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Mu2e
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This calculation determines the required relief valves for the helium phase separators located in the feedboxes.

▸ REFPROP2Mathcad script

▸ Formulas

▸ Material properties

▾ Calculations

Sizing of helium relief valves for the feedbox phase separators.

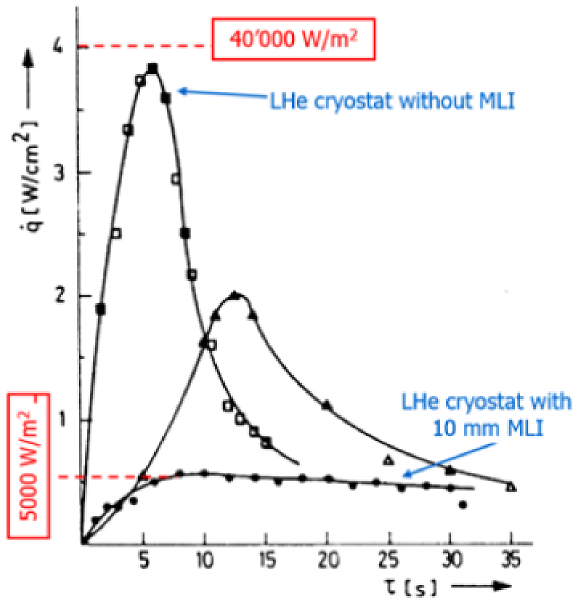
$$q_{He.quench} := 4\cdot\frac{W}{cm^2} = 40000\cdot\frac{W}{m^2}$$

Sources:

1. A. Dalesandro, et. al. "Experiment for transient effects of sudden catastrophic loss of vacuum on a scaled superconducting radio frrequency cryomodule", FERMILAB-CONF-11-262-AD
2. Harrison, S. M., “Loss of Vacuum Experiments on a Superfluid Helium Vessel,” in IEEE Transactions on Applied Superconductivity, Vol. 12, No.1, edited by J. Schwartz, 2002, pp. 1343- 1346
3. Lehmann, W., and Zahn, G., “Safety Aspects for LHe Cryostats and LHe Transport Containers,” Proceedings of International Cryogenic Engineering Conference 7, IPC Science and Technology Press, London, 1978, pp. 569-579
4. Wiseman, M. et al, “Loss of Cavity Vacuum Experiment at CEBAF,” in Advances in Cryogenic Engineering 39, edited by P. Kittel, Plenum Press, New York, 1994, pp. 997-1003
5. GM2-doc-1981-v5: G Minus 2 E989 note 21: g-2 mandrel LHe piping enginneering note, E. Voirin, Appendix A

$$q_{He.quench} := 6000\cdot\frac{W}{m^2} = 0.6\cdot\frac{W}{cm^2}$$

Redifined based on Reference 3 and 5 data, shown above and below. FOS applied.



W. Lehmann & G. Zahn, *Safety aspects for LHe cryostats*, Proc. ICEC7, IPC Science & Technology (1978) 569-579

$\text{Height} := 53 \cdot \text{in} = 4.417 \cdot \text{ft}$ Source: F10038110 from 02/05/2016

$\text{OD} := 16.000 \cdot \text{in}$ Source: F10038110 from 02/05/2016

$\text{ID} := 15.500 \cdot \text{in}$ Source: F10038110 from 02/05/2016

$\text{Surf}_{\text{Area}} := \text{Height} \cdot \pi \cdot \text{OD} + 2\,\text{Area}(\text{OD}) = 3066.194 \cdot \text{in}^2$

$\text{Vol} := \text{Height} \cdot \text{Area}(\text{ID}) = 43.293 \cdot \text{gal}$

$\text{Vol} = 163.882\,\text{L}$

$Q := q_{\text{He.quench}} \cdot \text{Surf}_{\text{Area}} = 11.869 \cdot \text{kW}$

