RELIABILITY PLAN

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MODIFICATIONS RECORDING

ISSUE OFMODIF	DATE	WRITTEN BY	CHECKED BY	EVOLUTION OF THE DOCUMENT (Updated pages)	JUSTIFICATION OF THE MODIFICATION
(0)	03/21/2016	G.FLAVIEN		Issue for PDR	Preliminary List for critical components MTBF and MTTR for PDR
(1)	06/11/2016	C.GIRE	G.FLAVIEN	Issue for FDR	Adding FMEA turbine and methodology for MTBF
(2)	06/27/2017	G.FLAVIEN		Issue 120 Days BI	Adding FMEA for other equipments
(3)	09/01/2017	G.FLAVIEN		Up-date following JLAB comments	Adding missing equipments and corrections based on JLAB comments
(4)	10/13/2017	G.FLAVIEN		Up-date following JLAB comments	Adding Level Transmitters

TABLE OF CONTENTS

1. INTRODUCTION

This document is a reliability plan for the LCLSII 4.5K Cold Box System.

It is composed of:

Analysis sub-parts	Project Milestone due date
Analysis of the effects of component failure on system performance (FMEA)	o FDR for Turbines o 120 days before installation for other components
Determination of Mean Time Between Failures, MTBF, for the following major cold box system components: • Turbo-expanders • Heat exchangers • 80K and 20K Beds • Valves required for normal operating and utility modes • Instruments required for normal operating and utility modes	o Preliminary Study for PDR o Final Study for FDR
Determination of System Mean Time Between Failures, being the reciprocal of the sum of the failure rates for each functional item of the delivery	o Preliminary Study for PDR o Final Study for FDR
Mean Time To Repair Analysis (MTTR) for the system indicating the time period required to repair a malfunction or to remove and replace a component down to the lowest line-replaceable unit (LRU)	o Preliminary Study for PDR o Final Study for FDR

2. FMEA

Failure Mode Effects Analysis aims to assess LCLSII 4.5K Cold Box System performances in case of failure of critical equipment. Failure of an equipment can provoke:

- Degraded mode. In this case, effect on performances (cold power, availability) will be described in this document.
- Cold box shut down. In this case, no degraded mode is possible cold box must be repaired

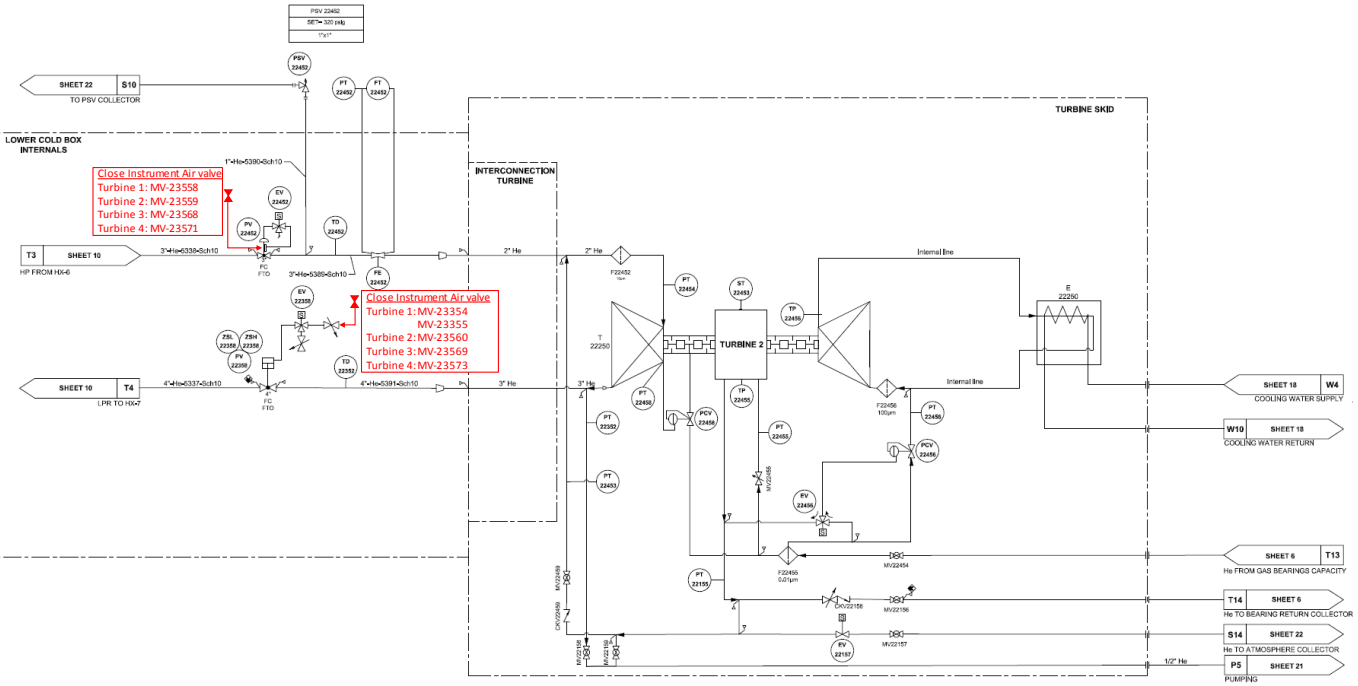
2.1 TURBINE SHUT DOWN

2.1.1 Turbines isolation, warm-up and re-conditioning

In case of a turbine failure, cold box shut down is not necessary. Turbine can be isolated and replaced while cold box continues to work.

