1 INTRODUCTION

The JLab Dipole has three connecting pipes from the Magnet Assembly Helium Vessel to the CCR. These pipes are referred to as the “Chminey” and this report examines the pressure drop in Chimney during the emergency vent conditions. The parameters for the analysis are taken from the earlier report describing the pressure relief which is titled “JLab Dipole Safety Relief: Quench & Loss of Vacuum – Helium System” having the filename “JLab Dipole Relief 301_2 He Pressure Relief.pdf”.

Reference	SF Dipole Chimney 201_8 Flow Drg 317111-JLA-700-001 - cross-section-for-charles-23.09.2015 – Max Flow.xls
	SF Dipole Chimney 202_2 Vent Pipe 4.00 nb BD 5.0 atm Axius 12.0 in at 5.1 barA – Max Flow.xls
	SF Dipole Chimney 201_8 Flow Drg 317111-JLA-700-001 - cross-section-for-charles-23.09.2015 – Quench.xls
Attachments	SF Dipole Chimney 201_8 Flow Drg 317111-JLA-700-001 - cross-section-for-charles-23.09.2015 – Max Flow.pdf
	SF Dipole Chimney 202_2 Vent Pipe 4.00 nb BD 5.0 atm Axius 12.0 in at 5.1 barA – Max Flow.xls
	SF Dipole Chimney 201_8 Flow Drg 317111-JLA-700-001 - cross-section-for-charles-23.09.2015 – Quench.pdf
Geometry documents	317111-JLA-700-001-cross-section-for-charles-23.09.2015.PDF
	Scans14705.pdf Drg No 67145-00501 Sheet 1 of 1
	Scans15047.pdf Drg No 67145-00500 Sheet 1 of 1

Documents which are referenced in the earlier report “JLab Dipole Relief 301_2 He Pressure Relief.pdf” are not necessarily re-listed in this section.

Rev	Date	Description

2 METHOD

The method of analysis uses the results from the earlier pressure relief calculations documented in the report titled “JLab Dipole Safety Relief: Quench & Loss of Vacuum – Helium System” having the filename “JLab Dipole Relief 301_2 He Pressure Relief.pdf”.. This report evaluated the vent flow rate for Loss of Vacuum (LOV) plus Quench with No Protection as 64 400 kg / hr. The analysis examined the pressure drop in the vent pipe from the helium reservoir of the CCR to the atmospheric discharge. It showed that the set pressure of the burst disc of 6.58 bar A, as an operating pressure in the CCR, was more than sufficient to vent the gas from the CCR. However the analysis did not evaluate the pressure drop in the three Chimney pipes connecting the Magnet Assembly Helium Vessel to the helium reservoir in the CCR. This pressure drop would result in the CCR operating at a lower pressure. This raises the question as to whether there is sufficient pressure in the Magnet Assembly Helium Vessel to discharge the fluid along the Chimney, through the CCR helium reservoir and along the CCR emergency vent pipe.

The method presented in this report to address this issue contains two steps listed below.

- First to evaluate the pressure drop in the Chimney using the vent flow rate for the Helium Vessel and the Chimney pipes. This will result in a pressure and a temperature for the helium in the CCR helium reservoir.
- Second to revisit the flow analysis from the CCR in order to evaluate the pressure at the outlet of the CCR vent pipe given the entire vent flow rate and the pressure for the helium reservoir of the CCR as calculated in the first step.

If the calculated discharge pressure of CCR vent pipe is greater than atmospheric pressure, then the pressure in the Magnet Assembly Helium Vessel is sufficient to vent the necessary flow rate for the Loss of Vacuum plus Quench with No Protection.

The penultimate section of the report examines the pressure drop in the Chimney during a quench and the resulting pressure in the Magnet Assembly Helium Vessel.

3 ASSUMPTIONS

The assumptions made to prepare the earlier report “JLab Dipole Relief 301_2 He Pressure Relief.pdf” should be reviewed.

The CCR has a non-return valve installed on the vent path. Analysis has been undertaken to estimate the Kv of this valve as 270 (units as a function of bar and m³ / hr). Confirmation of this is required from Jlab.

