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RECORD OF REVISIONS

Rev	Date	Description	POC	RM
0	9/17/2014	Initial issue. Was Appendix D of Section I, rev. 3	Ari Ben Swartz, *ES-EPD*	Larry Goen, *ES-DO*
1	9/22/2023	Complete revision of Attachment ADMIN-2-1, Relief Device Selection Process for Gas Bottle Systems (Guidance).	Ari Ben Swartz, *ES-FE*	Dan Tepley, *ES-DO*

Contact the Standards point of contact (POC) for upkeep, interpretation, and variance issues.

Chapter 17	Pressure Safety POC

This document is online at https://engstandards.lanl.gov

1.0 INTRODUCTION AND PURPOSE

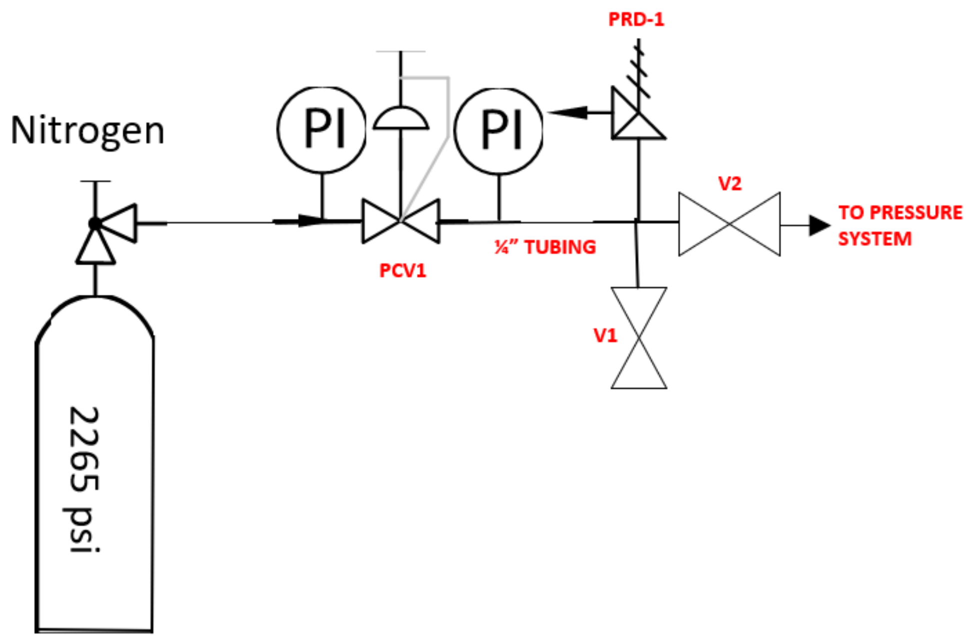
This document provides examples of overpressure scenarios for various types of pressure systems/sources and the evaluations necessary to determine requirements for overpressure protection of those systems. This document provides commonly encountered scenarios and should not be considered exhaustive.

The example evaluations in this guide consider a single fault / single point-of-failure (SPOF) to determine overpressure protection needs, in compliance with the requirements of this Engineering Standards Manual (ESM) chapter. Latent failures (see Attachment GEN-1, *Definitions and Acronyms*) also need to be considered but this guide does not directly address any latent failure scenarios.

Throughout this document, web links are provided to product pages for some components. Copies of the documents contained in the links are also available for reference on the "Reference Data" SharePoint linked on the ESM Chapter 17 website.

2.0 GAS CYLINDER AND PRESSURE REGULATOR

A typical starting configuration for a single gas cylinder and pressure regulator manifold is as follows:



A. Scenario 1 – Failure flow rate of regulator does not exceed pressure relief device (PRD) capacity

The following design parameters are used for this example:

- Gas cylinder: Nitrogen at 2265 psig max fill pressure
- Pressure regulator: Swagelok KCY series two-stage regulator with a flow coefficient (C_V) of 0.02

- Maximum operating pressure: 40 psig
- Downstream system Design Pressure: 50 psig

In this scenario, the pressure system downstream of the regulator, PCV1, must be protected from the single fault / single point-of-failure overpressure scenario of PCV1 failing in the fully open position (i.e., fails to regulate pressure entirely). When PCV1 fails, the downstream pressure system would be exposed to the full gas cylinder pressure of 2265 psig which exceeds the system maximum allowable working pressure (MAWP) of 50 psig.