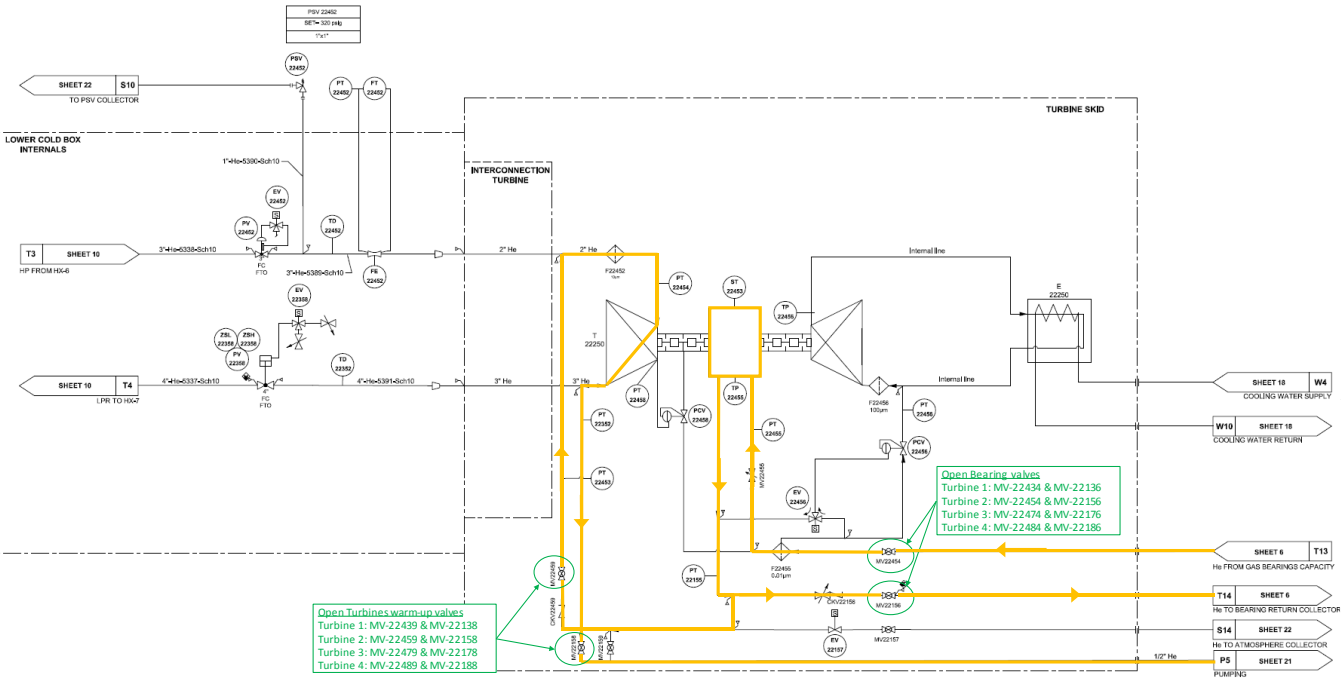
- Turbines isolation:

Once Turbine is stopped, and inlet and outlet valves are closed, it can be safely isolated by closing the following valves:

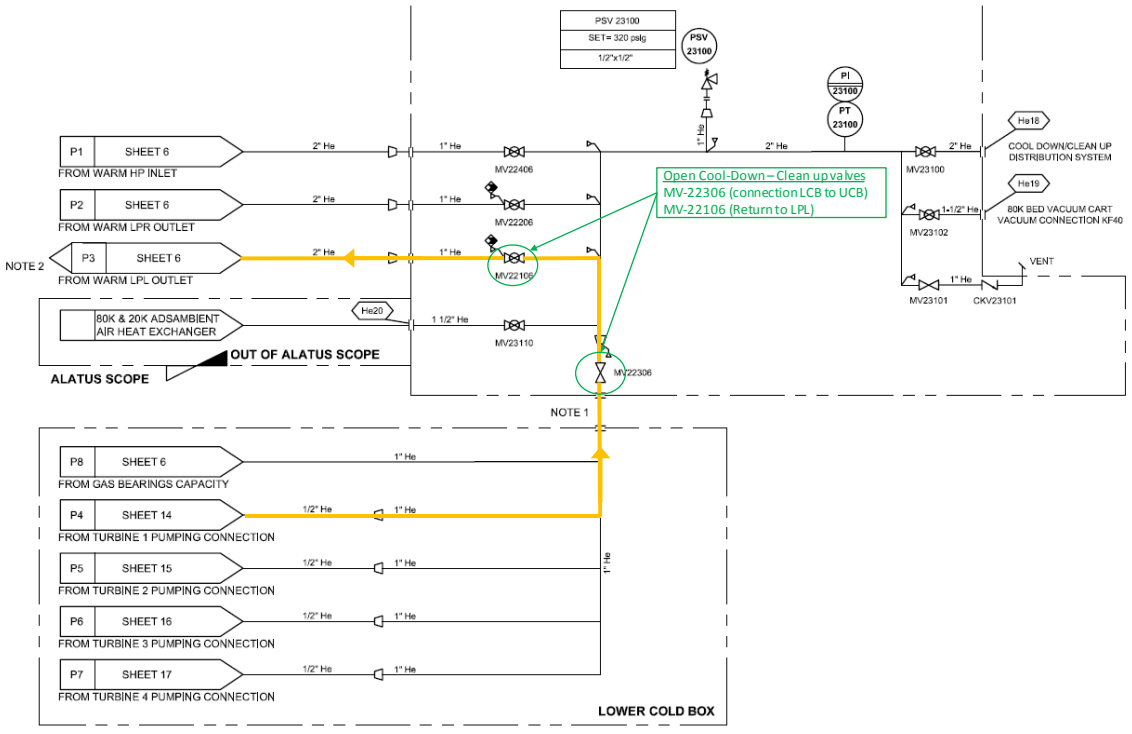


- Turbine Warm-up:

Turbines can be independently warmed up using the following circuit:
- On Turbine skid



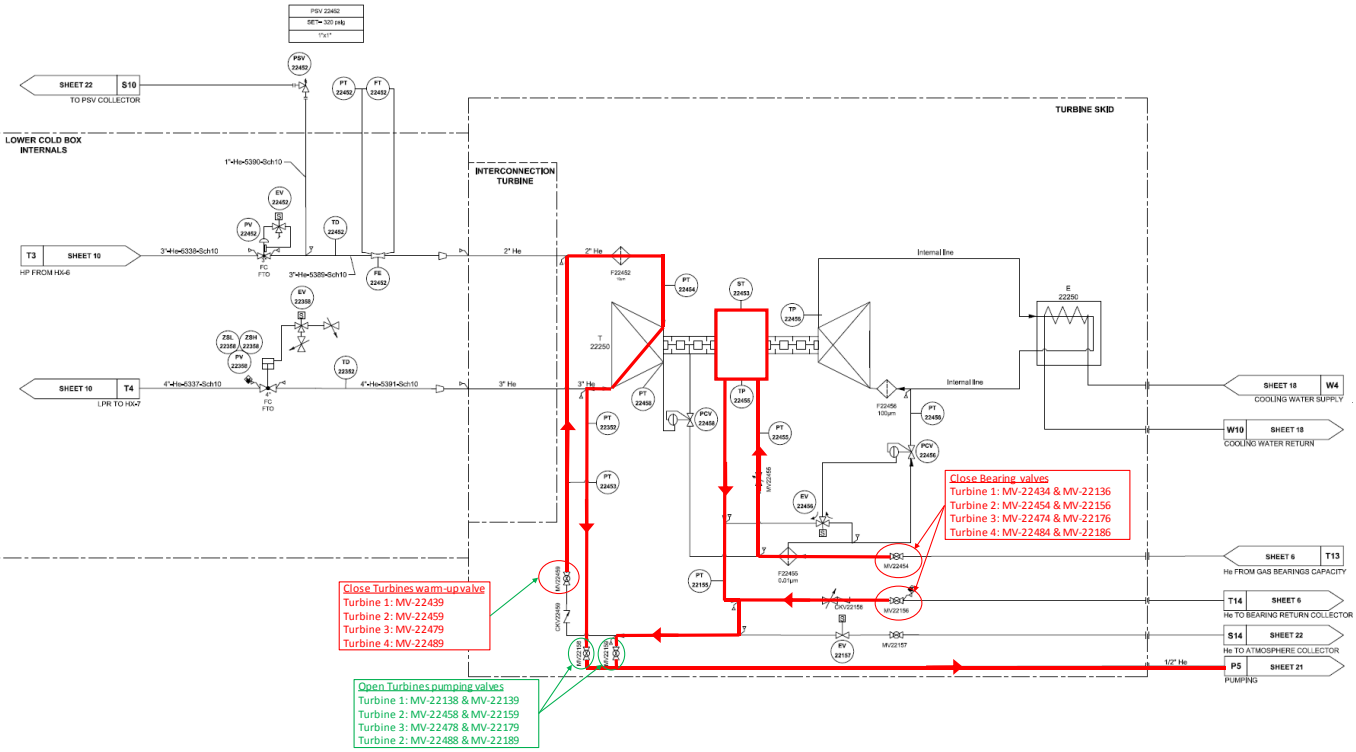
- On cool down / clean up distribution system rack:

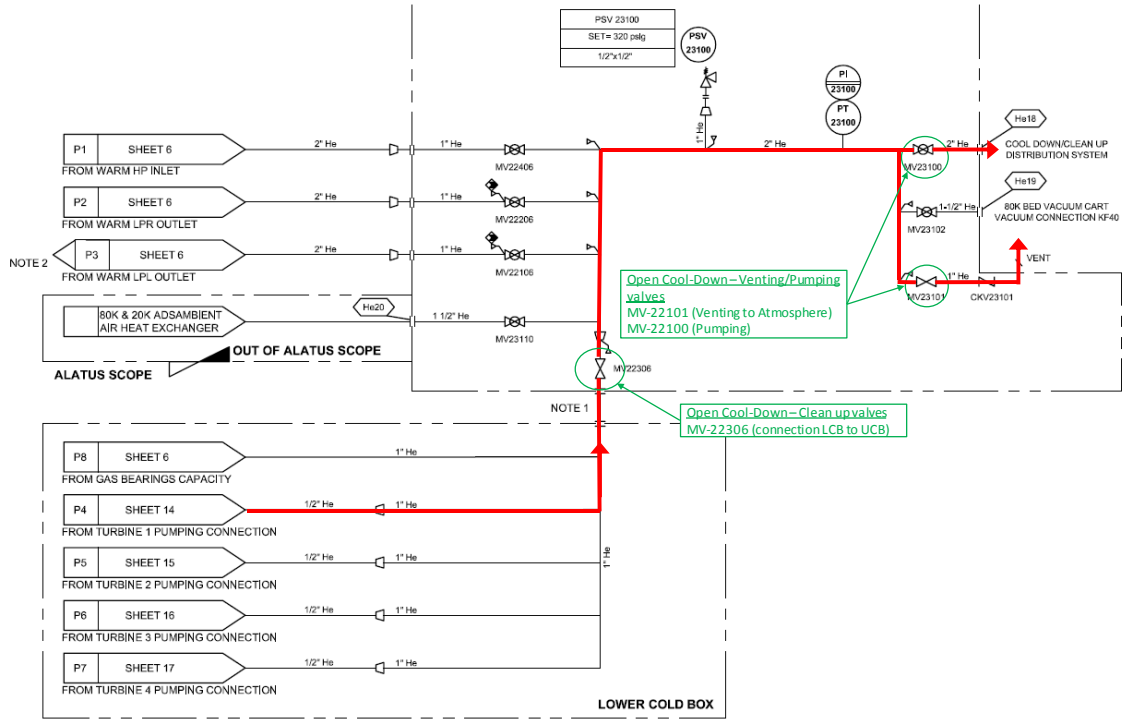


- Turbine re-conditioning:

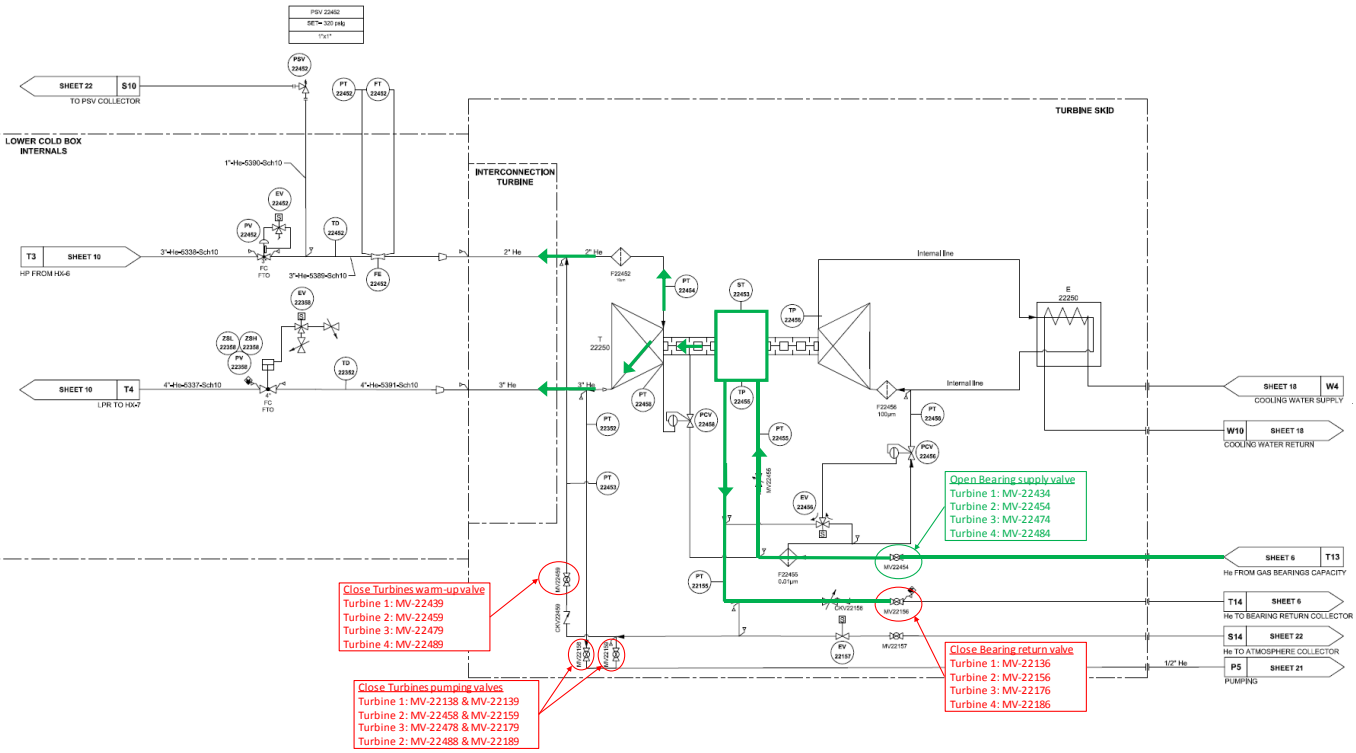
Reconditioning consists in venting and pumping the Turbines circuits, and filling with pure Helium.

