SCENE

Piping Engineering Note
Rev. 6

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Rev 4 Updated by Hugh Lippincott	**Organization** Fermilab	**Phone** 630-840-3258	**Signature**	**Date** August 7, 2017
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1.0 Introduction

The SCENE detector, has been designed and installed at the Fermilab building PAB in 2012. It has run successfully with liquid argon since then.

In 2014, for Rev 3, this document was updated to run it with liquid xenon. The design pressure remains the same, but the temperature is now 170K. No changes in the design are needed. At this time, Appendix E was added to verify that the Pressure Relieving Device is suitable for these conditions as well. A note was added to Section 11.0 to that effect.

The P&ID shown in Appendix A was changed, but the changes were in warm piping. A pressure vessel has also been added: PPD-10120. It is U-stamped and it already has the PPD sticker.

All the rest remained the same.

In December of 2016, for Rev 4 of this document, the inner vessel was changed. The 4” diameter vessel that was used for the original design was replaced by a 6" diameter vessel. In addition, a differential pressure transducer was inserted between the inner vessel and the condenser. These changes are detailed in new Sections 7.2, 7.3, 8.2 and 8.3, including a new P&ID relevant just for those sections. A paragraph was also added to Section 11.0 confirming that the original pressure relief is still correctly sized for the new inner vessel. The two vessels are meant to be interchangeable. In the course of preparing Rev. 4, it was noticed that many of the previous calculations used 15 psig for the working pressure. While this is true relative to atmosphere, the detector itself and much of the piping operates in an insulating vacuum, and so the differential pressure is 30 psid. The previous calculations were not updated, but all new calculations use 30 psid. All other details, including the pressure relief devices, are unchanged.

In August of 2017, for Rev 5 of this document, the pressure relief valve was replaced by a slightly larger pressure relief valve with a relieving pressure of 20 psig. As a result, the MAWP of the system was changed to 20 psig, and all calculations were updated, including Appendix D containing the PRV sizing calculations.

Revision 6 was created for this document on January 31, 2018. The current SCENE cryostat has one primary relief valve. This valve (PSV-01) has already been approved and meets the flow capacity requirements for both argon and xenon cases. A small leak, suspected to stem from this relief valve, is affecting the purity when the experiment is operating under normal conditions. For this revision, a burst disc was added between the relief valve and the vessel to prevent the leaking relief valve from contaminating the xenon or argon inside.

Additionally, a check valve was added to prevent the relief valve from going off during the filling process. The check valve leads to a large 440L dewar (PPD-10120) with a MAWP of 200 psi. The check valve is manufactured by Swagelok and has part number SS-8CPA2-3. It has a cracking pressure of 30 psi.

The SCENE detector will be used for the study of scintillation and ionization from recoils in liquid Argon and liquid Xenon. This detector will operate in three modes: filling, recirculation and data-taking.

The filling takes place once, at the beginning. During the filling, the gas handling system supplies a stream of ultra pure Argon gas to the detector from a commercial cylinder. The Argon flows through a commercial getter to remove residual impurities, then through a commercial heat exchanger where it is pre-cooled down by the cold Argon gas coming from the detector. It then enters the condenser where it is liquified. Liquid Argon fills the detector by gravity. The cold gas from the detector goes to the condenser and back in the piping through the heat exchanger, to pre-cool down the incoming warm Argon gas. Detector, condenser and heat exchanger are only connected by straight pieces of pipe. After the required amount of Argon has entered the detector, the outside supply of Argon gas will be shut off. The gas system transits into recirculation mode, where Argon gas from inside the detector is pumped through the getter then back into the detector. Once the Argon in the detector reaches the desired purity, recirculation is halted, and data-taking begins. Recirculation is restarted whenever the Argon purity falls below the threshold.

The cooling power of the condenser is given by a PT-60 cryocooler from Cryomech, whose cold head is directly connected to the top flange of the condenser.

A vacuum jacket surrounds heat exchanger, condenser, detector and all the cryogenic lines.

This document summarizes the design calculations for the following cryogenic lines:

1) GAr line from heat exchanger to condenser (Section 4)
2) Condenser (Section 5)
3) LAr line from condenser to detector (Section 6)
4) Detector (Section 7)
5) GAr line from detector to condenser (Section 8)
6) GAr line from detector to heat exchanger (Section 9)

2.0 Design codes and evaluation criteria

The piping of the SCENE system must satisfy the requirements listed in the “Piping System” Section of the Fermilab ES&H Manual (Section 5031.1). This section states that piping systems containing cryogenic fluids fall under the category of Normal Fluid Service and shall adhere to the requirements of the ASME Process Piping Code B31.3.

The Maximum Allowable Working Pressure (MAWP) of the SCENE piping system is 20 psig. The operating temperature is about 94K.

3.0 Materials

The piping of the SCENE system is fabricated from 304L seamless stainless steel tube. The lowest allowable stress from Table K-1 of ASME B31.3 will be used in this analysis.

The piping of the SCENE system will operate at about 94K. According to 323.2.2 of the Code impact test is required, except as stated in Table 323.2.2 Note 6 where impact test is not required when the maximum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in). All the tubes used in the SCENE piping system have a wall thickness lower than 0.098 in, therefore impact test is not required for the piping system.

Moreover, Fermilab has extensive service experience using the 300 series stainless steel at cryogenic temperatures even much lower than 94K.

Table 3.1 summarizes the material used and the corresponding allowable stresses from the Code, ASME B31.3, Table K-1.

Table 3.2 summarizes the results of the wall thickness calculations.

Component	Material	Code Allowable Stress
GAr line from heat exchanger to Condenser	304L SS tube seamless	20,000 psi
Condenser	304L SS tube seamless	20,000 psi
LAr line from Condenser to Detector	304L SS tube seamless	20,000 psi
Detector	304L SS tube seamless	20,000 psi
GAr line from Detector to Condenser	304L SS tube seamless	20,000 psi
GAr line from Detector to heat exchanger	304L SS tube seamless	20,000 psi

Table 3.1 - Materials

Component	P Design Int/Ext	D	S	Nominal thickness t	Required thickness Internal	Required thickness External	E
	psi	*in*	*psi*	*in*	*in*	*in*	
GAr line from heat exchanger to Condenser	35/15	0.5	20,000	0.035	0.0005	0.0005	0.8
Condenser	35/15	4	20,000	0.083	0.0044	0.004	0.8
LAr line from Condenser to Detector	35/15	0.5	20,000	0.035	0.0005	0.0005	0.8
Detector	35/15	6	20,000	0.065	0.0066	0.01	0.8

Component	P Design Int/Ext	D	S	Nominal thickness t	Required thickness Internal	Required thickness External	E
GAr line from Detector to Condenser	35/15	0.5	20,000	0.035	0.0005	0.0005	0.8
GAr line from Detector to heat exchanger	35/15	0.5	20,000	0.035	0.0005	0.0005	0.8

Table 3.2 - Summary of the results

The selected wall thicknesses are greater than the minimum for both internal and external pressure. The requirements are therefore satisfied.

4.0 GAr line from heat exchanger to condenser

The GAr line from heat exchanger to condenser brings the cold gaseous Argon from the heat exchanger to the condenser, where it condenses. This line is a standard 304L stainless steel seamless tube with 0.50 inch OD and 0.035 inch wall thickness.

Operating pressure is 35 psid. Operating temperature is about 94K.

During the installation, there will be external atmospheric pressure. It is then necessary to analyze the GAr line from heat exchanger to condenser under external atmospheric pressure.

Figure 1 - GAr line from heat exchanger to condenser

This line is a standard 0.50 inch OD with 0.035 inch wall thickness 304L seamless stainless steel tube ASTM A 269. The minimum thickness is evaluated using 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

$$t = \frac{P \cdot D}{2 \cdot \left(S \cdot E \cdot W + P \cdot Y\right)}$$

$t < D/6$ satisfied

P=35 psi design pressure

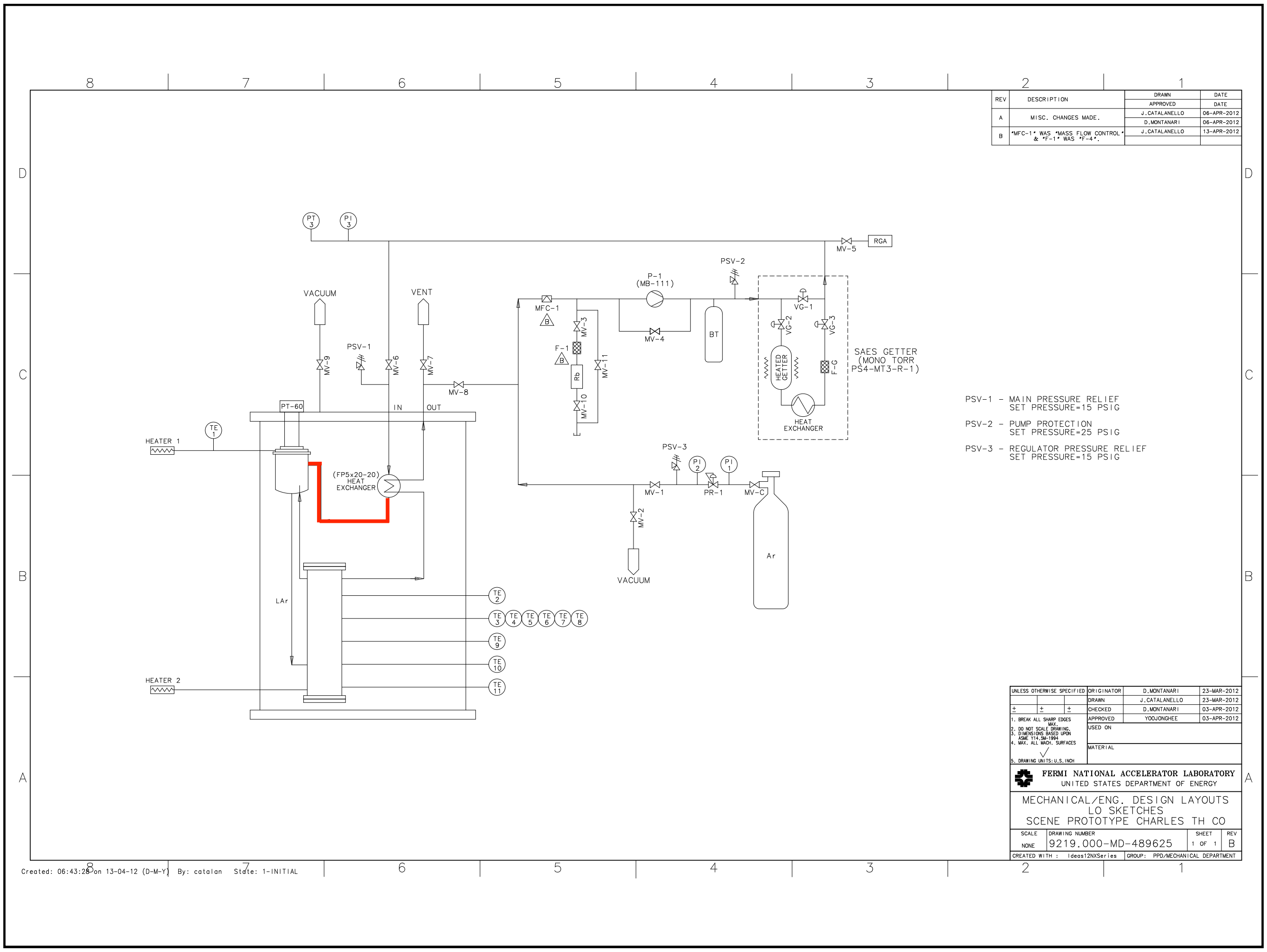
$D = 0.50\ in$ tube outer diameter

$S = 20{,}000\,psi$ allowable stress, from Table A-1

$E = 0.8$ quality factor, from Table A1-A (worst case)

$W = 1$ weld join strength reduction factor

$Y = 0.4$ coefficient, from Table 304.1.1



The minimum wall thickness is 0.0005 inch, the tube wall thickness is 0.035 inch, the requirement is therefore satisfied.

The Code analysis for shell under external pressure is governed by equation UG-28:

$$P_a = \frac{4 \cdot B}{3 \cdot \left(D_0 / t \right)}$$

P_a is the maximum allowable external working pressure, D_0 the external diameter of the shell, t the shell wall thickness and B a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 4.1 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	15	*psi*	External pressure design
D_0	0.50	*in*	Shell outer diameter
L	30.00	*in*	Shell length

Variable	Value	Unit	Description
t	0.035	*in*	Shell thickness
L/D0	60.00		
D0/t	14.29		
A	0.005		Subpart 3, Section II, Part D, Figure G
B	12,000		Subpart 3, Section II, Part D, Figure HA-3
P_a	1,120	*psi*	Maximum external working pressure
t_{min}	0.0005	*in*	Minimum thickness for external pressure design

Table 4.1 - GAr line from heat exchanger to condenser

The maximum allowable external working pressure is 1,120 psi, the requirement is therefore satisfied.