The heat loads on the pipeline are as follows:

Loss of Vacuum to bare metal	38 000	W / m²
Loss of Vacuum to surfaces with multi-layer superinsulation	7 000	W / m²
Surfaces with multi-layer superinsulation in a vacuum	2	W / m²

4 PARAMETERS

4.1 GEOMETRY - CHIMNEY

The geometry of the two Chimney pipes carrying the current leads and the single Chimney pipe carrying the instrumentation is defined in the drawing “317111-JLA-700-001-cross-section-for-charles-23.09.2015.PDF”.

4.2 GEOMETRY - VENT PIPE INTERNAL TO THE CCR

Internal to the CCR the vent pipe is 4.00” nb Schedule 10 and includes a non-return valve. The pressure drop for this pipe will be modeled using the following geometry.

Sharp edge entry						
Pipe	Length	127	mm	Diameter	108.2	mm
Non return valve	Kv	270	(Estimate)			
Pipe	Length	576.1	mm	Diameter	108.2	mm

The flow coefficient for the non-return valve should be confirmed by JLab.

4.3 GEOMETRY - VENT PIPE EXTERNAL TO THE CCR

The geometry and the insulation of the pipe downstream of the flange on the CCR is defined in the following drawings:

Scans14705.pdf	Drg No 67145-00501 Sheet 1 of 1
Scans15047.pdf	Drg No 67145-00500 Sheet 1 of 1

4.4 PRESSURES

The helium vessel will be protected by a relief valve and a burst disc. The set pressures and the venting pressures are listed below.

Burst Disc	Set pressure	5.0	atm gauge
		5.07	bar G
	Over pressure	10%	
	Vent pressure	5.57	bar G
		6.58	bar A

Therefore the maximum vent pressure in the Magnet Assembly Helium Vessel is defined as 6.58 bar A.

4.5 VENT FLOW RATES

The contribution of the vent flow rates from each section of the system and the total vent flow rate is listed below using figures from the earlier analysis.

	Surface Area m²	Heat Flux W / m²	Heating kW	Vent Flow kg / hr	Fraction
Helium Vessel	25.76	7 000	180.4	22 510	35.0 %
Magnet Assembly	19.74	7 000	138.2	17 250	26.8 %
Magnet Assembly - Quench	4.37	38 000	166.1	20 730	32.2 %
Chimney	3.53	7 000	24.7	3 080	4.8 %
CCR	0.98	7 000	6.9	860	1.3 %
Total			516	64 430	

For the purposes of this analysis, the pressure drop in the Chimney pipes is conservatively calculated assuming that the flow rate which is generated along the Chimney in fact enters the Chimney.

Therefore the flow rate in the Chimney is 63 570 kg / hr; the temperature of the helium, as defined in the earlier report, is 6.94 K.

5 VENT CAPACITY

The flow rate and the geometry is used to calculate the pressure drop in the Chimney from the Magnet Assembly Helium Vessel to the CCR and then for the vent pipe from the CCR to atmosphere.

5.1 VENT FLOW: MAGNET VESSEL TO CCR

The pressure drop for the three pipes of the Chimney assembly is evaluated in the design spreadsheet “SF Dipole Chimney 201_8 Flow Drg 317111-JLA-700-001 - cross-section-for-charles-23.09.2015 – Max Flow.xls” using the geometry illustrated in the drawing “317111-JLA-700-001-cross-section-for-charles-23.09.2015.PDF”.

The flow rate is reduced to exclude the flow rate generated in the CCR.

A summary of the calculation method of the design spreadsheet is listed below:

1. The pressure drop due to friction losses, section changes, pipe fittings and hydrostatic pressure is calculated. The section changes include the restriction at each superconductor or instrumentation clamp. The pipe flow area makes an allowance for the restriction caused by the instrumentation and the superconductor.
2. The change in pressure and temperature as calculated in one node are used to adjust the properties for the subsequent node along the length of the flow path of the Chimney.
3. A convergence routine adjusts the flow rate in the three Chimney pipes so that the pressure drop along the length of each Chimney is equal.
4. The vent flow rate is generated by the volume expansion due to the heat loads. A proportion of the flow rate is generated by the heat load on the

Chimneys and in theory this additional flow rate accumulates along the length of the Chimneys. The analysis is conservative by including this increment of flow rate at the inlet to the Chimneys. To avoid double counting this heating, it is not included as a heat load on the wall of the Chimneys.