- Venting / Pumping:





- Pure Helium filling



2.1.2 Analysis of the impact of a Turbine failure

In case of one turbine failure, the minimum cold power to be reached is the stand by mode (mode 6 in process note C1303 NT101). That is to say :

Table 3.4(F) – Mode 6, Standby
Minimum loads at 4.5K

		Supply		*Return*		
Load	***w*** **[g/s]**	**p [atm]**	**T [K]**	**p [atm]**	**T [K]**	**q [kW]**
Warm Shield	≤96.7	Note 1	≤35	≥2.7	≤55	≥10.1
Cold Intercept	≤25	≥3.2	≤5.3	≥1.23	≤7.5	≥0.9
4-K Refrigeration	≤27	≥3.2	≤4.5	≥1.23	≤4.5	≥0.5
4-K Liquefaction						
Sub-Atmospheric						

Notes: For Tables 3.4(A) to 3.4(F)

[1] Shield load pressure drop shall be 1.0 atm for all modes.
[2] 4.5-K refrigeration load return condition is saturated vapor at the specified pressure.
[3] Mode-6 (Stand-by) shall be designed for minimum equipment operation (both the number of compressors and turbines) and with at least 40% of the Mode-1 compressors off.
[4] ≤ indicated listed value is a maximum allowed/required.
≥ indicated listed value is a minimum allowed/required.

Extract from technical specification for the procurement of CHL 4.5K Cold box system

In some case, adjustment on process must be done to optimise the cold power. The following compliance matrix describes them.

Degraded mode	adjustments
T1 off	Warm shield supplied at 55.9K, return at 75,9K
T2 off	No adjustment
T3 off	Cold intercept supplied at 6.2K, mass flow increased at 55g/s (to keep return at 7.5K)
T4 off	No adjustment

The corresponding process flow diagram and data for every turbine failure are given in annex 1.

2.2 OTHER COMPONENT SHUT DOWN

Risk Category

For each failure mode a risk severity is assigned based on the following classification:

Severity	5 (High)	Safety Hazard to Personnel
	4	Component Damage
	3	Impact to Cryoplant Functionality
	2	Impact to 4.5K Cold Box Functionality
	1 (Low)	Loss of diagnostics with no major system impact

The complete FMEA tables for other components are in Annex 2 of this document.

The main conclusions are:

Component	Worse Severity	Failure Mode	Hazard/Effect	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
1- Heat Exchanger	4	Fails	- Performance Loss - Pressure increase in Vacuum Shell	Leak in the Vacuum Enclosure or LN2/LHe phase separator Loss of Helium inventory Loss of Performance	Vacuum Shell relief pressure device. Interlocks on pressure rise.
2- Control Valves	2	Failed Open or Failed Close	- Performance Loss - Flow interruption - Pressure increase	Valve position is defined by the 4.5K CB PLC logic.	System ultimately protected by: - Software: Interlocks - Hardware: Relief Valves
3- Heaters	1	No Heating	- No regeneration possible on Adsorbers - Less Heating capacity in LHe Subcooler	Heater power is defined by the 4.5K CB PLC logic.	Maintenance / Switch to redundant Heater
4- Pressure Transducers	2	Fail High or Fail Low	- Loss of control loops - Unwanted interlock - Misleading Alarms	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure to disconnect Pressure controller and allow fixed position for the control valves?
5- Temperature sensors	2	Fails (only sensor)	- Loss of control loops - Unwanted interlock - Misleading Alarms	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock?
6-Level Transmitters	2	Fails	- Loss of control loops - Misleading Alarms	LN2 and LHe levels information and associated control and alarms are defined by the 4.5K CB PLC logic	
7- Relief Valves	5	Failed Open or Failed Close	- Loss of Helium Inventory - Relief function is lost thus potential process line failure	- Periodic monitoring of helium inventory required - Relief System to be inspected and tested periodically per CGA requirements. - Relief inspection procedure/schedule to be developed.	