The GAr line from heat exchanger to condenser includes a flexible hose, to allow flexibility, see Table 4.2.

4.1 Unlisted components

Table 4.2 shows the unlisted components installed in the GAr line from heat exchanger to condenser of the SCENE piping system, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
Elbow	Swagelok, P/N: 6LV-8MW-9	3,700 psi	35 psid	304.7.2(a) Extensive service experience
Flex hose	Hose Master, Masterflex, P/N: AF5550 1/2”	1,186 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: 6LV-8-VCR-3S-8TB2	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-1	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-4	3,500 psi	35 psid	304.7.2(a) Extensive service experience

Table 4.2 - Unlisted components

5.0 Condenser

The condenser is 4 inch outer diameter with 0.083 inch wall thickness, and 3.2 inch high.

Operating pressure is 35 psid, operating temperature is about 94K. Fluid is liquid Argon.

The minimum thickness is evaluated using 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

$$t = \frac{P \cdot D}{2 \cdot (S \cdot E \cdot W + P \cdot Y)}$$

$t < D/6$	satisfied
P= 35 psid	design pressure
$D = 4.00\ in$	tube outer diameter
$S = 20{,}000\, psi$	allowable stress, from Table A-1
$E = 0.8$	quality factor, from Table A1-A (worst case)
$W = 1$	weld join strength reduction factor
$Y = 0.4$	coefficient, from Table 304.1.1

The minimum wall thickness is 0.0044 inch, the tube wall thickness is 0.083 inch, the requirement is therefore satisfied.

The Code analysis for shell under external pressure is governed by equation UG-28:

$$P_a = \frac{4 \cdot B}{3 \cdot \left(D_0 / t \right)}$$

P_a is the maximum allowable external working pressure, D_0 the external diameter of the shell, t the shell wall thickness and B a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 5.1 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	15	*psi*	External pressure design
D_0	4.00	*in*	Shell outer diameter
L	3.20	*in*	Shell length
t	0.083	*in*	Shell thickness
L/D0	0.80		
D0/t	48.19		

Variable	Value	Unit	Description
A	0.005		Subpart 3, Section II, Part D, Figure G
B	12,000		Subpart 3, Section II, Part D, Figure HA-3
P_a	332	*psi*	Maximum external working pressure
t_{min}	0.0038	*in*	Minimum thickness for external pressure design

Table 5.1 - Condenser under external pressure

The maximum allowable external working pressure is 320 psi, the requirement is therefore satisfied.

There is one opening in the condenser shell with 0.50 inch diameter.

UG-36 of the Code states that an opening in a shell doesn't require additional reinforcement if:

- the opening diameter is less than half the shell diameter, UG-36(b)(1)
- the opening diameter is less than 3.5 inch in shell with a required minimum thickness of ⅜ inch or less, UG-36(c)(3)

The opening meets the above criteria and no additional reinforcement is required.

5.1 Unlisted components

Table 5.2 shows the unlisted components installed in the condenser, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
Cap	Robert James, CAP 3.5" SCH5S.	417 psi	35 psid	304.7.2(a) Extensive service experience

Table 5.2 - Unlisted components

6.0 LAr line from condenser to detector

The LAr line from condenser to detector carries the liquid Argon from the condenser to the detector, by gravity. This line is a standard 304L stainless steel seamless tube with 0.50 inch OD and 0.035 inch wall thickness.

Operating pressure is 35 psid. Operating temperature is about 94K.

During the installation, there will be external atmospheric pressure. It is then necessary to analyze the LAr line from condenser to detector under external atmospheric pressure.

This line is a standard 0.50 inch OD with 0.035 inch wall thickness 304L seamless stainless steel tube ASTM A 269. The minimum thickness is evaluated using 304.1.2(a) of

ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

$$t = \frac{P \cdot D}{2 \cdot \left(S \cdot E \cdot W + P \cdot Y \right)}$$

$t < D/6$	satisfied
P= 35 psid	design pressure
$D = 0.50\ in$	tube outer diameter
$S = 20{,}000\, psi$	allowable stress, from Table A-1
$E = 0.8$	quality factor, from Table A1-A (worst case)
$W = 1$	weld join strength reduction factor
$Y = 0.4$	coefficient, from Table 304.1.1

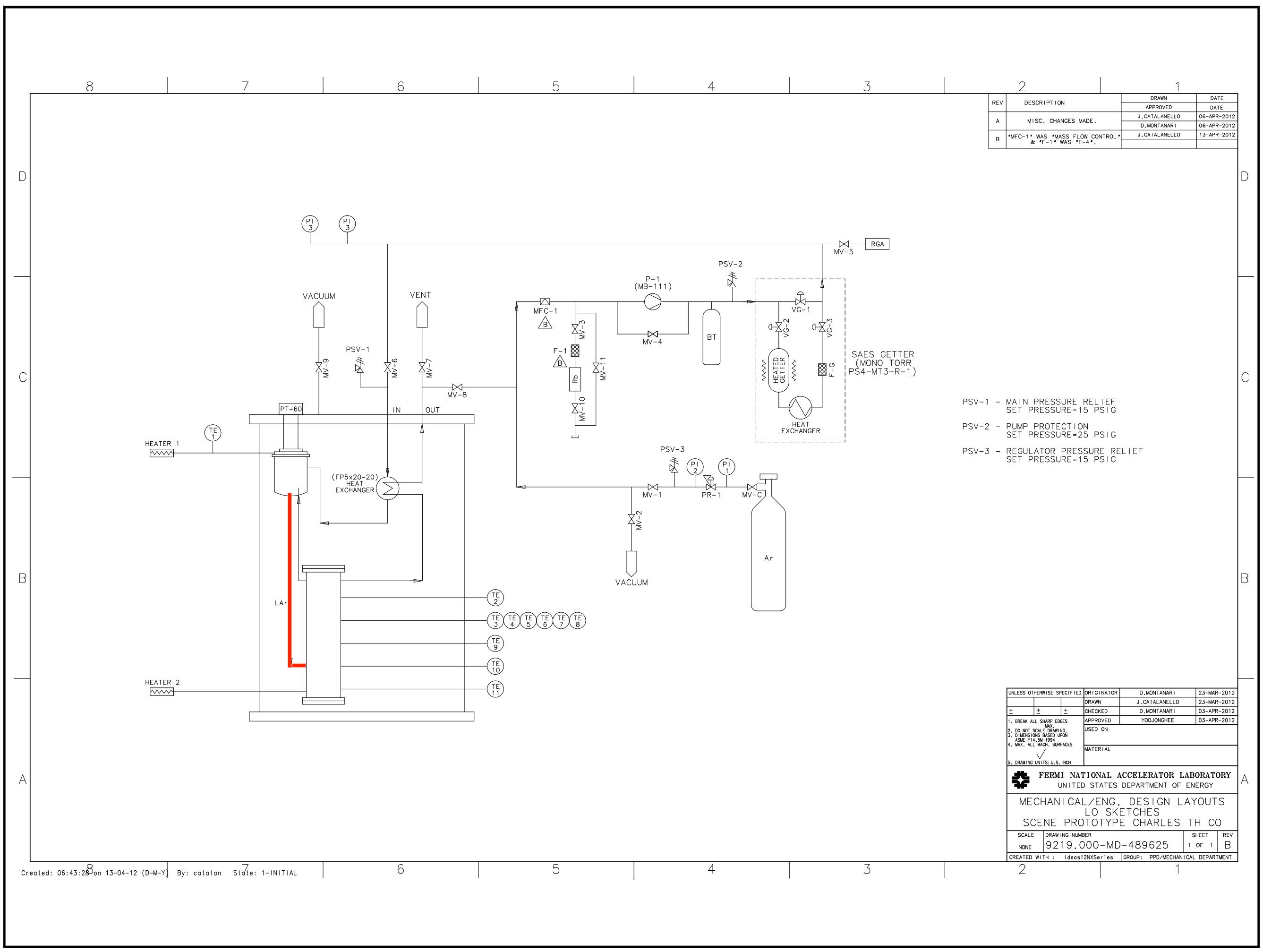


Figure 2 - LAr line from condenser to detector

The minimum wall thickness is 0.0005 inch, the tube wall thickness is 0.035 inch, the requirement is therefore satisfied.

The Code analysis for shell under external pressure is governed by equation UG-28:

$$P_a = \frac{4 \cdot B}{3 \cdot \left(D_0 / t \right)}$$

P_a is the maximum allowable external working pressure, D_0 the external diameter of the shell, t the shell wall thickness and B a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 6.1 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	15	*psi*	External pressure design
D_0	0.50	*in*	Shell outer diameter
L	34.00	*in*	Shell length
t	0.035	*in*	Shell thickness
L/D0	68.00		
D0/t	14.29		
A	0.005		Subpart 3, Section II, Part D, Figure G
B	12,000		Subpart 3, Section II, Part D, Figure HA-3
P_a	1,120	*psi*	Maximum external working pressure
t_{min}	0.0005	*in*	Minimum thickness for external pressure design

Table 6.1 - LAr line from condenser to detector

The maximum allowable external working pressure is 1,120 psi, the requirement is therefore satisfied.

The LAr line from condenser to detector includes a flexible hose, to allow flexibility, see Table 6.2.

6.1 Unlisted components

Table 6.2 shows the unlisted components installed in the LAr line from condenser to detector of the SCENE piping system, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
Elbow	Swagelok, P/N: 6LV-8MW-9	3,700 psi	35 psid	304.7.2(a) Extensive service experience
Flex hose	Hose Master, Masterflex, P/N: AF5550 1/2”	1,186 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: 6LV-8-VCR-3S-8TB2	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-1	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-4	3,500 psi	35 psid	304.7.2(a) Extensive service experience

Table 6.2 - Unlisted components

7.0 Detector

The Detector is 4 inch outer diameter with 0.065 inch wall thickness, and 30 inch high.
Operating pressure is 35 psid, operating temperature is about 94K. Fluid is liquid Argon.

The minimum thickness is evaluated using 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

$$t = \frac{P \cdot D}{2 \cdot \left(S \cdot E \cdot W + P \cdot Y\right)}$$

$t < D/6$ satisfied

P = 35 psid design pressure

$D = 4.00\ in$ tube outer diameter

$S = 20{,}000\,psi$ allowable stress, from Table A-1

$E = 0.8$ quality factor, from Table A1-A (worst case)

$W = 1$ weld join strength reduction factor

$Y = 0.4$ coefficient, from Table 304.1.1

The minimum wall thickness is 0.0044 inch, the tube wall thickness is 0.065 inch, the requirement is therefore satisfied.

The Code analysis for shell under external pressure is governed by equation UG-28:

$$P_a = \frac{4 \cdot B}{3 \cdot \left(\frac{D_0}{t} \right)}$$

P_a is the maximum allowable external working pressure, D_0 the external diameter of the shell, t the shell wall thickness and B a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 7.1 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	15	*psi*	External pressure design
D_0	4.00	*in*	Shell outer diameter
L	30.00	*in*	Shell length
t	0.065	*in*	Shell thickness
L/D0	7.50		
D0/t	61.54		
A	0.00035		Subpart 3, Section II, Part D, Figure G
B	4,700		Subpart 3, Section II, Part D, Figure HA-3
P_a	102	*psi*	Maximum external working pressure
t_{min}	0.0096	*in*	Minimum thickness for external pressure design

Table 7.1 - Condenser under external pressure

The maximum allowable external working pressure is 102 psi, the requirement is therefore satisfied.

There are three openings in the detector shell with 0.50 inch diameter.

UG-36 of the Code states that a openings in a shell do not require additional reinforcement if:

- the opening diameter is less than half the shell diameter, UG-36(b)(1).
- the opening diameter is less than 3.5 inch in shell with a required minimum thickness of ⅜ inch or less, UG-36(c)(3)(a).

- no two isolated unreinforced openings in accordance with the above shall have their centers closer to each other than the sum of their diameters, UG-36(c)(3)(c).

The openings are more than 0.5 inch apart. They therefore meet the above criteria and no additional reinforcement is required.

7.1 Unlisted components

Table 7.2 shows the unlisted components installed in the detector, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
6-Way Cross	Kurt Lesker, P/N: C6-0275	285 psi	35 psid	304.7.2(a) Extensive service experience
Feedthrough	Ceram Tech, P/N: 17187-01-CF	1,400 psi	35 psid	304.7.2(a) Extensive service experience
Feedthrough	Ceram Tech, P/N: 17216-02-CF	1,200 psi	35 psid	304.7.2(a) Extensive service experience
Feedthrough	Ceram Tech, P/N: 17187-01-CF	1,500 psi	35 psid	304.7.2(a) Extensive service experience

Table 7.2 - Unlisted components

7.2 Detector Update for Rev 4, December 2016

The new Detector is a 6 inch outer diameter vessel with 0.120 inch wall thickness, and 13.12 inch height (MDC Vacuum part 402008).