To protect the pressure system, a pressure relief device (in this case, a pressure relief valve) needs to be installed. To determine the necessary relief capacity of the PRV, LANL's "Determining-regulator-flow" Excel tool (found here) may be utilized. This tool outputs the air-equivalent flow rate in standard cubic feet per minute (SCFM) of several commonly used gases. The air-equivalent flow rate (rather than the flow rate of the source gas itself) is necessary because pressure relief device capacity is measured with air.

DETERMINING REGULATOR FLOW BY Cv

EQUIVALENTS AS AIR

REGULATOR	SOURCE	Nitrogen
	SOURCE PRESSURE (psi)	2265
	C_v	0.02
	FAILURE FLOW RATE AS AIR (SCFM)	27.44

The overpressure protection needs to meet or exceed 27.44 SCFM capacity with a setpoint no higher than the downstream system MAWP of 50 psig. The overpressure protection also cannot exceed ¼" inlet size to match the size of the connecting system.

A ¼" inlet Control Devices ST25 relief valve is specified for this system. At a 50 psig setpoint, this relief valve provides ~53 SCFM flow capacity which exceeds the 27.44 SCFM failure flow rate. This relief valve will protect the system from overpressure.

NOTES
1. SET PRESSURE RANGE IS 25 PSI TO 350 PSI.
2. RELIEF CAPACITY IS GIVEN BY THE EQUATION
   Q = .759(1.1P + 14.7), WHERE
   Q = RELIEF CAPACITY IN SCFM, AND
   P = SET PRESSURE IN PSI
3. MATERIALS OF CONSTRUCTION
   BODY, ROD, CUP, SCREW--BRASS
   SPRING--MUSIC WIRE
   PAD--SILICONE OR FLUOROCARBON
   PULL RING--STAINLESS STEEL
4. MAX TEMPERATURE 250° F
5. MAX INSTALLATION TORQUE 20 FT-LBS
6. ORIFICE DIA. = .250 IN.

TOLERANC
(EXCEPT AS NC
DECIMAL ±
FRACTIONAL ±
ANGULAR ±

B. Scenario 2 – Failure flow rate of regulator exceeds PRD capacity

The following design parameters are used for this example:

- Gas cylinder: Nitrogen at 2265 psig max fill pressure
- Pressure regulator: Swagelok KCY series two-stage regulator with a flow coefficient (C_V) of 0.06
- Maximum operating pressure: 40 psig
- Downstream system Design Pressure: 50 psig

Scenario 2 has the same single fault / single point-of-failure situation as Scenario 1. However, in this scenario the pressure regulator has a flow coefficient (C_V) of 0.06, which results in a higher failure flow rate.

DETERMINING REGULATOR FLOW BY Cv

EQUIVALENTS AS AIR

REGULATOR	SOURCE	Nitrogen
	SOURCE PRESSURE (psi)	2265
	C_v	0.06
	FAILURE FLOW RATE AS AIR (SCFM)	82.32

The overpressure protection needs to meet or exceed 82.32 SCFM capacity with a setpoint no higher than the downstream system design pressure of 50 psig. The overpressure protection also cannot exceed ¼" inlet size to match the size of the connecting system.

A ¼" inlet Conrader SRV250 relief valve is specified for this system. At a 50 psig setpoint, this relief valve provides only ~53 SCFM flow capacity (see data sheet page 8) which is less than the 82.32 SCFM failure flow rate. This PRV alone will not sufficiently protect the system from overpressure. This issue can be corrected in at least two different ways:

- Install two SRV250 relief valves. The total combined capacity of the two PRVs is 102 SCFM, which exceeds 82.32 SCFM.
- Install a Restrictive Flow Orifice (RFO) upstream of the pressure regulator to limit the maximum flow. A 0.035” orifice diameter would reduce the maximum flow rate to 38.42 SCFM, which is less than the ~53 SCFM capacity of a single SRV250 relief valve.