The summary results are included as the attachment “SF Dipole Chimney 201_8 Flow Drg 317111-JLA-700-001 -cross-section-for-charles-23.09.2015 – Max Flow.pdf”. (Compared to the vent process from the CCR described in the next section, the details of the analysis are too extensive to be listed in the report and should be obtained from the attachment.)

The results show that with an inlet pressure of 6.58 bar A, the outlet pressure and temperature at the CCR helium reservoir are 5.15 bar A and 6.62 K. (The temperature drops since the gas conditions are below the Joule-Thomson Inversion temperature and the gas is expanding.)

A summary of the parameters is listed below.

		Instrumentation Chimney	Superconductor Chimney	Total	
	Number	1	2	3	
	Mass flow rate	24 130	19 720	63 570	kg / hr
Pressure Drop	- Friction losses	170	82		mbar
	- Section change	550	264		mbar
	- Fittings	678	1051		mbar
	- Hydrostatic	30	29		mbar
Total Pressure drop		1 427	1 427	1 427	mbar

5.2 VENT FLOW: CCR TO ATMOSPHERE

The calculations for the pressure drop for the vent pipe from the CCR to the burst disc are summarised below. At each node the pressure and the temperature is calculated and the corresponding helium gas properties are evaluated. The detailed results are listed in “SF Dipole Chimney 202_2 Vent Pipe 4.00 nb BD 5.0 atm Axius 12.0 in at 5.1 barA– Max Flow.pdf”.

A heat load is imposed on each node as follows: 7 000 W / m² for the sections inside the CCR under Loss of vacuum conditions, 2 W / m² for the vacuum insulated section of the “Relief Tree Assembly”, assuming that this section has an independent vacuum compared to the CCR; and 33 000 W / m² which are exposed to ambient air.

	Pipe inside diameter	108.2	mm
Inlet Conditions	Pressure	5.15	bar A
	Temperature	6.62	K
	Vent flow rate	64430	kg / hr
	Density	75.60	kg / m³
	Viscosity	2.59 E-6	kg / m.s

Sudden Contraction					
	Upstream diameter	Large			
	Loss coefficient	0.464			
	Pressure drop			116.3	mbar
Pipe Loss	Unit pressure drop	7.79	mbar per m		
	Length	0.127	m		
	Pressure drop			1.0	mbar
Non-Return Valve	Valve Kv	270			
	Pressure drop			1168	mbar
Pipe Loss	Unit pressure drop	9.01	mbar per m		
	Length	0.576	m		
	Pressure drop			5.2	mbar
Pipe Loss	Unit pressure drop	9.05	mbar per m		
	Length	0.09	m		
	Pressure drop			0.8	mbar
Pipe Loss	Unit pressure drop	9.08	mbar per m		
	Length	0.43	m		
	Pressure drop			3.9	mbar
Tee as Elbow	Unit pressure drop	9.09	mbar per m		
	Nominal length	0.2	m		
	Pressure drop			1.8	mbar
	Loss coefficient	0.90			
	Pressure drop			274.3	mbar
Pipe Loss	Unit pressure drop	9.50	mbar per m		
	Length	0.08	m		
	Pressure drop			0.7	mbar
Tee as Run	Unit pressure drop	9.53	mbar per m		
	Nominal length	0.2	m		
	Pressure drop			1.9	mbar
	Loss coefficient	0.30			
	Pressure drop			96.6	mbar
Pipe Loss	Unit pressure drop	9.77	mbar per m		
	Length	0.08	m		
	Pressure drop			0.7	mbar
Elbow (long radius)	Unit pressure drop	9.80	mbar per m		
	Nominal length	0.24	m		
	Pressure drop			2.4	mbar
	Loss coefficient	0.24			
	Pressure drop			79.8	mbar

Pipe Loss	Unit pressure drop	10.04	mbar per m		
	Length	0.25	m		
	Pressure drop			2.5	mbar
Burst Disc	Manufacturer	FIKE			
	Type	AXIUS Low Pressure			
	MNFA	12.7	in² (manufacturer’s date)		
		8194	mm²		
	Effective orifice diameter	102.8	mm		
	Kr	0.45	(manufacturer’s date)		
	Helium density	55.09	kg / m³		
	Pressure drop			203	mbar
Sudden Expansion					
	Downstream diameter	Large			
	Pressure drop			369	mbar
Total Pressure Drop				2330	mbar
Calculated outlet pressure				2.83	bar A
				1.81	bar G

By this analysis the calculated outlet pressure is greater than atmospheric pressure by 1.8 bar. Therefore there is sufficient pressure to vent the gas from the helium reservoir of the Magnet Assembly Helium Vessel and through the vent path of the CCR under conditions of a Loss of Vacuum with a simultaneous quench having no protection.