Operating pressure is 35 psid (since it operates with an external vacuum), operating temperature is down to 94K. Fluid is either liquid argon or liquid xeon.

The minimum thickness is evaluated using 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

$$t = \frac{P \cdot D}{2 \cdot \left(S \cdot E \cdot W + P \cdot Y\right)}$$

$t < D/6$ satisfied

P = 35 psid relative to the vacuum in the Outer Vacuum Can
D = 6 in tube outer diameter

$S = 20{,}000\,psi$	allowable stress, from Table A-1
$E = 0.8$	quality factor, from Table A1-A (worst case)
$W = 1$	weld join strength reduction factor
$Y = 0.4$	coefficient, from Table 304.1.1

The minimum wall thickness is 0.0066 inch, the tube wall thickness is 0.120 inch, the requirement is therefore satisfied.

The Code analysis for shell under external pressure is governed by equation UG-28:

$$P_a = \frac{4 \cdot B}{3 \cdot \left({D_0}/{t} \right)}$$

P_a is the maximum allowable external working pressure, *D_0* the external diameter of the shell, *t* the shell wall thickness and *B* a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 7.3 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	30	*psi*	External pressure design
D_0	6.00	*in*	Shell outer diameter
L	13.12	*in*	Shell length
t	0.120	*in*	Shell thickness
L/D0	2.19		
D0/t	50.00		
A	0.00035		Subpart 3, Section II, Part D, Figure G
B	4,700		Subpart 3, Section II, Part D, Figure HA-3
P_a	125	*psi*	Maximum external working pressure
t_{min}	0.0287	*in*	Minimum thickness for external pressure design

Table 7.3 - Detector under external pressure

The maximum allowable external working pressure is 125 psi, the requirement is therefore satisfied. From ED0004253, the design pressure for an 8” CF is 200 psi.

There is one opening in the detector shell with 0.50 inch diameter.

UG-36 of the Code states that a openings in a shell do not require additional reinforcement if:

- the opening diameter is less than half the shell diameter, UG-36(b)(1).

- the opening diameter is less than 3.5 inch in shell with a required minimum thickness of ⅜ inch or less, UG-36(c)(3)(a).
- no two isolated unreinforced openings in accordance with the above shall have their centers closer to each other than the sum of their diameters, UG-36(c)(3)(c).

The opening meets the above criteria and no additional reinforcement is required.

7.3 Unlisted components

Table 7.4 shows the unlisted components installed in the 2016 detector configuration, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
6-Way Cross	Kurt Lesker, P/N: C6-0275	350 psi	35 psid	Report ED0004253 304.7.2(a) Extensive service experience
4-Way Cross	Kurt Lesker, P/N: C4-0275	350 psi	35 psid	Report ED0004253 304.7.2(a) Extensive service experience
2.75CF to VCR4	Kurt Lesker, P/N: F0275X4FVCR	350 psi	35 psid	Report ED0004253 304.7.2(a) Extensive service experience
Feedthrough	Ceram Tech, P/N: 17187-01-CF	1,400 psi	35 psid	304.7.2(a) Extensive service experience
Feedthrough	Ceram Tech, P/N: 17216-02-CF	1,200 psi	35 psid	304.7.2(a) Extensive service experience
Feedthrough	Ceram Tech, P/N: 17187-01-CF	1,500 psi	35 psid	304.7.2(a) Extensive service experience

Table 7.4 - Unlisted components

8.0 GAr line from detector to condenser

The GAr line from detector to condenser brings the cold gaseous Argon from the detector back to the condenser, where it re-condenses. This line is a standard 304L stainless steel seamless tube with 0.50 inch OD and 0.035 inch wall thickness.

Operating pressure is 35 psid. Operating temperature is about 94K.

During the installation, there will be external atmospheric pressure. It is then necessary to analyze the GAr line from detector to condenser under external atmospheric pressure.

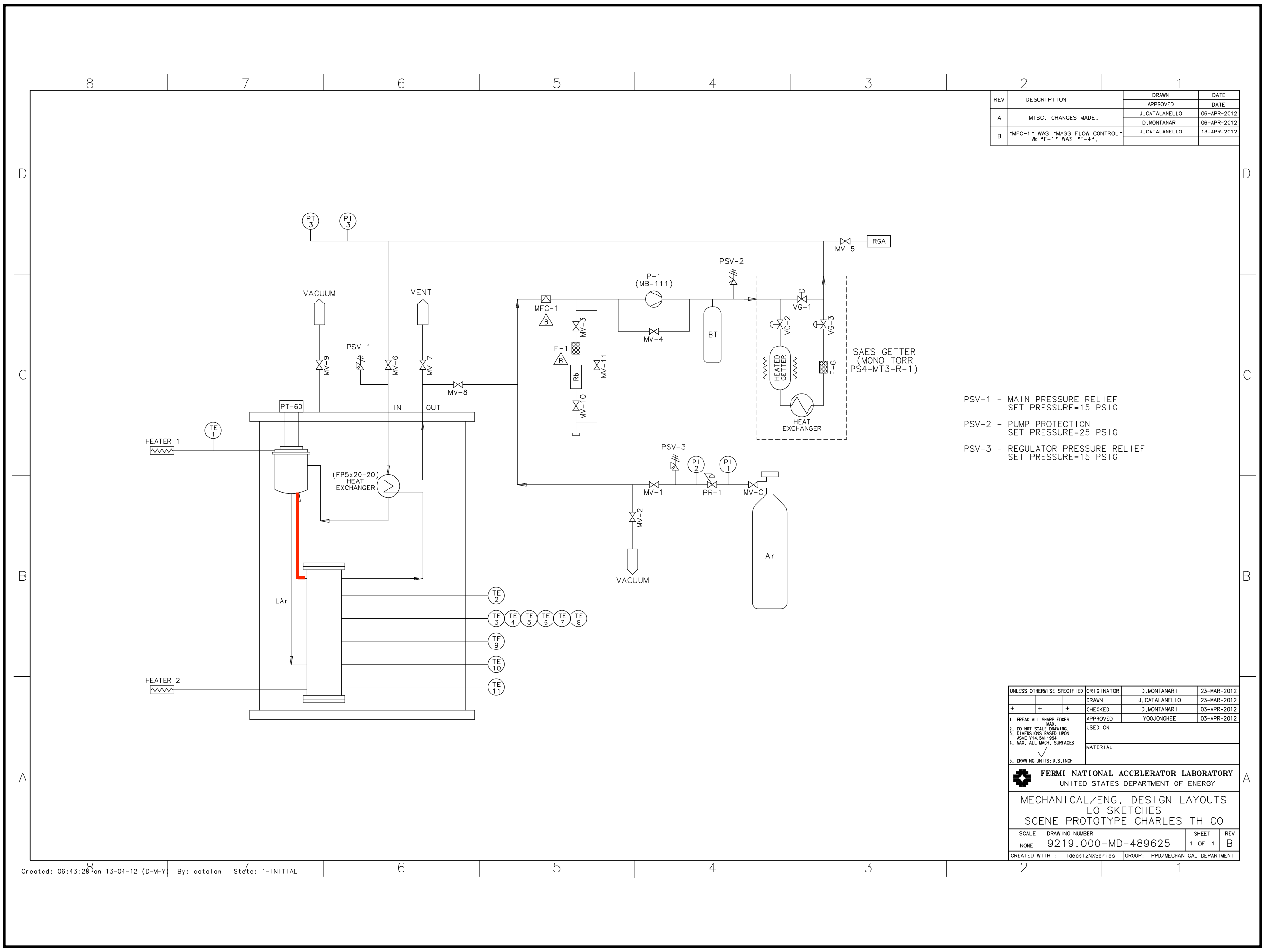


Figure 3 - GAr line from detector to condenser

This line is a standard 0.50 inch OD with 0.035 inch wall thickness 304L seamless stainless steel tube ASTM A 269. The minimum thickness is evaluated using 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

$$t = \frac{P \cdot D}{2 \cdot \left(S \cdot E \cdot W + P \cdot Y\right)}$$

$t < D/6$	satisfied
P = 35 psid	design pressure
$D = 0.50\ in$	tube outer diameter
$S = 20{,}000\,psi$	allowable stress, from Table A-1
$E = 0.8$	quality factor, from Table A1-A (worst case)
$W = 1$	weld join strength reduction factor
$Y = 0.4$	coefficient, from Table 304.1.1

The minimum wall thickness is 0.0005 inch, the tube wall thickness is 0.035 inch, the requirement is therefore satisfied.

The Code analysis for shell under external pressure is governed by equation UG-28:

$$P_a = \frac{4 \cdot B}{3 \cdot \left(D_0 / t \right)}$$

P_a is the maximum allowable external working pressure, D_0 the external diameter of the shell, t the shell wall thickness and B a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 8.1 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	15	*psi*	External pressure design
D_0	0.50	*in*	Shell outer diameter
L	15.00	*in*	Shell length
t	0.035	*in*	Shell thickness
L/D0	30.00		
D0/t	14.29		
A	0.005		Subpart 3, Section II, Part D, Figure G
B	12,000		Subpart 3, Section II, Part D, Figure HA-3
P_a	1,120	*psi*	Maximum external working pressure
t_{min}	0.0005	*in*	Minimum thickness for external pressure design

Table 8.1 - GAr line from detector to condenser

The maximum allowable external working pressure is 1,120 psi, the requirement is therefore satisfied.

The GAr line from detector to condenser includes a flexible hose, to allow flexibility, see Table 8.2.

8.1 Unlisted components

Table 8.2 shows the unlisted components installed in the GAr line from detector to condenser of the SCENE piping system, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
Elbow	Swagelok, P/N: 6LV-8MW-9	3,700 psi	35 psid	304.7.2(a) Extensive service experience
Flex hose	Hose Master, Masterflex, P/N: AF5550 1/2”	1,186 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: 6LV-8-VCR-3S-8TB2	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-1	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-4	3,500 psi	35 psid	304.7.2(a) Extensive service experience

Table 8.2 - Unlisted components

8.2 GAr line from detector and condenser to differential pressure transducer - Rev 4

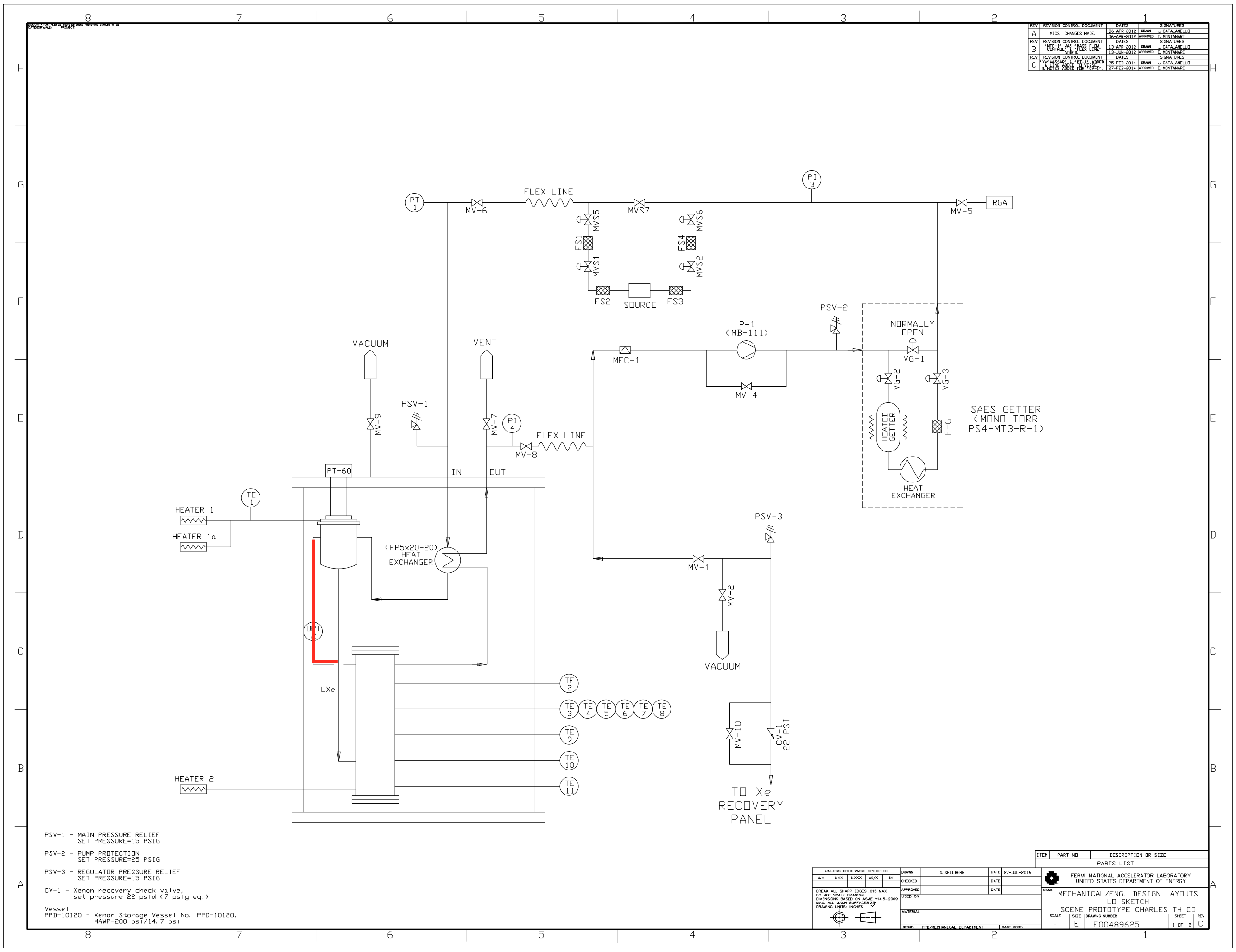
For the Rev 4 modification, there is a differential pressure transducer (DPT) placed between the detector and condenser. In this modification, gas goes around the full circulation loop to return to the condenser and prevent vapor lock, and the DPT measures any issues maintaining the pressure balance. This line is a standard 304L stainless steel seamless tubing made from a combination of with 0.50 inch OD and 0.25 inch OD tubing, with 0.035 inch wall thickness.