DETERMINING REGULATOR FLOW BY ORIFICE

EQUIVALENTS AS AIR	Diameter (in)	C_v	
Diameter to Cv	0.035	0.028	(This diameter and

REGULATOR	SOURCE	Nitrogen
	SOURCE PRESSURE (psi)	2265
	Equivalent C_v (if not listed)	0.028
	FAILURE FLOW RATE AS AIR (SCFM)	38.42

C. Scenario 3 – Downstream system MAWP exceeds pressure source

The following design parameters are used for this example:

- Gas cylinder: Nitrogen at 2265 psig max fill pressure
- Pressure regulator: Swagelok KCY series two-stage regulator with a flow coefficient (C_V) of 0.20
- Maximum operating pressure: 500 psig
- Downstream system Design Pressure: 2500 psig

Scenario 3 has the same single fault / single point-of-failure situation as Scenarios 1 and 2. When the pressure regulator fails, the system downstream of the regulator would be exposed to the full gas cylinder pressure of 2265 psig. However, the downstream system has an MAWP of 2500 psig, meaning all downstream components meet or exceed a 2500 psig pressure rating.

The pressure source is considered self-limiting (i.e., the gas cylinder pressure source is finite). This pressure system cannot be over pressurized in the worst-case failure scenario. Therefore, the pressure system is protected from overpressure by system design. For more information on overpressure protection by system design, see American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) Section XIII, Part 13 and ASME B31.3 para. 301.2.2.

3.0 AIR COMPRESSOR

The following design parameters are used for this example:

- Pressure source: Quincy GQV-40 variable speed rotary screw air compressor

- Maximum operating pressure: 125 psig
- Downstream system Design Pressure: 150 psig
- Piping design basis: ASME B31.9, *Building Services Piping*
- Piping system size: 1-1/2"
- System includes ASME BPVC Section VIII, Division 1 air receiver and air dryer, each with an MAWP of 200 psig
- Operating at ambient indoor temperatures

The single fault / SPOF overpressure scenario for air compressors assumes that the air compressor controls fail, which would permit the compressor to run continuously. While all air compressors have a pressure at which zero flow will occur, this point is generally not known, and it is assumed that this value would exceed the downstream system MAWP.

Rotary Screw Air Compressors 8

QGV Variable Speed Technical Data

Model No.	HP	KW	PSI	ACFM	Length	Width	Height	Lbs	DBA
QGV-40	40	30	100	209.8	67	37.7	65.8	2277	67
QGV-40	40	30	125	183.0	67	37.7	65.8	2277	67
QGV-40	40	30	150	173.9	67	37.7	65.8	2277	67

Per the technical data available from Quincy, at 125 psig delivery pressure the compressor provides 183 actual cubic feet per minute (ACFM) Free Air Delivery (FAD). Conservatively, this ACFM value may be used to size the overpressure protection. A more accurate SCFM value can be determined by correcting for altitude – atmospheric pressure at LANL altitude (7500 ft) results in a performance reduction of the air compressor. The performance reduction is a ratio of (Pressure at 7500 ft)/(Pressure at sea level), (11.13 psi/14.7 psi) = 0.757.
NOTE: It is the responsibility of the designer to ensure that the relief device capacity is not significantly oversized if using the ACFM output instead of the altitude-corrected output.

For this compressor, the anticipated altitude corrected output would be 183*0.757=139 SCFM. A ¼" inlet Kingston 118CSS relief valve is specified for this system. This relief valve is ASME 'UV' code stamped, which is required for PRVs that protect ASME Section VIII pressure vessels.

Accepted interpretation of ASME B31.9 overpressure protection requirements concludes that the working pressure scope of the code is not permitted to be exceeded. For compressed air, the working pressure cannot exceed 150 psig. 'UV' stamped relief valves are designed to permit 10% pressure accumulation above its set pressure, so the relief valve set pressure should be about 10% below 150 psig (approx. 135 psig). At a 135 psig setpoint, this relief valve provides 175 SCFM capacity, which exceeds the maximum output of the compressor at 150 psig delivery pressure.

A ¼" inlet relief valve is sufficient for this system, which has 1-1/2" piping. A relief valve with an inlet smaller than the connecting piping system is acceptable and often necessary. Specifying a larger inlet relief valve to closer match the connecting piping system is a common mistake that can lead to oversized relief devices. For example, the 1" inlet Kingston 118CSS has a flow capacity of 659 SCFM at 150 psig setpoint which is 5 times the 139 SCFM altitude-corrected maximum flow.

