scope, basis, and project guidelines (this step will already have been conducted during the audit preparation stage)
- Gather project and process data (this step may also already have been conducted during the audit preparation stage)
- Develop overpressure scenarios for each protected system
- Determine relief requirement for each applicable overpressure scenario
- Calculate relief device capacity for each applicable overpressure scenario
- Check reaction forces, acoustic induced vibration, discharge temperatures, and relief device stability
- Identify relief system deficiencies and formulate options
- Generate report

Overpressure scenario identification is a critical aspect of the relief systems evaluation. For each selected system, a list of all credible potential causes of overpressure should be developed; stating whether an overpressure scenario is applicable or not applicable, and why. The overpressure scenarios considered should include, but are not necessarily limited to, those provided in API Standard 521 **[3]**.

For each potential overpressure scenario, the required relief rate should be calculated. Additionally, the flow capacity should be calculated to determine whether each relief system provides adequate capacity to prevent overpressure. The calculation methods used to determine each required relief rate and flow capacity should be documented in the individual relief systems calculation documentation. Additionally, the required orifice area and actual orifice area should be calculated.

Additional key pieces of data such as inlet pressure drops (between protected equipment and the relief device) and outlet pressure drops (between the relief device and main header) should also be calculated and documented based on actual expected relief capacities. A report for each relief system being analyzed as part of the audit sample should be developed. The report should be consistent with the documentation requirements specified in API Standard 521 **[3]**, 6th Edition, Section 4.7.

The purpose of revalidation is to identify any design issues within the audit sample, which may not have previously been addressed. It is a worthwhile exercise to determine why the original relief systems design basis may differ from the audit sample calculations. This could be due to a number of reasons such as:

- Changes in operating conditions (flowrates, temperatures, pressures)
- Changes in process equipment (equipment sizes, pump impellers, control valve trims)
- Missed scenarios
- Changes in calculation methodologies (for example, two phase modeling has progressed significantly over the past twenty years)

The types of issues that may be uncovered during this stage of the audit include:

- Undersized relief valves for a specific overpressure scenario
- Improper set pressure on relief valves
- Inlet pressure loss which exceeds three percent of set pressure
- Outlet backpressure which exceeds the limit for the type of relief device
- Excessive reaction forces
- Missed overpressure scenario
- Discharge temperatures below Minimum Design Metal Temperature (MDMT)
- Data discrepancies or missing process safety information

Should any design deficiencies such as those listed above be identified, recommendations should be formulated to resolve these issues. The relief systems design basis auditor should also bear in mind that analysis of individual audit sample systems, which may be scattered all across the facility, tends to be more time-consuming than when conducting a unit-wide analysis, which allows the designer to gain efficiency as progress is made throughout the unit.

4.5 Ensuring Adequacy of Existing Relief Systems Design Basis Documentation

Another key part in conducting the audit is to ensure the adequacy of existing relief systems design basis documentation. This step involves reviewing a facility's existing documentation, and determining if the level of documentation meets required criteria. The OSHA PSM Standard, Section d (3)(i)(D) lists relief systems design and design basis, as part of the required process safety information (PSI) for a covered facility. However the OSHA PSM standard is performance based and does not specify the required contents of a relief system design and design basis.

API Standard 521, 6th Edition, Section 4.7 provides guidance on documentation requirements for individual relief systems design basis. While the documentation requirements provided by API Standard 521 are extensive, this tends to be the most commonly accepted set of design criteria used within industry.

Most vintage relief systems are typically not compliant with the documentation requirements put forth by API Standard 521, and the auditor should note these exceptions and determine their significance on the overall quality of the relief systems design basis.

Additionally, the auditor should ensure that there are no open action items or deficiencies that have arisen from any previous relief systems design basis studies. PHA studies should also be reviewed, to ensure that any time a PHA study takes credit for a relief system, it is important to verify that the relief system is designed to handle the scenario in question. A good relief systems design basis will generate fewer PHA action items.

4.6 Further Work

Upon completion of the audit activities, it is important to draw conclusions on the overall adequacy of the relief systems design basis that was audited. Percentage compliant and percentage non-compliant should be shown, with a breakdown of non-compliant statistics provided. The purpose of the audit sample is to act as a representative sample, which could be extrapolated to indicate the broader status of the unit or facility in general. If deficiencies are identified, these need to be assessed and prioritized for mitigation as part of a corrective action plan.

Additionally, in the way that this paper describes auditing individual relief systems design basis, consideration should be given to conducting similar audits of flare systems to verify their adequacy.

5. Conclusions

Auditing is an important and independent element of process safety management systems. It is useful for assuring regulatory compliance, conformance to Recognized and Generally Accepted Good Engineering Practice (RAGAGEP); and can help improve the quality of a company's management systems. Given the increased focus in pressure relief systems, it is important that companies are aware of the completeness and quality of their existing relief systems design basis, before implementing corrective action plans.

6. References

[1] "Sizing, Selection, and Installation of Pressure Relief Devices in Refineries" 9th Edition, API Standard 520 Part I (2014).

[2] "Sizing, Selection, and Installation of Pressure Relief Devices in Refineries" 6th Edition, API Recommended Practice 520 Part II (2015).

[3] "Pressure-relieving and Depressuring Systems" 6th Edition, API Standard 521 (2014).

[4] "Guidelines for Auditing Process Safety Management Systems", 2nd Edition, AIChE/CCPS (2011).