Operating pressure is 35 psid. Operating temperature is down to 94K.

During the installation, there will be external atmospheric pressure, and the differential pressure transducer is mounted externally. It is then necessary to analyze the GAr line from detector to condenser under external atmospheric pressure.

This line is a combination of standard 0.50 inch and 0.25 inch OD with 0.035 inch wall thickness 304L seamless stainless steel tube ASTM A 269. The minimum thickness is evaluated using 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

$$t = \frac{P \cdot D}{2 \cdot (S \cdot E \cdot W + P \cdot Y)}$$



$t < D/6$	satisfied
P = 35 psid	relative to the vacuum in the Outer Vacuum Can
$D = 0.50\ in$	tube outer diameter
$S = 20{,}000\,psi$	allowable stress, from Table A-1
$E = 0.8$	quality factor, from Table A1-A (worst case)
$W = 1$	weld join strength reduction factor
$Y = 0.4$	coefficient, from Table 304.1.1

The minimum wall thickness for the 0.5 inch section is 0.0005 inch, the tube wall thickness is 0.035 inch, the requirement is therefore satisfied. For the 0.25 inch section, the requirement is also satisfied.

Figure 4 - GAr line from detector to condenser to DPT

The Code analysis for shell under external pressure is governed by equation UG-28:

$$P_a = \frac{4 \cdot B}{3 \cdot \left(D_0 / t \right)}$$

P_a is the maximum allowable external working pressure, D_0 the external diameter of the shell, t the shell wall thickness and B a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 8.1 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	30	*psi*	External pressure design
D_0	0.50	*in*	Shell outer diameter
L	15.00	*in*	Shell length
t	0.035	*in*	Shell thickness
L/D0	30.00		
D0/t	14.29		
A	0.005		Subpart 3, Section II, Part D, Figure G
B	12,000		Subpart 3, Section II, Part D, Figure HA-3
P_a	1,120	*psi*	Maximum external working pressure
t_{min}	0.0009	*in*	Minimum thickness for external pressure design

Table 8.3 - GAr line from detector to condenser

The maximum allowable external working pressure is 1,120 psi, the requirement is therefore satisfied.

The GAr line from detector to condenser includes a flexible hose, to allow flexibility, see Table 8.4.

8.3 Unlisted components

Table 8.4 shows the unlisted components installed in the GAr line from detector to condenser of the SCENE piping system, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
Differential Pressure Transducer	MKS, P/N 226A-32831	40 psig	20 psi	12 psid full range
Elbow	Swagelok, P/N: 6LV-8MW-9	3,700 psi	35 psid	304.7.2(a) Extensive service experience
Flex hose	Hose Master, Masterflex, P/N: AF5550 1/2”	1,186 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: 6LV-8-VCR-3S-8TB2	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-1	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-4	3,500 psi	35 psid	304.7.2(a) Extensive service experience

Table 8.4 - Unlisted components

9.0 GAr line from detector to heat exchanger

The GAr line from detector to heat exchanger brings the cold gaseous Argon from the detector to the heat exchanger, then the purification loop. This line is a standard 304L stainless steel seamless tube with 0.50 inch OD and 0.035 inch wall thickness.

Operating pressure is 35 psid. Operating temperature is about 94K.

During the installation, there will be external atmospheric pressure. It is then necessary to analyze the GAr line from detector to heat exchanger under external atmospheric pressure.

This line is a standard 0.50 inch OD with 0.035 inch wall thickness 304L seamless stainless steel tube ASTM A 269. The minimum thickness is evaluated using 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping is given by:

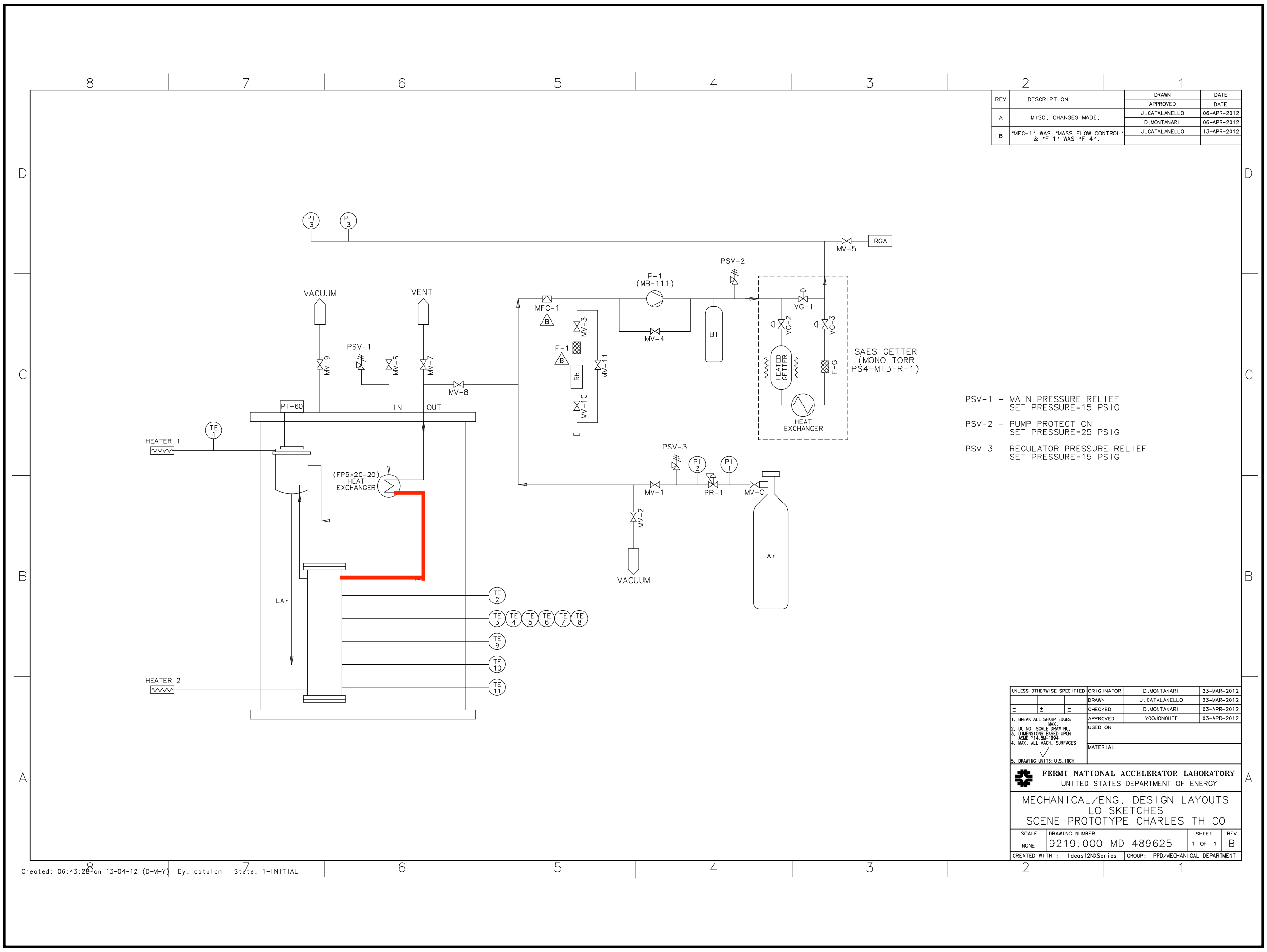
$$t = \frac{P \cdot D}{2 \cdot \left(S \cdot E \cdot W + P \cdot Y\right)}$$

$t < D/6$ satisfied

P = 35 psid design pressure

$D = 0.50\ in$ tube outer diameter

$S = 20{,}000\, psi$ allowable stress, from Table A-1



$E = 0.8$	quality factor, from Table A1-A (worst case)
$W = 1$	weld join strength reduction factor
$Y = 0.4$	coefficient, from Table 304.1.1

The minimum wall thickness is 0.0005 inch, the tube wall thickness is 0.035 inch, the requirement is therefore satisfied.

The Code analysis for shell under external pressure is governed by equation UG-28:

Figure 4 - GAr line from detector to heat exchanger

$$P_a = \frac{4 \cdot B}{3 \cdot \left(D_0 / t \right)}$$

P_a is the maximum allowable external working pressure, D_0 the external diameter of the shell, t the shell wall thickness and B a factor from Subpart 3, Section II, Part D, Figure HA-3.

Table 9.1 summarizes the results for the external pressure analysis.

Variable	Value	Unit	Description
P	15	*psi*	External pressure design
D_0	0.50	*in*	Shell outer diameter
L	10.00	*in*	Shell length
t	0.035	*in*	Shell thickness
L/D0	20.00		
D0/t	14.29		
A	0.005		Subpart 3, Section II, Part D, Figure G
B	12,000		Subpart 3, Section II, Part D, Figure HA-3
P_a	1,120	*psi*	Maximum external working pressure
t_{min}	0.0005	*in*	Minimum thickness for external pressure design

Table 9.1 - GAr line from detector to heat exchanger

The maximum allowable external working pressure is 1,120 psi, the requirement is therefore satisfied.

The GAr line from detector to heat exchanger includes a flexible hose, to allow flexibility, see Table 9.2.

9.1 Unlisted components

Table 9.2 shows the unlisted components installed in the GAr line from detector to heat exchanger of the SCENE piping system, in accordance with B31.3 Section 304.7.2.

Component	Manufacturer	Max Pressure	MAWP	Comment
Elbow	Swagelok, P/N: 6LV-8MW-9	3,700 psi	35 psid	304.7.2(a) Extensive service experience
Flex hose	Hose Master, Masterflex, P/N: AF5550 1/2”	1,186 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: 6LV-8-VCR-3S-8TB2	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-1	3,500 psi	35 psid	304.7.2(a) Extensive service experience
Fitting	Swagelok, P/N: SS-8-VCR-4	3,500 psi	35 psid	304.7.2(a) Extensive service experience

Table 9.2 - Unlisted components

10.0 Weld documentation

There are welds in the Argon supply system piping and they have been performed by Leonard Harbacek, from Fermilab, ASME Sect. IX qualified welder. Appendix E presents PQR, WPS and WPQ.

11.0 Pressure relief system - Updated January 31, 2018

The main venting scenario is the loss of insulating vacuum. It is assumed that air fills the vacuum region, because air has a higher thermal conductivity than Argon. There is one vacuum jacket around all the SCENE system. The detector is conservatively assumed full of liquid Argon. The same analysis has also been performed for Xenon.