Component	Worse Severity	Failure Mode	Hazard/Effect	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
8- Check Valves	2	Failed Close	Flow blocked: No supply of gas / pressure increase	Warm Check Valves to be inspected and tested periodically. Consequences of Check valve issue are managed in 4.5K cold box control logic. Safety relief Valves also protect lines against Check Valves failing closed.	Control logic will stop Turbines if necessary. Safety Valve will protect lines.
9- Filters	2	Clogging	Loss of performance (increased pressure drop)	Filters pressure drop is monitored by the 4.5K CB PLC Logic. Maintenance procedures to be developed.	Alarms if pressure drop increase.
10- Cooling Water	2	Equipment failure or wrong operation	Loss of Cooling Water	Operation and Maintenance procedures to be developed.	
11- Instrument Air	2	Equipment failure or wrong operation	Loss of Instrument Air	Operation and Maintenance procedures to be developed.	CB General Trip if Pressure switch Low activated
12- 3atm He distribution	2	Equipment failure or wrong operation	Helium loss Difficulties to fill lines with Helium	Operator training and operating procedure required	
13- Cool Down - Clean up distribution system	2	Equipment failure or wrong operation	Helium loss Difficulties to vent/pump lines	Operator training and operating procedure required	
14- Vacuum Pumps	2	Fails / Stop	No more dynamic vacuum on the Cold Box enclosure	Vacuum pumps are managed by 4.5K CB PLC Logic	Interlock Vacuum logic and close vacuum valves if Pumps failure is detected

3. MTBF FOR MAJOR COLD BOX COMPONENTS

3.1 MTBF SOURCE FOR MAJOR COMPONENT

For items with a high degree of history, meaning they are commonly used in the industry, values were taken from Air Liquide master reliability database. This database gathers selected information issued from well known public database such as OREDA Offshore Reliability Data, EIREDA European Industry Reliability Data, AIChE : American Institute of Chemical Engineers etc. and also includes AL experience feedback and expert opinions.

For items that are proper to Air Liquide department, the failure rate is estimated based upon testing a population of items and associated observed failures. This estimation is based on a statistical interpretation of failures, given a certain confidence level for this estimation.

3.1.1 Data for plate and fins aluminum heat exchangers

Similar aluminium heat exchangers have been used in the past in the cryogenic industry operating in similar conditions, i.e.

- under vacuum
- with similar leak rates (towards vacuum vessel and inter-stream)
- with several streams (from 2 to 5)
- operating at the same temperature levels

Therefore the failure rate value used for heat exchanger is taken from AIR LIQUIDE master database which selected the failure rate value from public data base FEVE (10/08/1999).

3.1.2 Valves

Similar valve technologies have been used in the past in the cryogenic industry operating in similar conditions, i.e.

- under vacuum
- with similar leak rates
- operating at the same temperature levels

Therefore the failure rate value used for valves are taken from AIR LIQUIDE master database which selected the failure rate value from public data base NPRD 97 page 2-164

3.1.3 Turbo-expanders

Turbo-expanders technology is based on Air Liquide know-how. It is not a material bought of the supplier shelf, unlike the previously mentioned critical components.
Therefore the failure rate value is taken directly from Air Liquide experience feed-back. Air liquide has a maintenance service facility dedicated to turbo-expanders, therefore most of the turbo-expanders sold and in operation are followed as far as operating hours and failures are concerned.

Providing the number k of observed failures is low and the failure rate is considered as constant, it is demonstrated that in the case testing is stopped on a time criteria, $2t\lambda$ follows a chi-square $\chi 2$ distribution with $2*k+2$ degrees of freedom for a given confidence level.

The sequence below summarises the use of chi-square table in order to assess failure rate value based on testing, in our case testing from experience feed back.

1. Measure T (cumulative functioning hours from similar items) and k (observed failures)
2. Choose a confidence level, work out risk level α = (1-confidence level)
3. Calculate estimate failure rate using following formula: $\chi^2(\alpha, 2k+2) = 2 \times \lambda \times T$

Air Liquide policy regarding failure rate values is to consider values at 90% confidence level, which means that 90% of the time, the actual observed value for the failure rate is below the estimated failure rate value. Over a total of 1880000 cumulative hours, 17 failures have been observed.

⇨ Result is $7{,}15\mathrm{E}^{-06}$ fail/hour, which gives : $\boldsymbol{MTBF = {}^{1}/_{7,15\mathrm{E}^{-06}} = 140\,000\ hours}$

3.2 RESULTS

Equipment	MTBF (hour)	MTBF Source
Pressure vessels		
LN2 phase separator / LHe phase separator	92 000 000	CCPS p205
Exchangers		
Cryogenic heat exchangers (Plate)	6 540 000	AL Data
Electrical heaters inside cold box	58 823	OREDA 2002 (p501) and OREDA 2009 (P412)
Filters and adsorbers		
Filters: GHe	833 333	FEVE source: IEEE-500 (p.1405)
Filters: Dust	833 333	FEVE source: IEEE-500 (p.1405)
Adsorbers (Molecular sieve 13X / Activated Carbon)	1 900 000	IEEE-500 p1422
Rotating equipment		
Turbines	140 000	AL Data
Valves		
Control valves (warm)	824 487	CERN[1]
Cryovalves	2 298 333	CERN
Pressure reducer (PCV)	2 816 900	NPRD 95 - p.2-164
Instrumentation & control		
Pressure sensors	2 035 667	CERN
Temperature sensors	1 250 000	EIReDA 98 p.239
Flow sensors	370 370	OREDA-97 p. 325 & EIReDA 98 p.233

[1] CERN - "first assessment of reliability data for the LHC accelerator and detector cryogenic system components" - Perinic & al.