The PRV needs to be installed near the outlet of the compressor, without any intervening stop valves between the compressor outlet and PRV (except when permitted by ASME code and ESM Ch 17). This PRV will protect the entire downstream compressed air system from the compressor SPOF scenario.
NOTE: The Section VIII pressure vessels may need their own overpressure protection if the risk of exposure to fire is a credible scenario, which is not covered by this example.

4.0 WATER PUMP

A. Scenario 1 – Process water system without make-up water

The following design parameters are used for this example:

- Pressure source: four (4) Grundfos CME 1-7 A-S-I-E-AQQE U-A-A-N, installed in parallel, operating at 100% [no variable frequency drive (VFD) present]
    - Pump curve
- System fill pressure: atmospheric (0 psig), with some residual system head pressure (5 psig)
- Piping system size: 1-1/2”
- Normal operating pressure: 75 psig
- System MAWP: 100 psig (ASME BPVC Section VIII Division 1 pressure vessel)

In this scenario, a process water system (e.g., deionized, distilled, reverse osmosis water) is supplied pressure by a water pump. The system does not connect to a make-up water system such as potable municipal water due to unprocessed potable water having the potential to disturb the balance of the process water. If the system ever needs to be refilled, it is done via atmospheric filling with process water during a shutdown. Due to system geometry, the maximum fill pressure is the lowest point of the system due to head pressure of water, 5 psig.

The system normally operates with flowing water at 75 psig (70 psig pump differential + 5 psig residual head pressure). The primary failure scenario is that valve(s) on the discharge piping are closed such that water flow is entirely blocked, creating a pump dead-head condition. In this zero-flow condition, the pump differential pressure reaches a maximum, potentially overpressurizing the piping system.

Per the pump curve linked above, the pump in this design is capable of approximately 300 ft. of total head in a zero-flow dead-head condition. One foot of head converts to 0.4334 psig, therefore the pump dead-head condition can produce 300*0.4334=130 psig. To determine the maximum system pressure on the discharge side of the pump, add the pump dead-head pressure to the residual system head pressure, which results in a maximum possible system pressure of 135 psig.

The system MAWP is 100 psig which is less than 135 psig. A pressure relief device is needed to protect the pressure system. Because an ASME BPVC Section VIII Division 1 pressure vessel needs to be protected, the pressure relief device needs to meet the requirements of Section VIII Division 1 and Section XIII (i.e., needs to be UV or UD stamped).

To determine the required flow capacity in gallons per minute (GPM) of the relief valve, the pump curve can be utilized to determine the flow rate of water at the point at which system pressure reaches 100 psig. This point is 95 psig pump differential, or 219 feet of head. Per the pump curve, the flow rate is about 8 GPM at 219 feet of head. Because the four pumps are operating in parallel, the total flow of the system at 219 feet of head is (8 GPM)*(4 pumps) = 32 GPM.

One relief valve that is deemed to be sufficient for this system is an Aquatrol series 740 with a "D" size orifice. Its Section VIII liquid flow capacity at 100 psig setpoint is 40 GPM (see data sheet page 8), which exceeds the maximum failure flow of 32 GPM. This relief valve is available from 1/2" to 1" inlet, which are all less than the 1-1/2" piping system size.

NOTE: This example assuming 100% operating speed without VFDs is very simplified. Pumps operating at less than 100% capacity with VFDs adds complexity to the evaluation due to the presence of VFD controls that may reduce maximum pressure output. VFDs are more common in new system installations or pump replacements and may aid in reducing or eliminating the need for overpressure protection.

NOTE: An alternative approach to installing a relief device in this scenario would be to replace the component(s) with an MAWP/pressure rating/etc. less than 135 psig, with items rated for 135 psig or higher. Assuming all other components are rated to 135 psig except for the pressure vessel, replacing the pressure vessel for one rated for at least 135 psig would eliminate the need for overpressure protection.