The minimum required flow capacity for the primary Pressure Relieving Device (PRD) on insulated line for cryogenic fluids is given by 6.2.2 from CGA S-1.3-2008:

$$Q_a = \frac{(590 - T)}{4 \cdot (1660 - T)} \cdot F \cdot G_i \cdot U \cdot A$$

$$T = T_s$$

$$F = \sqrt{\frac{Z_i \cdot T_i}{Z \cdot T}} = \sqrt{\frac{P_i \cdot v_i}{P \cdot v}}$$

$$U = \frac{k_{Air}}{x_{MLI}}$$

$$G_i = \frac{73.4 \cdot (1660 - T)}{C \cdot L} \cdot \left(\frac{v_g - v_l}{v_g} \right) \cdot \sqrt{\frac{Z \cdot T}{M}}$$

$$A = \frac{A_{Ext,Inner} + A_{Int,Outer}}{2}$$

$$Z(T,P)$$

$$Z_i(T_i,P_i)$$

$$v(T,P)$$

$$v_i(T_i,P_i)$$

$$L(T,P)$$

$$P = 1.1 \cdot P_{Set} + 14.7$$

$$A = \frac{A_{Ext,Inner} + A_{Int,Outer}}{2}$$

$$T_i = 590 - \frac{590 - T_S}{e^{\left(\frac{0.55 \cdot D \cdot L_{pipe}}{W \cdot C_p}\right)}}$$

$$C_p(T_1,P)$$

$$T_1 = \frac{T_s + 1{,}660}{2}$$

$$P_i = P - 3.36 \cdot 10^{-6} \cdot \frac{f \cdot l \cdot W^2 \cdot v(P,T_f)}{d^5}$$

$$T_f = \frac{T + T_i}{2}$$

$$W = \frac{Q_{ae} \cdot C}{18.35} \cdot \sqrt{\frac{M}{Z \cdot T}}$$

Q_a is the minimum required flow capacity for the primary PRD in *SCFM* of free air.

Q_{ae} is the calculated flow capacity using formula 6.2.2 with F=1 in *SCFM* of free air.

W is the required mass flow rate of lading through the PRD in *lbm/hr* of the fluid being relieved. From 6.1.4 a).

P is the flow rating pressure in *psia*.

P_{set} is the PRD set pressure.

T is the saturation temperature at the flow rating pressure in *deg R*.

T_i is the temperature at the inlet of the PRD for operational emergency conditions without fire in *deg R*. From 6.1.4 b).

P_i is the pressure at the inlet of the PRD for operational emergency conditions without fire in *psia*. From 6.1.4 c).

U is the overall heat transfer coefficient of the insulating material of the container when saturated with air (greater than Argon and same as Nitrogen) in *Btu/(hr·ft²·F)*.

G_i is a factor from Note 1 to Table 1.

L is the latent heat of product at the flow rating pressure in *Btu/lb*.

C is the constant for gas related to the ratio of specific heat (k=Cp/Cv) at standard conditions.

Z is the compressibility factor.

v is the specific volume in *ft³/lbm*.

M is the molecular weight of the fluid.

A is the mean area between external inner tube and internal outer tube in *ft²*.

f is the friction factor, from Crane TP-410 1-21.
l is the equivalent length of pipe in *ft*, from Crane TP-410.
D is the outer diameter of the relieving pipe in *in*.
d is the inner diameter of the relieving pipe in *in*.
L_{pipe} is the length of the relieving pipe, from the tube to the PRD, in *ft*.

The required flow area of the relief device is given by 6.3.1:

$$A_{PRD} = \frac{4.6476 \cdot S \cdot A \cdot k^2 \cdot \sqrt{M}}{k_d \cdot C \cdot P} \geq 0.011\ in^2$$

$$k = \frac{C_p}{C_v}$$

S is the safeguarding factor, conservatively assumed as 1.
A is the outer surface area, in ft^2.
k is the ratio of specific heats at standard conditions (60F and 15 psia).
M is the molecular weight of the lading gas.
C is the constant for gas related to k at standard conditions.
k_d is the discharge coefficient of the relief valve, assumed as 0.975.

The detector requires a 0.026 square inch orifice and a 5 SCFM air pressure relief valve for Argon operations. Calculations in Appendix E.

The 6” detector requires a 0.026 square inch orifice and a 4 SCFM air pressure relief valve for Xenon operations. Calculations in Appendix E.

The condenser and the piping are much smaller than the detector, but conservatively assuming the same results, the total required area is 6 x 0.026 = 0.156 square inch with 6 x 5 (max between 4 and 5) = 30 SCFM of air flow capacity.

PSV-1 is the pressure relief valve for the detector, the condenser and the piping.

In Rev 5, we have selected a pressure relief valve set to 20 psig opening pressure, model type C776 from Cash (ASME Code VIII for Cryogenic Service), with a flow capacity of 92 SCFM and an orifice size of 0.169 square inch. The requirement is therefore satisfied for both Argon and Xenon operations and both 4” and 6” detectors.

DEPRECATED in Rev 4, but kept in case we ever go wish to use the old relief valve : (We have selected a pressure relief valve, model number 760NBDF-A015 from Rockwood Swendeman (UV Stamped) with an orifice size of 0.204 square inch and a flow capacity of 74 SCFM. The requirement is therefore satisfied for both Argon and Xenon operations, and both 4” and 6” detectors.) - END DEPRECATION

There is a parallel plate relief valve to protect the vacuum jacket. The set pressure is 1 psig. The flow rate is given by the maximum fluid mass flow converted to gas from liquid in the whole system:

$$W_{Ar} = 35\ {}^{lb}\!/_{hr}$$

$$W_{Xe} = 38\ {}^{lb}\!/_{hr}$$

The minimum required relieving area is defined by:

$$A = \frac{W \cdot \sqrt{T \cdot Z}}{C \cdot K \cdot P_1 \cdot K_b \cdot \sqrt{M}}$$

$T_{Ar} = 94K = 170R$ temperature of the fluid at the valve inlet

$T_{Xe} = 178K = 321R$ temperature of the fluid at the valve inlet

$Z = 1$ compressibility factor

$P_1 = P_{set} \cdot 1.10 + 14.7 = 15.8\,psia$ relieving pressure

$P_{set} = 1\,psig$ set pressure

$C_{Ar} = 377$ C-factor (from Figure 11-1, Section VIII, Appendix 11)

$C_{Xe} = 385$

$K = 0.975$ effective coefficient of discharge (conservatively taken as unit for gas or vapor)

$K_b = 1$ capacity correction factor due to back pressure (unit for atmospheric back pressure or back pressure above relieving pressure ratio above 0.55)

$M_{Ar} = 39.95$ molecular weight

$M_{Xe} = 131$

The minimum required relieving area is:

$$A_{Ar} = 0.013\ sq\ in$$
$$A_{Xe} = 0.010\ sq\ in$$

The device is connected to a 1.5” OD and 0.065” wall thickness nozzle. The relieving area available is therefore 1.479 square inch. We have selected a parallel plate relief valve connected to a 2.75” CF with 1.5” OD and 0.065” wall thickness. The requirement is therefore satisfied.

The maximum relieving capacity is given by:

$$W_{Max}(Ar) = \frac{A_{Select} \cdot P_1 \cdot C \cdot K \cdot K_b \cdot \sqrt{M}}{\sqrt{T \cdot Z}} = 2,815\ {}^{lb}/_{hr}$$
$$W_{Max}(Xe) = \frac{A_{Select} \cdot P_1 \cdot C \cdot K \cdot K_b \cdot \sqrt{M}}{\sqrt{T \cdot Z}} = 3,094\ {}^{lb}/_{hr}$$
$$A_{Select} = 1.479\ sq\ in$$

W_{Max} is the maximum relieving capacity based on the selected valve, whose area is A_{Select}, k the ratio of specific heats of the fluid.

Additional Burst Disc added to Relief System

With the burst disc installed between the pressure vessel and the existing relief valve, section UG-127 of ASME Boiler and Pressure Vessel Code was followed. This section of the code dictates the following requirements [1]:

1. The existing relief valve's marked capacity must be multiplied by a factor of 0.90 when installed with a rupture disc.
2. A pressure gage, try cock, free vent, or other indicator is necessary between the burst disc and relief valve.
3. The burst disc capacity must be equal to or greater than the capacity of the relief valve and when the burst disc is open, it must not interfere with the functions of the relief valve.
4. The area of the burst disc cannot be less than the area of the relief valve.

For the first requirement, the existing relief valve's capacity is 92 scfm. When multiplied by 0.90, the new capacity of the relief valve is 82.8 scfm. This is much larger than the required flow rates of 5 scfm for the argon case and 4 scfm for the xenon case. For the second requirement, a pressure gage will be installed between the burst disc and the relief valve. For the third requirement, the capacity of the burst disc was calculated to be 134.9 scfm for the xenon case. For the argon case, the capacity was found to equal 174.1 scfm. This is greater than the existing relief valve capacity. The burst disc will be installed such that there is room for the disc to open without interfering with the relief valve. For the fourth requirement, the minimum required area of the burst disc is 0.43in^2. This is larger than the 0.026in^2 area of the relief valve. The attached calculations show that the burst disc sized for the SCENE experiment meets the requirements (listed above) of the ASME Boiler and Pressure Vessel Code.

12.0 Pressure Test

The system has to be pressure tested in accordance with Section 5034 of the Fermilab ES&H Manual and 345.5 of the Code.

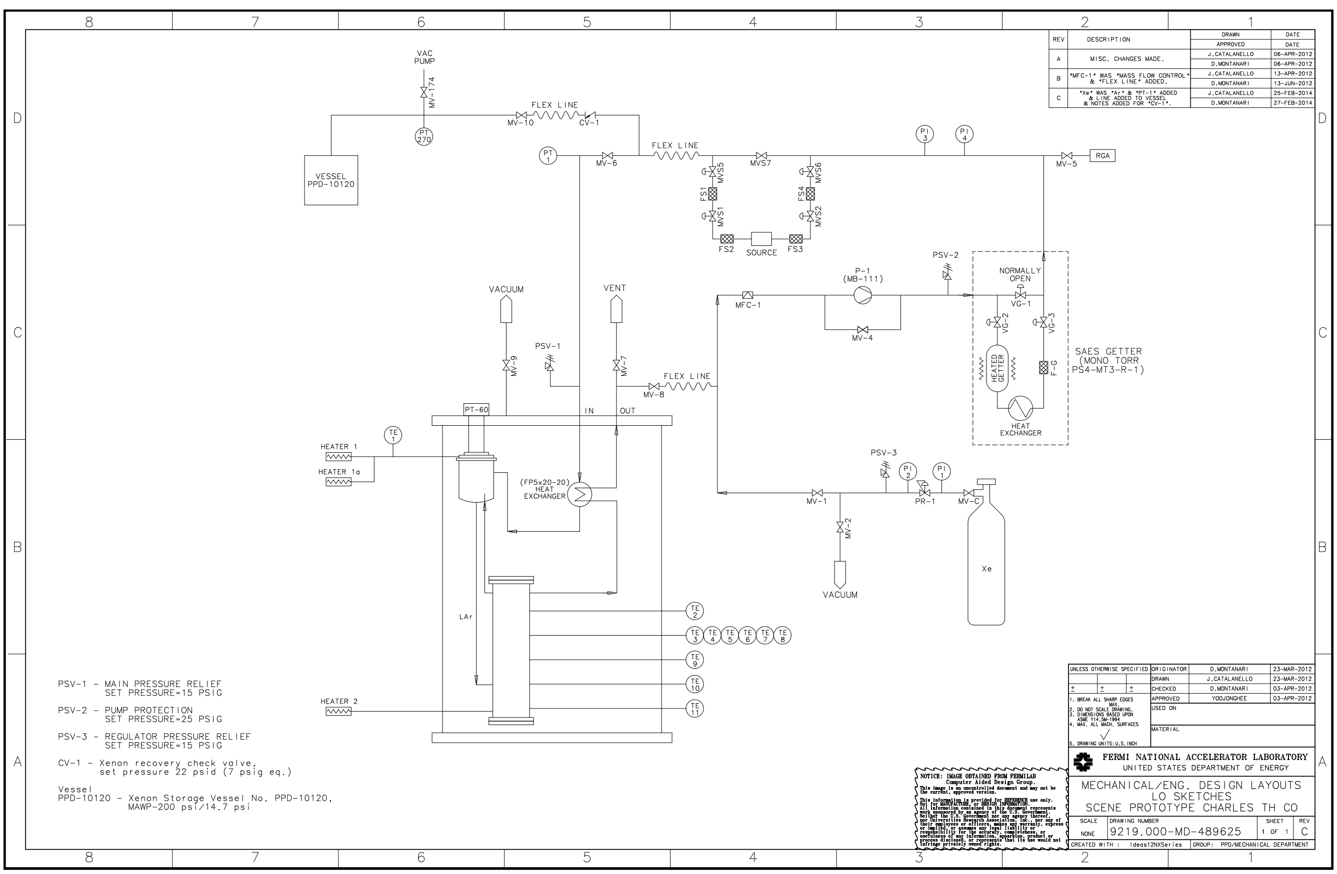
The test pressure was 28 psig, that is 1.4 times the Maximum Allowable Working Pressure of 20 psig.

The test medium was gaseous Argon. Results of the pressure tests in the Piping Engineering Notes. Results of the pressure tests in Appendix D.