The velocity and Mach Number in the pipe rises from 26 m / s and 0.18 at the inlet to 38 m / s and 0.31 at the outlet.

With a heat flux of 7 000 W / m² on the sections with superinsulation and 38 000 W / m² on the sections without superinsulation, the calculated temperature rise due to heating is offset by the temperature drop due to the expansion process. The net temperature drop along the vent pipe is 0.9 K.

The pressure on the outlet of the burst disc is calculated for a gas expansion from a sharp edge. The drawing provided by JLab number 67145-00500 shows a top plate which is 1¾” above the exit flange of the burst disc holder. On the basis of a visual examination, and as stated in the earlier report, it is recommended that this gap be increased.

6 QUENCH

The operation during a quench with protection is examined. The parameters are listed below as documented in the earlier report “JLab Dipole Safety Relief: Quench & Loss of Vacuum – Helium System” having the filename “JLab Dipole Relief 301_2 He Pressure Relief.pdf”.

Relief Valve	Set pressure	4.0	atm gauge
		4.05	bar G
	Over pressure	10%	
	Vent pressure	4.46	bar G
		5.47	bar A
Quench	Vent flow rate	23 800	kg / hr
	Vent temperature	5.65	K
CCR Vent Pipe	Pressure drop	0.181	bar

The analysis for the pressure drop in the Chimney pipes is repeated as described in the previous sections and the results are included as the attachment “SF Dipole Chimney 201_8 Flow Drg 317111-JLA-700-001 -cross-section-for-charles-23.09.2015 – Quench.pdf”.

The results show that the pressure drop in the Chimney is 0.219 bar.

A summary of the parameters is listed below.

		Instrumentation Chimney	Superconductor Chimney	Total	
	Number	1	2	3	
	Mass flow rate	8 980	7 410	23 800	kg / hr
Pressure Drop	- Friction losses	27	13		mbar
	- Section change	71	34		mbar
	- Fittings	87	138		mbar
	- Hydrostatic	34	34		mbar
Total Pressure drop		219	219	219	mbar

As a result of a quench the pressures in the system are listed below.

Relief valve fully open pressure	4.46	bar G	
Pressure drop – CCR vent pipe			0.181 bar
Pressure in the CCR	4.64	bar G	
Pressure drop – Chimney			0.219 bar
Pressure Magnet assy helium vessel	4.86	bar G	
Total pressure drop			0.40 bar

The pressure rise in the vent path is high at 0.40 bar which is 9% of the fully open pressure of the relief valve. As a result the pressure in the Magnet Assembly Helium Vessel will rise to 4.86 bar G which is 5.87 bar A. This is less than the design pressure. If it is considered a problem then the relief valve should be reset to lift at a lower pressure.

7 CONCLUSIONS

The analysis described in this report should be read in conjunction with the previous report titled “JLab Dipole Safety Relief: Quench & Loss of Vacuum – Helium System” having the filename “JLab Dipole Relief 301_2 He Pressure Relief.pdf”.

Confirmation is required from the designers of the flow capacity of the non-return valve within the CCR (Kv value).

As a provisional conclusion, conditional on confirmation of the flow capacity of the non-return valve, the total pressure drop from the helium vessel to the downstream side of the burst disc is 3.75 bar at the required vent flow rate of 64 430 kg / hr and when the pressure in the Magnet Assembly Helium Vessel is 5.57 bar G. Since this the pressure drop is less than the gauge pressure there is sufficient flow capacity to vent the gas.

During a quench the pressure rise in the vent path from the Magnet Assembly Helium Vessel to the relief valve is 0.40 bar. With the relief set pressure at 4.0 atm gauge which is 4.05 bar G and the fully open pressure at 4.46 bar G then the pressure in the Magnet Assembly Helium Vessel will rise to 4.86 bar G during a quench. If this pressure is considered a problem then the pressure relief valve should be reset to lift at a lower pressure.

Rev	Date	Description