Level sensor	277 778	EXIDA 2005 - p.76

4. SYSTEM MTBF

4.1 CALCULATION FORMULA

The system MTBF is the reciprocal of the sum of the failure rates for each functional item of the delivery. Failure rate for an equipment or a system is the reciprocal of its MTBF.

4.2 MTBF SOURCE FOR OTHER COMPONENT

4.2.1 Pressure sensors

Similar pressure sensor technologies have been used in the past in the cryogenic industry operating in similar conditions.
Therefore the failure rate value used for pressure sensors are taken from AIR LIQUIDE master database which selected the failure rate value from public data base OREDA 97 (p332)

4.2.2 Temperature sensors

Similar temperature sensor technologies have been used in the past in the cryogenic industry operating in similar conditions, i.e.

- under vacuum
- using the same type of assembly
- operating at the same temperature levels

Therefore the failure rate value used for temperature sensors are taken from AIR LIQUIDE master database which selected the failure rate value from public data base EIReDA 98 (p239)

4.3 RESULTS

The following table gives an analysis of the needed components for nominal operation (maximum design case).

Equipment	MTBF (hour)	Qty for Nominal Operation	Justification	Qty/MTBF
Pressure vessels				
LN2 phase separator / LHe phase separator	92 000 000	2	2 Phase separators needed	2.17E-08
Exchangers				
Cryogenic heat exchangers (Plate)	6 540 000	8	8 Exchanger "core"	1.22E-06
Electrical heaters inside cold box	58 823	3	80K Adsorbers: 2 20K Adsorbers: 1	3.10E-05
Filters and adsorbers				
Filters: GHe	833 333	2	HP inlet: 2	2.4E-06
Filters: Dust	833 333	4	80K Adsorbers: 2 20K Adsorbers: 2	4.8E-06
Adsorbers (Molecular sieve 13X / Activated Carbon)	1 900 000	2	80K Adsorbers: 1 20K Adsorbers: 1	1.05E-06
Rotating equipment				
Turbines	140 000	4	4 Turbines needed for maximum design case	2.86E-05
Valves				
Control valves (warm)	824 487	2	HP split control: 2	2.43E-06
Cryovalves	2 298 333	18	LN2 supply: 1 4 Turbines: 8 Warm/ Cold shields: 5 Subcooler: 2 Subatmospheric: 2	7.83E-06
Pressure reducer (PCV)	2 816 900	8	2 per turbine	2.84E-06
Relief valves	TBD	-	-	TBD
Instrumentation & control				
Pressure sensors	2 035 667	14	4 Turbines: 12 Warm shields: 1 Dewar: 1	6.88E-06
Temperature sensors	1 250 000	17	HP split control: 2 4 Turbines: 12 Warm / Cold shields: 2 Subatmospheric return: 1	1.36E-05
Flow sensors	370 370	0	No need for the control	0
Level sensors	277 778	2	LN2 and LHe levels	7.20E-06
SYSTEM MTBF	**7702 hours**			

5. MTTR ANALYSIS

The following is the preliminary MTTR analysis for PDR. Complete analysis will be prepared for FDR considering finalized 3D Model and frozen P&ID/Instrument list.

The values shown in the table are just mean time to repair the failed equipment. It is not considering the warm-up time or the time to set the system back to nominal operation.

Equipment	MTTR (hour)	Justification	Warm Up needed	Vacuum Break and opening needed
Pressure vessels				
LN2 phase separator / LHe phase separator	168	Eireda p79/81 for vessels gives 168h	Yes	Yes
Exchangers				
Cryogenic heat exchangers (Plate)	504	Mean value estimation, MTTR = 3 weeks	Yes	Yes
Electrical heaters inside cold box	12	Spare heater available (electrical connection to be switched)	No	No
Filters and adsorbers				
Filters: GHe	12	Y type filter.	No	No
Filters: Dust	84	Eireda 98 P37 for dust filters gives 84h	Yes	Yes
Adsorbers (Molecular sieve 13X / Activated Carbon)	48	Estimation to vacuum prepare, evacuate adsorbent and refill with new adsorbent	Yes	TBC
Rotating equipment				
Turbines	6	Air Liquide experience for cartridge replacement	No	No
Valves				
Control valves (warm)	3	Considering spare part kit available	No	No
Cryovalves	3	Considering spare part kit available	Yes	No
Pressure reducer (PCV)	3	Considering spare part kit available	No	No
Relief valves	3	Considering spare part available	No	No
Instrumentation & control				
Pressure sensors	3	Considering spare part available	No	No
Temperature sensors	3	Considering spare part available	Yes	Yes
Flow sensors	3	Considering spare part available	No	No
Level sensors	3	Considering spare part available	No[2]	No