13.0 Summary

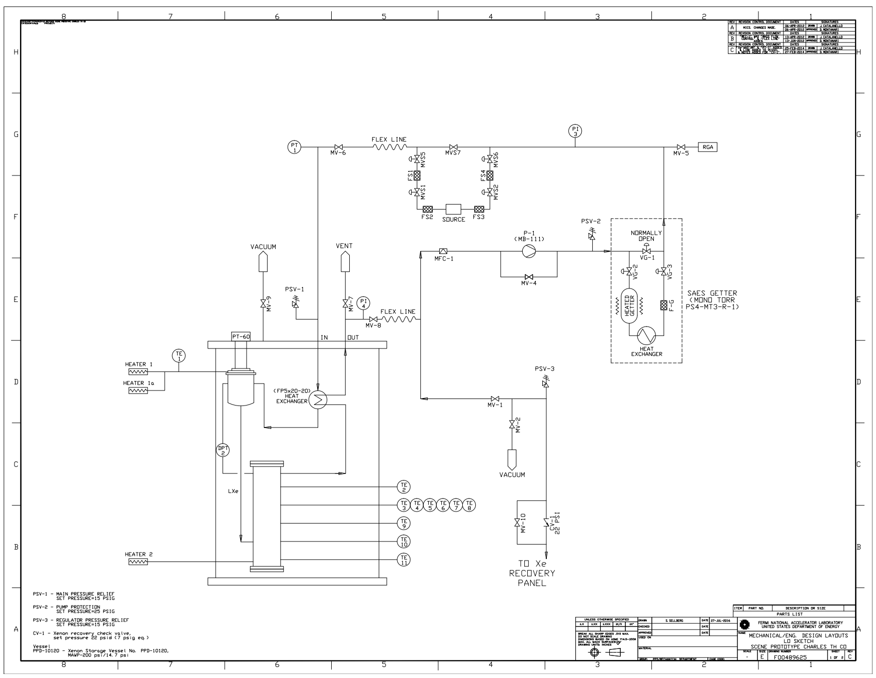
The SCENE piping system satisfies the requirements of the ASME Code and of Section 5031.1 of the Fermilab ES&H Manual. The piping system is adequate to ensure that its operation represents no hazard to personnel or to any of the external systems to which it will be connected. It had been shown that the design is satisfactory for the defined MAWP of 20 psig and MAEP of 15 psia.

APPENDIX A



SCENE P&ID

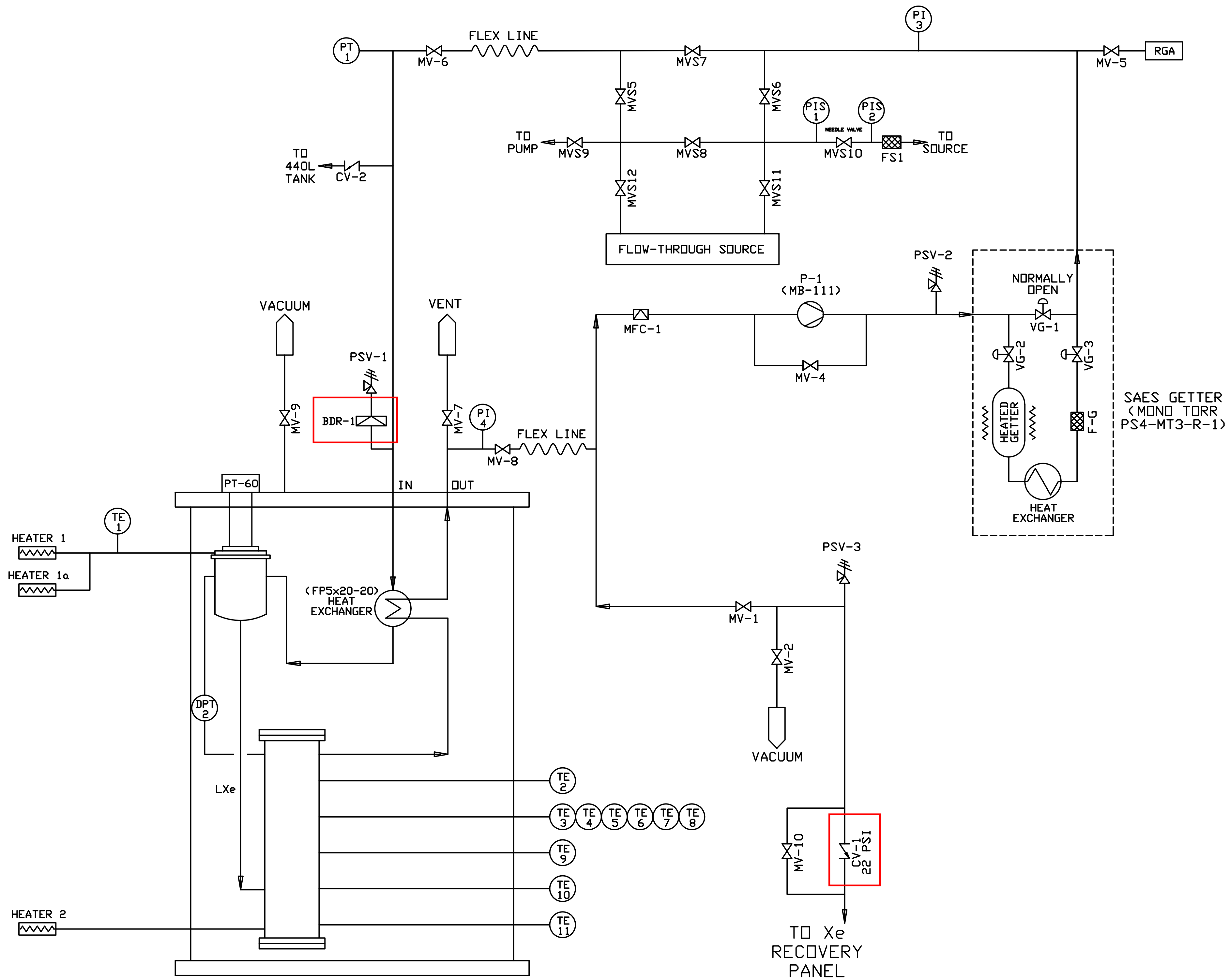
SCENE P&ID REV 4



FLEX LINE
PT 1
MV-6
MVS7
MVS5
MVS6
FS1
FS4
MVS1
MVS2
FS2
SOURCE
FS3
PI 3
MV-5
RGA
PSV-2
P-1 (MB-111)
MFC-1
MV-4
NORMALLY OPEN
VG-1
VG-2
VG-3
HEATED GETTER
F-G
HEAT EXCHANGER
SAES GETTER (MONO TORR PS4-MT3-R-1)
VACUUM
VENT
PSV-1
MV-9
MV-7
PI 4
MV-8
FLEX LINE
PT-60
IN
OUT
HEATER 1
HEATER 1a
TE 1
(FP5x20-20) HEAT EXCHANGER
DPT 2
LXe
TE 2
TE 3
TE 4
TE 5
TE 6
TE 7
TE 8
TE 9
TE 10
TE 11
HEATER 2
PSV-3
MV-1
MV-2
VACUUM
MV-10
CV-1 22 PSI
TO Xe RECOVERY PANEL
PSV-1 - MAIN PRESSURE RELIEF SET PRESSURE=15 PSIG
PSV-2 - PUMP PROTECTION SET PRESSURE=25 PSIG
PSV-3 - REGULATOR PRESSURE RELIEF SET PRESSURE=15 PSIG
CV-1 - Xenon recovery check valve, set pressure 22 psid (7 psig eq.)
Vessel
PPD-10120 - Xenon Storage Vessel No. PPD-10120, MAWP-200 psi/14.7 psi
PARTS LIST
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
MECHANICAL/ENG. DESIGN LAYOUTS
LD SKETCH
SCENE PROTOTYPE CHARLES TH CD
S. SELLBERG
27-JUL-2016
F00489625

REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES	
A	MICS. CHANGES MADE.	06-APR-2012	DRAWN	J. CATALANELLO
		06-APR-2012	APPROVED	D. MONTANARI
B	'MFC-1' WAS 'MASS FLOW CONTROL' & 'FLEX LINE' ADDED.	13-APR-2012	DRAWN	J. CATALANELLO
		13-JUN-2012	APPROVED	D. MONTANARI
C	'Xe' WAS 'AR' & 'PT-1' ADDED. & LINE ADDED TO VESSEL & NOTES ADDED FOR 'CV-1'.	25-FEB-2014	DRAWN	J. CATALANELLO
		27-FEB-2014	APPROVED	D. MONTANARI

Updated 1/24/18



PSV-1 - MAIN PRESSURE RELIEF
SET PRESSURE=15 PSIG

PSV-2 - PUMP PROTECTION
SET PRESSURE=25 PSIG

PSV-3 - REGULATOR PRESSURE RELIEF
SET PRESSURE=15 PSIG

CV-1 - Xenon recovery check valve,
set pressure 22 psid (7 psig eq.)

CV-2 - Xenon recovery check valve,
set pressure 30 psid

XXX-1 - Burst disk to primary relief,
set pressure 20 psig

Vessel
PPD-10120 - Xenon Storage Vessel No. PPD-10120,
MAWP-200 psi/14.7 psi

ITEM	PART NO.	DESCRIPTION OR SIZE	

PARTS LIST

UNLESS OTHERWISE SPECIFIED

±.X	±.XX	±.XXX	±X/X	±X°

BREAK ALL SHARP EDGES .015 MAX.
DO NOT SCALE DRAWING
DIMENSIONS BASED ON ASME Y14.5-2009
MAX. ALL MACH SURFACES 125
DRAWING UNITS: INCHES

DRAWN	S. SELLBERG	DATE	27-JUL-2016
CHECKED		DATE	
APPROVED		DATE	

USED ON

MATERIAL

GROUP: PPD/MECHANICAL DEPARTMENT
CAGE CODE:

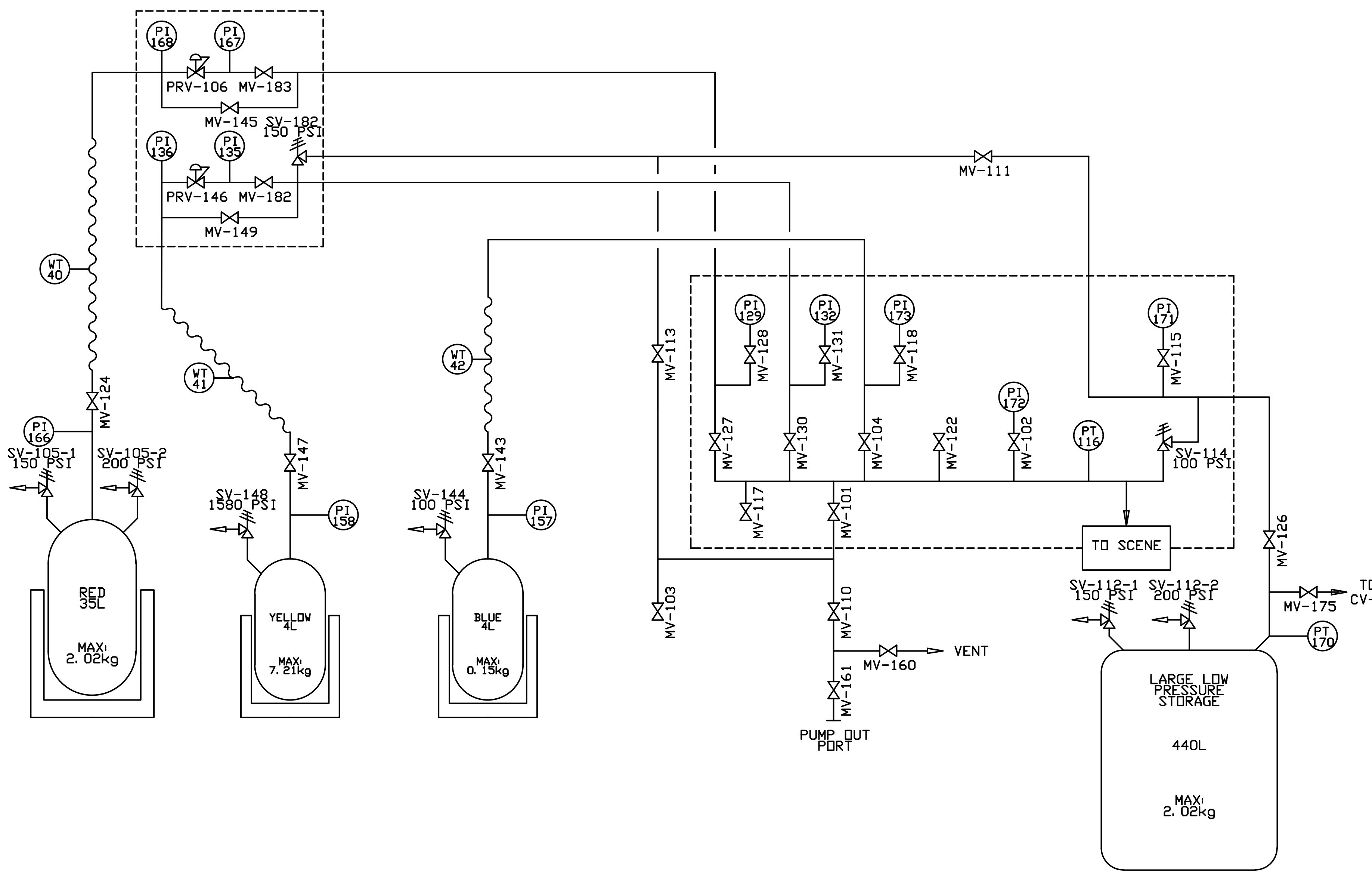
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