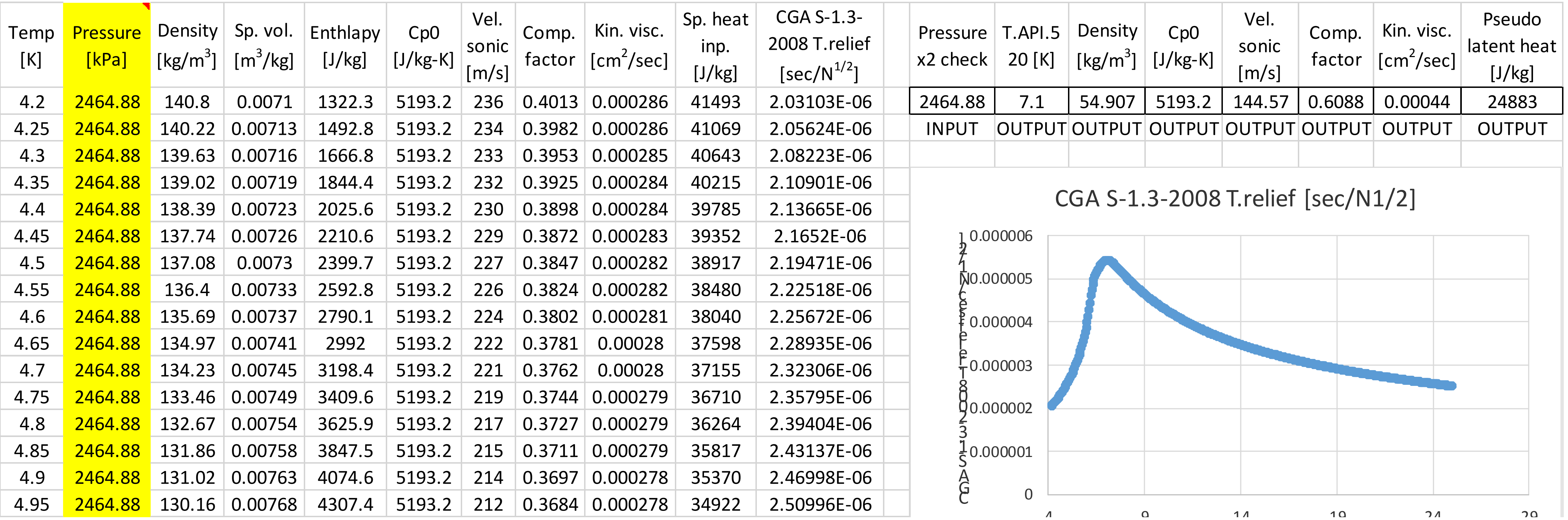
$p_{\text{set.pressure.He.valves}} := 325 \cdot \text{psi}$ Set these relief valves @ 65 psig as seen in valve SV-366 of drawing 3973.720-ME-484925 (Muon campus Mu2e refrigerator P&ID), *but calculate area required at 325 psig*

$$P_{1.\text{API}.520} := \frac{\left(\max\left(\frac{p_{\text{set.pressure.He.valves}}}{\text{psi}} + 3 \cdot \frac{\text{psi}}{\text{psi}}, \frac{p_{\text{set.pressure.He.valves}}}{\text{psi}} \cdot 1.10\right) + 14.7\right) \cdot \text{psi}}{\text{kPa}} = 2.566 \times 10^3$$

Upstream relieving gauge pressure subject to 10% overpressure per ASME BPVC VIII UG-125 (c)

$$P_{1.\text{API}.520.\text{absolute.kPa}} := \frac{P_{1.\text{API}.520} \cdot \text{kPa} - 14.7 \cdot \text{psi}}{\text{kPa}} = 2464.876$$

$$\begin{pmatrix} T_{API.520} \\ \rho_{He.unitless} \\ C_{p.0.unitless} \\ Vel_{sonic.unitless} \\ Z_{API.520} \\ \nu_{He.unitless} \\ \Delta h_{pseudo.He.unitless} \end{pmatrix} :=$$