B. Scenario 2 – Hydronic water system with make-up water

The following design parameters are used for this example:

- Pressure source 1: Bell & Gossett series e-90 pump, 1.5AAB model with 5.25" impeller, operating up to 3450 RPM
  - Pump curve (ref. PDF page 12)
- Pressure source 2: Make-up water connection to potable municipal water
  - Pressure regulating valve set at 60 psig
  - Pressure relief valve set at 90 psig
- System fill pressure: 60-psig make-up water supply pressure
- Normal operating pressure: 100 psig
- System Design Pressure: 125 psig

In this scenario, a hydronic water system (e.g., heating or cooling water for HVAC) is supplied pressure by a water pump. The system connects to a make-up water system that normally supplies water at a pressure of 60 psig via a pressure regulating valve. The normal operating pressure is 100 psig, which combines the 60-psig make-up water pressure and the normal operating pump differential pressure of 40 psi (92.4 ft). There are two feasible modes of failure that need to be evaluated:

1. Failure mode 1 – Pump dead-head condition

   This failure mode is similar to 4.A Scenario 1, except that the system fill pressure, normal operating pressure, and system Design Pressure are higher. The pump dead-head pressure is approximately 115 ft. head, or 50 psig.

Combining system fill pressure and pump dead-head pressure results in a maximum potential system pressure of 110 psig. This pressure system cannot be overpressurized in the worst-case failure scenario. Therefore, the pressure system is protected from overpressure by system design. For more information on overpressure protection by system design, see ASME BPVC Section XIII, Part 13.

2. Failure mode 2 – Make-up water pressure regulating valve failure

This failure mode assumes that the pressure regulating valve on the make-up water supply line fails fully open, ceasing regulation of make-up water pressure. The make-up water line includes a pressure relief valve set at 90 psig, limiting the make-up water pressure supply to 90 psig. The hydronic water pump is operating normally at 100%, with a pressure differential of 40 psig to provide the needed water flow.

This results in a discharge pressure of 130 psig, which exceeds the system Design Pressure of 125 psig. A relief device is needed to protect the system from overpressure. At 125 psig total pressure (90 psig make-up, 35 psig pump differential), the pump head will be ~80 ft, resulting in a flow of ~145 GPM per the pump curve.

One relief valve that is deemed to be sufficient for this system is an Aquatrol series 740 with a "G" size orifice. Its Section VIII liquid flow capacity at 125 psig setpoint is 195 GPM (see data sheet page 8), which exceeds the failure flow of 145 GPM. This relief valve is available from 1-1/4" to 2" inlet, so a 1-1/4" or 1-1/2" inlet size will need to be selected to not exceed the 1-1/2" piping system size.

NOTE: An alternative approach is to lower the set pressure of the pressure relief valve on the make-up water from 90 psig to 85 psig or less (down to 65 psig). The designer would need to check that the relief capacity is still adequate at this lower set pressure. This will depend on the capacity of the pressure regulator on the make-up water supply. Then another relief valve on the pump discharge is not needed.

5.0 FACILITY STEAM

The following design parameters are used for this example:

- Pressure source (P_1): 85 psig steam from a centralized distribution system, saturated (325 °F)
- Normal operating pressure: 15 psig
- Steam control valve: Armstrong Python 1500 series, 2" valve size with 1-1/4" trim (Cv=21)
- Piping system size: 2"
- System Design Pressure: 50 psig
- Assume bypass valve with a Cv less than or equal to the control valve Cv

In this scenario, either the steam control valve fails fully open or the bypass valve is fully opened during service of the control valve, resulting in an 85 psig pressure downstream of the control valve & bypass valve. This pressure exceeds the 50 psig Design Pressure of the downstream system, so a relief device set no higher than 50 psig is needed.