NAME
MECHANICAL/ENG. DESIGN LAYOUTS
LD SKETCH
SCENE PROTOTYPE CHARLES TH CO

SCALE	SIZE	DRAWING NUMBER	SHEET	REV
-	E	F00489625	1 OF 2	C

REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES	
A	MICS. CHANGES MADE.	06-APR-2012	DRAWN	J. CATALANELLO
		06-APR-2012	APPROVED	D. MONTANARI
B	"MFC-1" WAS "MASS FLOW CONTROL" & "FLEX LINE" ADDED.	13-APR-2012	DRAWN	J. CATALANELLO
		13-JUN-2012	APPROVED	D. MONTANARI
C	"Xe" WAS "AR" & "PT-1" ADDED. & LINE ADDED TO VESSEL & NOTES ADDED FOR "CV-1".	25-FEB-2014	DRAWN	J. CATALANELLO
		27-FEB-2014	APPROVED	D. MONTANARI

Updated 1/24/18



ITEM	PART NO.	DESCRIPTION OR SIZE

PARTS LIST

UNLESS OTHERWISE SPECIFIED

±.X	±.XX	±.XXX	±X/X	±X°

BREAK ALL SHARP EDGES .015 MAX.
DO NOT SCALE DRAWING
DIMENSIONS BASED ON ASME Y14.5–2009
MAX. ALL MACH SURFACES 125
DRAWING UNITS: INCHES

DRAWN	S. SELLBERG	DATE	27-JUL-2016
CHECKED		DATE	
APPROVED		DATE	

USED ON

MATERIAL

GROUP: PPD/MECHANICAL DEPARTMENT CAGE CODE:

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

NAME: MECHANICAL/ENG. DESIGN LAYOUTS
LD SKETCH
SCENE PROTOTYPE CHARLES TH CO

SCALE	SIZE	DRAWING NUMBER	SHEET	REV
-	E	F00489625	2 OF 2	C

Appendix B

COPY

FERMILAB

Welder Qualification Test Record

Welder's Name Leonard Harbacek Ident No. 122261 Date 03/19/99

Welding Process GTAW Type Manual

Test in Accordance With WPS # ES-155003 Root Open

Material Specification SA 53-B To Material Specification SA 53-B

P-No 1 To P-No 1 Thickness .280" Diam 6"

Filler Metal Specification SFA A5.18 Classification ER-70S-2 F-No 6

Thickness Deposited .280

Backing Argon Gas Shielding Argon

Position 6-G Progression Upward

Electrical Characteristics: Current DC Polarity Straight

Thickness Qualified .560" Max Diameter Qualified 2-7/8" O.D. and over

GUIDED BEND TEST RESULTS

Specimen No	Type	Figure	Results
1	Face	QW-462.3a	Acceptable
2	Face	QW-462.3a	Acceptable
3	Root	QW-462.3a	Acceptable
4	Root	QW-462.3a	Acceptable

Test Conducted By IFR Engineering Test No. 008-09-01 Date 3/19/99

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

By: [illegible]

Date: 4/20/99

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Welder I

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Revision:

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APPENDIX C

PRV SIZING according to CGA S-1.3-2008

Date: Aug 7, 2017
Description: SCENE PIPING
Gas: Argon

	Variable	Value	US	Value	SI	Source	Notes
2)	P_set	20.00	psig			DS-50	
	P	38.17	psia				
3)	T_s	170	R	94	K	REFPROP	
	P_Crit	859	psia			Air Liquide Encyclopedia	
	P/P_Crit	4.44%					
4)	P < P_Crit --> OK						
	F_Guess	1					
9)	U	0.447	Btu/(hr*ft^2*F)	2.54	W/m^2*K		
10)	A	13.11	ft^2			Mean area	
14)	G_i	9.626				CGA (Notes Table 1)	Gas Factor
15)	Q_ae	3.97	SCFM Air			CGA 6.2.2	Calculated Flow capacity of free air
16)	W	**37**	**Lbm/hr**	4.64E-03	kg/s	CGA 6.1.4 a)	Required Mass Flow Rate of lading through PRD of the fluid being relieved
21)	T_i	**268**	**R**	149	K	CGA 6.1.4 b)	Temperature at the INLET of the PRD
32)	P_i	**38.01**	**psia**			CGA 6.1.4 c)	
35)	F_Real	1.284					
36)	Q_a	**5**	**SCFM Air**	143	l/m	Air Equivalent	
37)	Q_Cond	2,461	Btu/hr	721	W		Cooling Power to condense
39)	Q_DT	474	Btu/hr	139	W		Cooling Power to cool down (C_p @ T_f)
40)	Q_Tot			**860**	**W**		Total Cooling Power

GAS RELIEVED DATA

	Variable	Value	SI	Source	Notes
	P	38.17	psia	Main Table	
	T = T_s (P)	170	R	Main Table	
1)	M	131		Xenon	
11)	v (T,P)	1.4396	ft^3/lbm	REFPROP	Specific volume
	R	0.082	ft^3*psi/(lbm*R)		
12)	C	385		CGA Table 4 (page 30)	
13)	L (T,P)	66.786	Btu/lbm	REFPROP	Latent Heat
	Z (T,P)	3.947			Compressibility
17)	T_1	380	R	CGA 6.1.4 b)	
18)	C_p (T_1)	0.126	Btu/lbm*R	REFPROP	
22)	T_f	219	R	CGA 6.1.4 c)	
23)	v (T_f)	1.918	ft^3/lbm	REFPROP	Specific volume
24)	μ (T_f)	6.79E-06	lbm/ft*s	REFPROP	Viscosity
38)	C_p (T_f)	0.131	Btu/lbm*R	REFPROP	
34)	v_i (T_i, P_i)	2.382	ft^3/lbm	REFPROP	Specific volume
	Z_i (T_i,P_i)	4.121			Compressibility
41)	k (STP)	1.74		CGA Table 4 (page 30)	

LEGEND

	Input Data
	Input Data from REFPROP
	To be Checked

PIPING DATA

	Variable	Value	SI	Value	US	Notes
5)	k_Air	0.0254	W/mK			Air thermal conductivity
7)	x_MLI	10	mm			MLI thickness
7)	k_?	0.0001	W/mK			? Thermal Conductivity
7)	x_?	0.00001	mm			? Thickness
6)	ID VJ	346.05	mm	13.624		ID Vacuum Jacket (14" OD)
6)	OD Pipe	152.40	mm	6		OD Inner pipe
6)	L	762	mm	30		Pipe Length
6)	L	1,829	mm	72		Length Vacuum Jacket
8)	A1	0.38	m^2	4.07	ft^2	External Area Inner Pipe
8)	A2	2.06	m^2	22.15	ft^2	Internal Area VJ

RELIEVING PIPE DATA

	Variable	Value	SI	Value	US	Source	Notes
19)	D	0.5	in				OD
19)	t	0.035	in				Thickness
19)	d	0.43	in	10.92	mm		ID
20)	Length	4.5	ft				Length of piping to PRD
25)	ε			0.0015	mm	SF PRESSURE DROP	Discharge pipe roughness
	ε/d			1.37E-04			Relative Roughness
26)	Re	53,566					
	A	7.16625147162178					
	B	6.85678167934682					
	C	6.8912318337777					
27)	f	0.0194350868617103				Crane TP-410 1-21	Friction Factor Turbulent
28)	f_T	1.27E-02				Crane TP-410 A-25/A-27	FF in zone of complete Turbulence
29)	n. Elbows	9				P&ID	
29)	n. Tee	1				P&ID	
30)	K	7.29955263486085				Crane TP-410	K-Factor
31)	l	13	ft				Equivalent length
33)	D_P	**0.16**	**psia**				
42)	k_D	0.975					Coefficient of discharge
43)	A_PRD	**0.026**	**in^2**	**0.170**	cm^2	CGA 6.3.1	Calculation of required Area of PRD
44)	A_PRD	= 43)	**in^2**			CGA 6.3.1	Minimum required Area of PRD

Detector - PRV sizing calculations (Argon case)

APPENDIX D

Fermilab

EXHIBIT B
Pressure Testing Perm

Date: 5.31.12

Type of Test: [ ]Hydrostatic [X] Pneumatic

Test Pressure 28 psig **Maximum Allowable Working Pressure** ~~X~~ 15 psig EJN

Items to be Tested
SCENE prototype detector assembly, LAr condensing system and gas purification system

Location of Test PAB **Date and Time** 6-7-12 7:00 Am

Hazards Involved (use Hazard Analysis form FESHM 2060 if more space is required)
Leak of compressed gas, componet failure.

Safety Precautions Taken
Area will be roped off. Pressure test will take place remotely (20ft). Eye protection will be worn.

Special Conditions or Requirements
None. Test is low low pressure and componet failure is unlikely

Qualified Person and Test Coordinator William Miner and Cary Kendziora
Dept/Date William Miner

Division/Section Safety Officer Eric McHugh 15747N
Dept/Date PD/ES&H 6.7.12

Results
Found no Leaks

Witness (Safety Officer or Designee) **Dept/Date** 6/7/12

* Must be signed by division/section safety officer prior to conducting test. It is the responsibility of the test coordinator to obtain signatures.

Fermilab ES&H Manual 5034TA - 5
Rev. 03/2009

WARNING: This paper copy may be obsolete soon after it is printed. The current version of this FESHM Chapter is found at http://www-esh.fnal.gov/pls/default/esh_manuals.html.

Pressure Test

APPENDIX E

PRV SIZING according to CGA S-1.3-2008

Date: Aug 7, 2017
Description: SCENE PIPING
Gas: Xenon

	Variable	Value	US	Value	SI	Source	Notes
2)	P_set	20.00	psig			DS-50	
	P	38.17	psia				
3)	T_s	321	R	178	K	REFPROP	
	P_Crit	859	psia			Air Liquide Encyclopedia	
	P/P_Crit	4.44%					
4)	P < P_Crit --> OK						
	F_Guess	1					
9)	U	0.447	Btu/(hr*ft^2*F)	2.54	W/m^2*K		
10)	A	13.11	ft^2			Mean area	
14)	G_i	10.868				CGA (Notes Table 1)	Gas Factor
15)	Q_ae	3.20	SCFM Air			CGA 6.2.2	Calculated Flow capacity of free air
16)	W	**40**	**Lbm/hr**	5.00E-03	kg/s	CGA 6.1.4 a)	Required Mass Flow Rate of lading through PRD of the fluid being relieved
21)	T_i	**469**	**R**	261	K	CGA 6.1.4 b)	Temperature at the INLET of the PRD
32)	P_i	**38.07**	**psia**			CGA 6.1.4 c)	
35)	F_Real	1.250					
36)	Q_a	**4**	**SCFM Air**	112	l/m	Air Equivalent	
37)	Q_Cond	1,576	Btu/hr	462	W		Cooling Power to condense
39)	Q_DT	241	Btu/hr	71	W		Cooling Power to cool down (C_p @ T_f)
40)	Q_Tot			**532**	**W**		Total Cooling Power

GAS RELIEVED DATA

	Variable	Value	SI	Source	Notes
	P	38.17	psia	Main Table	
	T = T_s (P)	321	R	Main Table	
1)	M	131		Xenon	
11)	v (T,P)	0.8037	ft^3/lbm	REFPROP	Specific volume
	R	0.082	ft^3*psi/(lbm*R)		
12)	C	385		CGA Table 4 (page 30)	
13)	L (T,P)	39.72	Btu/lbm	REFPROP	Latent Heat
	Z (T,P)	1.167			Compressibility
17)	T_1	455.5	R	CGA 6.1.4 b)	
18)	C_p (T_1)	0.039	Btu/lbm*R	REFPROP	
22)	T_f	395	R	CGA 6.1.4 c)	
23)	v (T_f)	1.062	ft^3/lbm	REFPROP	Specific volume
24)	μ (T_f)	1.1898E-05	lbm/ft*s	REFPROP	Viscosity
38)	C_p (T_f)	0.041	Btu/lbm*R	REFPROP	
34)	v_i (T_i, P_i)	1.26	ft^3/lbm	REFPROP	Specific volume
	Z_i (T_i,P_i)	1.248			Compressibility
41)	k (STP)	1.74		CGA Table 4 (page 30)	