Temp [K]	Pressure [kPa]	Density [kg/m^3]	Sp. vol. [m^3/kg]	Enthlapy [J/kg]	Cp0 [J/kg-K]	Vel. sonic [m/s]	Comp. factor	Kin. visc. [cm^2/sec]	Sp. heat inp. [J/kg]	CGA S-1.3-2008 T.relief [sec/N$^{1/2}$]
4.2	2464.88	140.8	0.0071	1322.3	5193.2	236	0.4013	0.000286	41493	2.03103E-06
4.25	2464.88	140.22	0.00713	1492.8	5193.2	234	0.3982	0.000286	41069	2.05624E-06
4.3	2464.88	139.63	0.00716	1666.8	5193.2	233	0.3953	0.000285	40643	2.08223E-06
4.35	2464.88	139.02	0.00719	1844.4	5193.2	232	0.3925	0.000284	40215	2.10901E-06
4.4	2464.88	138.39	0.00723	2025.6	5193.2	230	0.3898	0.000284	39785	2.13665E-06
4.45	2464.88	137.74	0.00726	2210.6	5193.2	229	0.3872	0.000283	39352	2.1652E-06
4.5	2464.88	137.08	0.0073	2399.7	5193.2	227	0.3847	0.000282	38917	2.19471E-06
4.55	2464.88	136.4	0.00733	2592.8	5193.2	226	0.3824	0.000282	38480	2.22518E-06
4.6	2464.88	135.69	0.00737	2790.1	5193.2	224	0.3802	0.000281	38040	2.25672E-06
4.65	2464.88	134.97	0.00741	2992	5193.2	222	0.3781	0.00028	37598	2.28935E-06
4.7	2464.88	134.23	0.00745	3198.4	5193.2	221	0.3762	0.00028	37155	2.32306E-06
4.75	2464.88	133.46	0.00749	3409.6	5193.2	219	0.3744	0.000279	36710	2.35795E-06
4.8	2464.88	132.67	0.00754	3625.9	5193.2	217	0.3727	0.000279	36264	2.39404E-06
4.85	2464.88	131.86	0.00758	3847.5	5193.2	215	0.3711	0.000279	35817	2.43137E-06
4.9	2464.88	131.02	0.00763	4074.6	5193.2	214	0.3697	0.000278	35370	2.46998E-06
4.95	2464.88	130.16	0.00768	4307.4	5193.2	212	0.3684	0.000278	34922	2.50996E-06

Pressure x2 check	T.API.520 [K]	Density [kg/m^3]	Cp0 [J/kg-K]	Vel. sonic [m/s]	Comp. factor	Kin. visc. [cm^2/sec]	Pseudo latent heat [J/kg]
2464.88	7.1	54.907	5193.2	144.57	0.6088	0.00044	24883
INPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT

CGA S-1.3-2008 T.relief [sec/N1/2]

$P_{1.API.520.absolute.kPa}$

$T_{API.520} = 7.1$

Relieving temperature @ inlet conditions. Source: CGA S-1.3 Section 6.1.3

$\rho_{He} := \rho_{He.unitless} \cdot \frac{kg}{m^3} = 54.907 \frac{kg}{m^3}$

$C_{p.0} := C_{p.0.unitless} \cdot \frac{J}{kg \cdot K} = 5193.2 \cdot \frac{J}{kg \cdot K}$

$Vel_{sonic.He} := Vel_{sonic.unitless} \cdot \frac{m}{sec} = 144.57 \cdot \frac{m}{sec}$

$Z_{API.520} = 0.609$

Compressibility factor @ inlet relieving conditions. Source: API 520 Part I, 2014, under section 5.6.3.1.1