To determine the required relief capacity, the maximum failure flow rate through the regulator needs to be determined. LANL's "MassFlowRate-SteamThroughRegulator" Excel tool (found here) may be utilized to make this determination based on whether the steam will be in a sonic or subsonic flow condition:

$$P_2/P_1 \leq .54 \text{ (sonic condition)}$$

$$P_2/P_1 > .54 \text{ (subsonic condition)}$$

P_1 = 85 psig upstream pressure
P_2 = relief device set pressure (assume 50 psig)
P_2/P_1 = 50/85 = 0.59, therefore subsonic condition

Mass Flow Rate of Steam Through a Regulator (Subsonic Flow Conditions)

Given Inlet Pressure:	**85**	**psig**
LANL Atm. Pressure	11.1	psia
Upstream Pressure (P1) [psia]	96.1	psia
Given Downstream Pressure:	**50**	**psig**
LANL Atm. Pressure	11.1	psia
Downstream Pressure (P2) [psia]	61.1	psia
Flow Coefficient (Cv)	**21**	
Mass Flow Rate of Steam	**3271.14**	**lb/hr**

The selected relief device therefore needs to meet or exceed 3271.14 lb/hr steam. One relief valve that is deemed to be sufficient for this system is a Kunkle 910 series with a "J" size orifice. Its Section VIII steam flow capacity at 50 psig setpoint is 4268 lb/hr (calculated via linear interpolation, see data sheet page 17), and then derated for altitude by (50+11.1)/(50+14.7) = 4031 lb/hr which exceeds the failure flow of 3271.14 lb/hr. This relief valve has a 2" nominal inlet, which is acceptable for use with a 2" piping system size.
NOTE: As the pressure is dropped, the steam becomes superheated. However, it is not enough to use a superheat correction factor in this case.

6.0 SECTION I POWER BOILER

The following design parameters are used for this example:

- Pressure source: ASME Section I (1995 construction) power boiler, rated for 3381 lb/hr maximum steaming capacity, saturated
- Normal operating pressure: 50 psig

- Boiler MAWP: 150 psig
- Boiler relief nozzle size: 3”
- Existing relief valve: 100 psig Kunkle 6010 Section I “V” stamp, 1-1/2” inlet with “H” orifice

In this scenario, the boiler controls fail such that an uncontrolled heating process occurs, which has the potential to build pressure that exceeds the MAWP of the boiler. All Section I boilers are required by ASME Section I to have a relief valve either directly attached to a boiler nozzle or close coupled to the discharge piping with no intervening stop valves between the relief valve and boiler discharge nozzle. Additionally, the nominal size of the relief valve inlet cannot be larger than the size of the connection (e.g., a 4” inlet relief valve cannot be connected to a 3” boiler relief nozzle or 3” discharge piping).

The minimum required capacity of the boiler relief valve is recorded by LANL’s Chief Boiler Inspector during inspections. A master list of boilers at Los Alamos National Laboratory (LANL) that provides this information is available via a link in the PSD and on the Pressure Safety Program website. This list can be utilized as a pre-approved overpressure protection evaluation for protecting the boiler itself. Per the boiler master list, the maximum designed steaming capacity is 3381 lb/hr.
NOTE: Overpressure protection needs of the connected pressure system may need to be evaluated separately, particularly if there are steam regulators or other integrated pressure sources (e.g., pumps) in the pressure system.

The existing relief valve has a capacity of 4593 lb./hr. per the Kunkle 6000 series data sheet (see page 9). This relief device exceeds the boiler’s maximum steaming capacity and is therefore acceptable for this application.
NOTE: the MAWP is 150 psig, the operating pressure is 50 psig, and the set pressure of the relief valve is 100 psig. It is a safe and acceptable practice for the relief device setpoint to be below the system MAWP when operating conditions warrant.

7.0 SECTION IV HEATING WATER BOILER

SThe following design parameters are used for this example:

- Pressure source: ASME Section IV (1994 construction) power boiler
  - Heating surface area: 67 sq. ft.
  - Maximum boiler output: 490,000 BTU/hr.
  - Gas-fired watertube boiler
- Normal operating pressure: 30 psig
- Boiler MAWP: 150 psig
- Boiler relief nozzle size: 0.75”
- Existing relief valve: 45 psig Watts M1 740 Section IV “HV” stamp, 3/4” inlet

In this scenario, the boiler controls fail such that an uncontrolled heating process occurs, which has the potential to build pressure that exceeds the MAWP of the boiler. All Section IV boilers are required by ASME Section IV to have a relief valve either directly attached to a boiler nozzle or close coupled to the discharge piping with no intervening stop valves between the relief valve and boiler discharge nozzle. Additionally, the nominal size of the relief valve inlet cannot be larger than the size of the connection (e.g., a 4” inlet relief valve cannot be connected to a 3” boiler relief nozzle or 3″ discharge piping) AND cannot be less than ¾″ unless meeting special circumstances permitted by code.