LEGEND

	Input Data
	Input Data from REFPROP
	To be Checked

PIPING DATA

	Variable	Value	SI	Value	US	Notes
5)	k_Air	0.0254	W/mK			Air thermal conductivity
7)	x_MLI	10	mm			MLI thickness
7)	k_?	0.0001	W/mK			? Thermal Conductivity
7)	x_?	0.00001	mm			? Thickness
6)	ID VJ	346.05	mm		13.624	ID Vacuum Jacket (14" OD)
6)	OD Pipe	152.40	mm		6	OD Inner pipe
6)	L	762	mm		30	Pipe Length
6)	L	1,829	mm		72	Length Vacuum Jacket
8)	A1	0.38	m^2	4.07	ft^2	External Area Inner Pipe
8)	A2	2.06	m^2	22.15	ft^2	Internal Area VJ

RELIEVING PIPE DATA

	Variable	Value	SI	Value	US	Source	Notes
19)	D	0.5	in				OD
19)	t	0.035	in				Thickness
19)	d	0.43	in	10.92	mm		ID
20)	Length	4.5	ft				Length of piping to PRD
25)	ε			0.0015	mm	SF PRESSURE DROP	Discharge pipe roughness
	ε/d			1.37E-04			Relative Roughness
26)	Re	32,920					
	A	6.79233922090554					
	B	6.51141879553188					
	C	6.54560366355919					
27)	f	0.0216372014696781				Crane TP-410 1-21	Friction Factor Turbulent
28)	f_T	1.27E-02				Crane TP-410 A-25/A-27	FF in zone of complete Turbulence
29)	n. Elbows	9				P&ID	
29)	n. Tee	1				P&ID	
30)	K	7.57609726004751				Crane TP-410	K-Factor
31)	l	13	ft				Equivalent length
33)	D_P	**0.10**	**psia**				
42)	k_D	0.975					Coefficient of discharge
43)	A_PRD	**0.026**	**in^2**	**0.170**	cm^2	CGA 6.3.1	Calculation of required Area of PRD
44)	A_PRD	= 43)	**in^2**			CGA 6.3.1	Minimum required Area of PRD

Detector - PRV sizing calculations (Xenon case)

Appendix F

Burst Disk Sizing for SCENE Experiment
K. Cipriano
1/30/18

Area of Burst Disk Orifice Outlet (in^2)

$Area := 0.43$

Determination of Pressure Values from API 520 Section 5.4.3.3.2, Table 5

MAWP of system (psig)

$MAWP := 20$

Max accumulated Pressure (psig)

$Max_{accumulated} := MAWP \cdot 1.21 = 24.2$

Relief device set pressure (psig)

$P_{set} := MAWP \cdot 1.05 = 21$

Allowable overpressure (psi)

$P_{over} := 4$

Atmospheric pressure (psia)

$P_{atm} := 14.7$

Relieving pressure (psia)

$P_{relieving} := P_{set} + P_{over} + P_{atm} = 39.7$

Coefficient of discharge (0.975 when a PRV is installed with a rupture disk in combination)

$K_D := 0.975$

Combination correction factor

$K_c := 0.9$

Capacity correction factor

$K_b := 1$

Comparison of relief valve orifice area to burst disc orifice area:

$A_{burst\_disc} := 0.43 in^2$ $\quad A_{psv1} := 0.026 in^2$

$A_{burst\_disc} = 2.774 cm^2$ $\quad A_{psv1} = 0.168 cm^2$

The orifice area of the burst disc is greater than the orifice area of the relief valve. Thus, a combination factor of 0.9 is valid.

Xenon Case
API 520 Section 5.6.3.1.1 Sizing for Critical Flow, Equation (3)

Molecular weight of xenon

$M_{xenon} := 131.29$

Compressibililty factor for xenon

$Z_{xenon} := 1.167$

Absolute temperature of xenon at inlet (Rankine)

$T_{xenon} := 469$

Constant based on specific heats (Cp/Cv = 1.7)

$C_{xenon} := 382$

Rated Flow Capacity (SCFM) from API 520

$$V_{xenon} := \frac{\left(Area \cdot 6.32 \cdot K_D \cdot C_{xenon} \cdot P_{relieving} \cdot K_b \cdot K_c\right)}{\sqrt{T_{xenon} \cdot Z_{xenon} M_{xenon}}}$$

$V_{xenon} = 134.911$ scfm

Rated Flow Capacity (SCFM) using orifice area of PSV1 (primary relief valve)

$A_{psv} := 0.026 \quad in^2$

$$V_{xenon2} := \frac{\left(A_{psv} \cdot 6.32 \cdot K_D \cdot C_{xenon} \cdot P_{relieving} \cdot K_b \cdot K_c\right)}{\sqrt{T_{xenon} \cdot Z_{xenon} M_{xenon}}}$$

$V_{xenon2} = 8.157$ scfm

Argon Case
API 520 Section 5.6.3.1.1 Sizing for Critical Flow, Equation (3)

Molecular weight of argon

$M_{argon} := 39.948$

Absolute temperature of argon at inlet (Rankine)

$T_{argon} := 268$

Compressibililty factor for argon

$Z_{argon} := 3.947$

Constant based on specific heats (Cp/Cv = 1.67)

$C_{argon} := 378$

Rated Flow Capacity (SCFM) from API 520

$$V_{argon} := \frac{\left(Area \cdot 6.32 \cdot K_D \cdot C_{argon} \cdot P_{relieving} \cdot K_b \cdot K_c\right)}{\sqrt{T_{argon} \cdot Z_{argon} \cdot M_{argon}}}$$

$V_{argon} = 174.087$ scfm

Rated Flow Capacity (SCFM) using orifice area of PSV1 (primary relief valve)

$$V_{argon2} := \frac{\left(A_{psv} \cdot 6.32 \cdot K_D \cdot C_{argon} \cdot P_{relieving} \cdot K_b \cdot K_c\right)}{\sqrt{T_{argon} \cdot Z_{argon} \cdot M_{argon}}}$$

$V_{argon2} = 10.526$ scfm

Capacity of Primary Relief Valve (scfm)

$V_{valve} := 92$

New rated capacity of relief valve in combination with burst disk (scfm)

$v_{valve\_new} := 0.9 \cdot 92 = 82.8$

With the newly rated capacity of the primary relief valve, the relief valve capacity (82.8 scfm) still exceeds the requirement of 4 scfm for the xenon case and 5 scfm for the argon case.

Allied Valve Inc.™

Quotation

Allied Valve Riverdale
4419 State St.
Riverdale IA 52722
563-359-8100
www.alliedvalveinc.com

Quote Date	Quote #
8/25/2017	71751

Bill To	Ship To
Fermilab Pine Street Batavia IL 60510 United States	Fermilab Pine Street Batavia IL 60510 United States

Contact Name	Memo/Details	Terms
NORTHWESTERN UNIVERSITY - EVANSTON : Dan Baxter	1182461	Net 30

Prepared By	Expires	FOB	Please Note:
Wright, Krista L	9/24/2017	SP	Please reference quote number upon ordering - All material quoted from stock subject to prior sale

Line	Qty	Size	Mfr	Description	Set	Tag	Delivery	Price	Amount
1	1	3/4”	CDC	Special 3/4” (20mm) G-C-SRA-C (FS) Continental Rupture Disc in 1000 PSIG Max. Tite-Seal Holder Per CD1#TBA 316 SS 3/4 MPT Outlet PTFE Outlet Gasket Aluminum Outlet Ring Fluoropolymer Outlet Coating Aluminum Disc Fluoropolymer Inlet Coating Black Buna-N Inlet O-Ring 316 SS 3/4 MPT Inlet RATED: 20 psig @ 72 Deg F -5 PSIG MFG. RNG.: 15 To 20 psig @ 72 Deg F ***BEST EFFORT BASIS***	20 PSIG		45 Working Days ARO	2,951.83	2,951.83

Allied Valve Inc.™

Allied Valve Riverdale
4419 State St.
Riverdale IA 52722
563-359-8100
www.alliedvalveinc.com

Quotation

Quote Date	Quote #
8/25/2017	71751

Line	Qty	Size	Mfr	Description	Set	Tag	Delivery	Price	Amount
				Leak rate not to exceed 1 x 10 E-8 atm cc/sec of helium Special Material Comply with ASME Section VIII Division 1 Krgl value: 3.59 NB Cert: 75282 Minimum Net Flow Area: 0.43 in2 Perform Liquid Relief Test per MP-7003 Tag: Gas/Vapor/Liquid Maximum Recommended Operating Pressure: 11.7 psig @ 72 Deg F The above pricing does not include Shipping costs. Any incurred freight will be additional.					

It is understood that the goods covered by this Estimate/Invoice are intended for U.S. domestic use. If you intend to export any part of these items, it is your obligation to comply with all applicable U.S. and/or local country export regulations.

Subtotal	2,951.83
Shipping Cost (BESTWAY)	0.00
Total	$2,951.83

Appendix G

SCENE Prototype Parts list Rev. 4 (Jan 24, 2018):

	P. & I.D. designation	Manufacturer	Part Number	Description	Range / Set Point	Comments
1	CV-1	Swagelok	SS-4CA-VCR-3	Check Valve	22 psi set	
2	CV-2	Swagelok	SS-8CPA2-3	Check Valve	30 psi set	
3	MV-1	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
4	MV-2	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
5	MV-4	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
6	MV-5	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
7	MV-6	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
8	MV-7	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
9	MV-8	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
10	MV-9	Nor-Cal Products	ESB1502NWB	Manual Valve	Vacuum range 1x10E-9 Torr	
11	MV-10	Swagelok	SS-4BG-V51	Manual Valve	max 1000 psi	
12	MVS5	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
13	MVS6	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
14	MVS7	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
15	MVS8	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
16	MVS9	Swagelok	6LVV-DPFR4-P	Manual Valve	Max. Pressure = 250 psig	
17	MVS10	Swagelok	SS-3NBVCR4	Needle Valve	Max. Pressure = 6000 psig	
18	MVS11	Swagelok	6LVV-DPFR4-P-RD	Manual Valve	Max. Pressure = 250 psig	
19	MVS12	Swagelok	6LVV-DPFR4-P-RD	Manual Valve	Max. Pressure = 250 psig	
20	FS1	SAES	MC1-902F	In-Line Gas Filter		
21	PSV-1	Cash Valve	C776	Pressure Safety Valve	20 psig	McMaster #8089K14
22	PSV-2	Swagelok	SS-RL3M4-F4	Pressure Safety Valve	15 psig	
23	PSV-3	Swagelok	SS-RL3M4-F4	Pressure Safety Valve	15 psig	
24	BDR-1	Continental	G-C-SRA-C (special)	Burst Disk	20 psig	not a stock part
25	MFC-1	Sierra Instruments	C100L-DD-8-OV1-SV1-PV2-V1-S1-C10	Mass Flow Controller	Max. Pressure = 500 psig	
26	P-1	Metal Bellows	MB-111	Vacuum Pump	Max. Discharge Pressure = 23 psig	
27	SAES GETTER MONO TORR	SAES	PS4-MT3-R-1	Purifier Getter w/ bypass	Maximum Inlet Pressure = 150 psig	
28	PT1	Pfeiffer	HPT 100	Ion Gauge	1e-9 - 1000 mbar	Mod No: PT R34 330
29	DPT2	MKS	Baratron 226A	Differential Sensor	500 Torr bidirectional	
30	PI3	WIKA	50328808	Pressure Gauge	Range -30 inHg / 160 psi	
31	PI4	MKS	750B23TGA4GL	Pressure Transmitter	Range 0-2000 torr	
32	PIS1	Matheson	63-2233-V	Pressure Indicator	3000 psi	
33	PIS2	Swagelok	PGU-50-PC300-C-4FSF	Pressure Indicator	300 Psi	
34	FP5x20-20 Heat Exchanger	GEA	FP5x20-20	Heat Exchanger	Max. Pressure = 450 psig	
35	Heater 1	TECO Rene Koch	custom	OFHC Cu heater block for PT60 cold head	25 ohms (2x 50 ohms wired in parallel)	
36	Heater 2	Watlow	C2A4-L36T	Firerod cartridge heater	120V, 2x 50W	
37	TE1	LakeShore	DT-670B-CU-HT	Silicon Diode	Max. Temperature = 500K, +/- 0.5K absolute accuracy	
38	TE2	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
39	TE3	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
40	TE4	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
41	TE5	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
42	TE6	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
43	TE7	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
44	TE8	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
45	TE9	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
46	TE10	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	
47	TE11	IST	P1K0-520-6W-Y-010	PT1000 Temperature Sensor	Range -200°C to +600°C	