$\nu_{He} := \nu_{He.unitless} \cdot \frac{cm^2}{sec} = 4.379 \times 10^{-4} \cdot \frac{cm^2}{sec}$

$$\Delta h_{pseudo.He} := \Delta h_{pseudo.He.unitless} \cdot \frac{J}{kg} = 24883 \cdot \frac{J}{kg}$$

$$m_{dot.relief} := \frac{Q}{\Delta h_{pseudo.He}} = 0.477 \cdot \frac{kg}{sec}$$

$$M_{API.520} := 4.0026$$

Molecular weight @ inlet relieving conditions. Source: API 520 Part I, 2014, under section 5.6.3.1.1 and REFPROP (**molar mass**)

$$W_{API.520} := \frac{m_{dot.relief}}{\left(\frac{kg}{hr}\right)} = 1717.189$$

Required flow rate through the device in kg/hour. Source: API 520 Part I, 2014, under section 5.6.3.1.1

$$W_{API.520} \cdot \frac{kg}{hr} = 476.997 \cdot \frac{gm}{sec}$$

$$k_{ideal.gas.sp.heat.ratio}\left(R_{sp.gas.constant}, C_{p.0}\right) := \frac{C_{p.0}}{C_{p.0} - R_{sp.gas.constant}}$$

Source: "Fundamentals of Engineering Thermodynamics", M. Moran, 6th Edition, Equation 3.44.
Use isobaric heat capacity (Cp0) in REFPROP for C.p.0.

$$C_{API.520.equation}\left(k_{ideal.gas.sp.heat.ratio}\right) := 0.03948 \sqrt{k_{ideal.gas.sp.heat.ratio} \cdot \left(\frac{2}{k_{ideal.gas.sp.heat.ratio} + 1}\right)^{\frac{k_{ideal.gas.sp.heat.ratio}+1}{k_{ideal.gas.sp.heat.ratio}-1}}}$$

Coefficient determined by ratio of ***IDEAL GAS*** specific heats. Source: API 520 Part I, 2014, under section 5.6.3.1.1

$$R_{sp.gas.constant.He} := 2.0769 \cdot 10^{3} \cdot \frac{J}{kg \cdot K}$$

$$k_{He} := k_{ideal.gas.sp.heat.ratio}\left(R_{sp.gas.constant.He}, C_{p.0}\right) = 1.666$$

$$C_{API.520} := C_{API.520.equation}\left(k_{ideal.gas.sp.heat.ratio}\left(R_{sp.gas.constant.He}, C_{p.0}\right)\right) = 0.029$$

$$P_{cf.API.520.equation}\left(P_1, k_{ideal.gas.sp.heat.ratio}\right) := P_1 \cdot \left[\left(\frac{2}{k_{ideal.gas.sp.heat.ratio} + 1}\right)^{\frac{k_{ideal.gas.sp.heat.ratio}}{k_{ideal.gas.sp.heat.ratio}-1}}\right]$$

Souce: API 520 Part I, 2014, section 5.6.2.4, where P.cf is the critical flow nozzle pressure

$$P_{cf.API.520} := P_{cf.API.520.equation}\left(P_{1.API.520} \cdot kPa, k_{He}\right) = 181.324 \cdot psi$$

$$K_{d.API.520} := 0.975$$

Effective coefficient of discharge, for when a PRV is installed with or without a rupture disk in combination. Source: API 520 Part I, 2014, under section 5.6.3.1.1

$$K_{d.API.520} := 0.816$$

Discharge coefficient of an AGCO type 81 relief valve (from vendor catalog)

$$K_{b.API.520} := 1.0$$

For conventional and pilot-operated valves. Source: API 520 Part I, 2014, under section 5.6.3.1.1

$K_{c.API.520} := 1.0$ When a rupture disk is not installed. Source: API 520 Part I, 2014, under section 5.6.3.1.1

$$A_{eff.discharge.minimum} := \frac{W_{API.520}}{C_{API.520} \cdot K_{d.API.520} \cdot P_{1.API.520} \cdot K_{b.API.520} \cdot K_{c.API.520}} \cdot \sqrt{\frac{T_{API.520} \cdot Z_{API.520}}{M_{API.520}}} \cdot \left(mm^2\right) = 0.046 \cdot in^2$$

$$D_{eff.discharge.minimum} := 2\sqrt{\frac{A_{eff.discharge.minimum}}{\pi}} = 0.242 \cdot in$$

Calculations