The minimum required capacity of the boiler relief valve is recorded by LANL's Chief Boiler Inspector during inspections. A master list of boilers at LANL that provides this information is available via a link in the PSD and on the Pressure Safety Program website. This list can be utilized as a pre-approved overpressure protection evaluation for protecting the boiler itself. *NOTE: Overpressure protection needs of the connected pressure system may need to be evaluated separately, particularly if there are other pressure sources (e.g., pumps or makeup water) in the pressure system.*

Per the boiler master list, the minimum relief valve capacity is 670,000 BTU/hr. Therefore, this boiler shall be provided a relief device that meets or exceeds 670,000 BTU/hr. The existing relief valve has a capacity of 1,245,000 BTU/hr per the Watts data sheet. This relief device meets code and is acceptable for this application.

8.0 POTABLE WATER HEATER

The following design parameters are used for this example:

- Pressure source: 25 kilowatt (kW) potable water heater
- Normal operating pressure: 30 psig
- Water heater MAWP: 125 psig
- Water heater relief nozzle size: 0.75″
- Existing relief valve: 125 psig Apollo 18C-402, ¾″ inlet, 3″ temperature sensing element length

In this scenario, the water heater controls fail such that an uncontrolled heating process occurs, which has the potential to build pressure and/or temperature that exceeds the MAWP of the water heater. Water heaters come equipped with temperature and pressure (T&P) relief valves that open when either the pressure reaches the pressure setpoint or the water temperature reaches 210 deg F.

Depending on the size/construction of the water heater, T&P relief valves will either have only a Canadian Standards Association (CSA) BTU/hr. rating or both a CSA and ASME BTU/hr. rating. Generally, water heaters that are *not* built to ASME Section IV standards (i.e., greater than 200,000 BTU/hr. input or nominal capacity of 120 gallons) will utilize the CSA BTU/hr. rating when sizing relief devices. Subsequently, ASME Section IV "HLW" stamped water heaters will utilize the ASME BTU/hr. rating when sizing relief devices.

Additionally, T&P relief valves have a temperature sensing element with lengths that vary. The Apollo 18C-402 used in this example can be procured with either 3″ or 8″ length elements. Element length may impact temperature sensing if it is too long or too short, so the best practice when planning preventive maintenance replacements of water heater T&P relief valves is to utilize the same or very similar element length compared to what was installed by the manufacturer. Ideally, the exact PRV model installed by the manufacturer should be used when possible.

The manufacturer-installed T&P relief valve is an Apollo 18C-402, which has a CSA rating of 105,000 BTU/hr. and an ASME Section IV rating of 500,000 BTU/hr. The water heater in this example is *not* an ASME Section IV water heater, therefore, the CSA rating of the T&P relief valve is to be used for sizing the relief device. The electric heating maximum input of 25 kW converts to 85,305 BTU/hr. (1 kW = 3412.2 BTU/hr.). The 105,000 BTU/hr. capacity exceeds the converted 85,305 BTU/hr. input rating of the water heater, so the relief valve is sized appropriately.

9.0 CRYOGENIC LIQUID LOCK

Comprehensive example evaluations for cryogenic liquid lock overpressure scenarios are available for reference on the "Reference Data" SharePoint linked on the ESM Chapter 17 website.

Generally, these evaluations utilize the equations provided by CGA S-1.3 (2020 edition) publication sections:

- Assuming loss of vacuum insulation in a double-walled pipe or vessel *without* fire – CGA S-1.3 section 6.2.2 "Insulated containers for liquefied compressed gases"
- Assuming loss of vacuum insulation in a double-walled pipe or vessel *with* fire – CGA S-1.3 section 6.3.2 "Liquefied compressed gases, refrigerated fluids, and refrigerated (cryogenic) fluids in uninsulated or insulated containers that lose insulation during fire"

10.0 REFERENCES

There are links to external websites throughout this document that go to product pages and data sheets for equipment or components used in this guide. PDF versions of the linked content are available for reference on the "Reference Data" SharePoint linked on the ESM Chapter 17 website.