[2] Superconductive probe in LHe Phase separator excluded: this probe needs a complete warm up of the system

ANNEX 1 : PFD FOR TURBINES FMEA

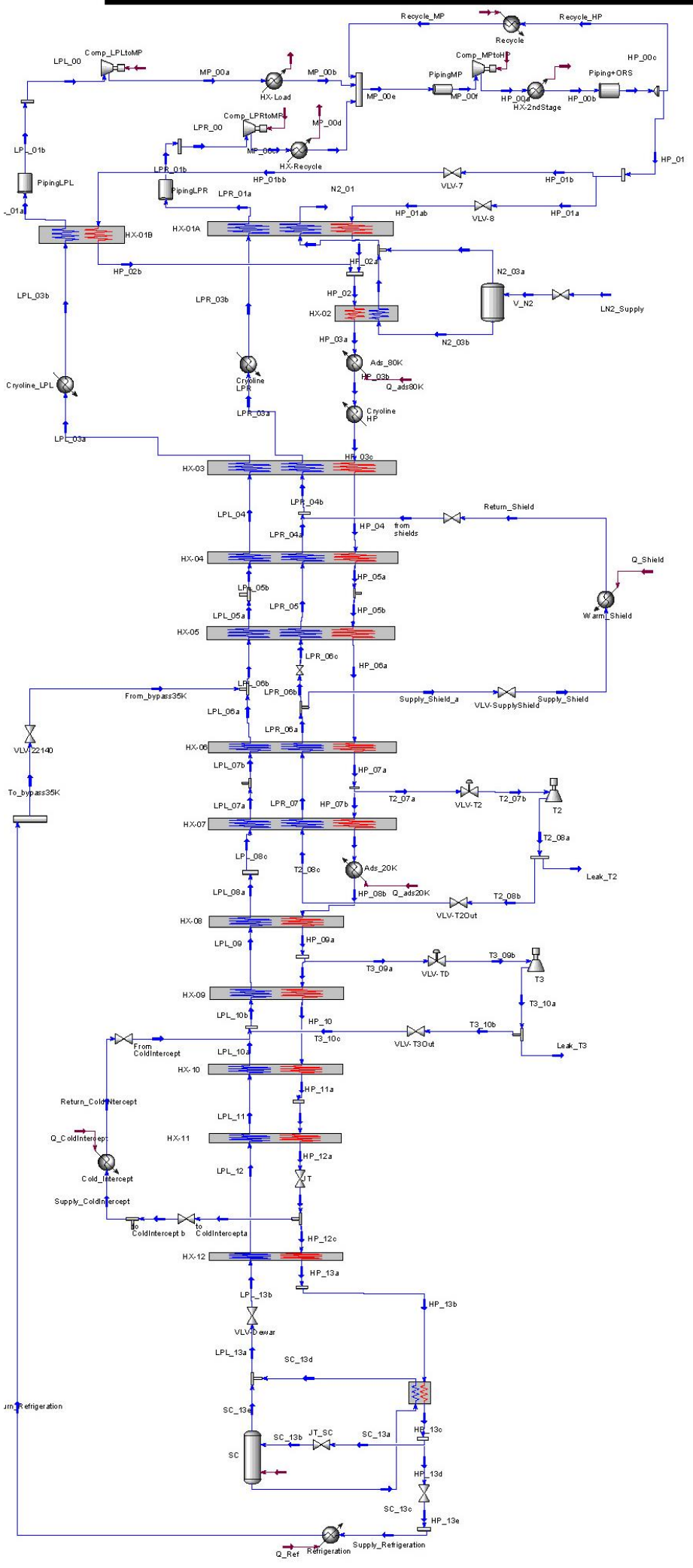
PFD n°1 : T1 off

PFD n°2 : T2 and T4 off

PFD n°3 : T3 off

A.1.1 TURBINE 1 OFF

Mode 6 : Standby T1 off, T2 and T3 on



Heat Loads						
		Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	11600	1095	670	0	0
Feed Temperature	K	55.85	5.68	4.55	4.55	4.55
Feed Pressure	atm	3.700	3.000	3.200	3.200	3.200
Product Temperature	K	75.85	7.50	4.47	300.00	30.00
Product Pressure	atm	2.700	1.230	1.250	1.100	1.120
Mass Flow	g/s	111.6	43.6	36.3	0.0	0.0

Warm Compression Station				
		Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)	ACT_m3/h	7012	4852	4942
Feed Pressure	atm	1.050	1.050	2.600
Feed Temperature	K	306.0	306.4	310.0
Product Pressure	atm	2.750	2.750	14.000
Mass Flow	g/s	325.9	225.2	561.1

Cryogenic Expanders			
		T2	T3
Power	kW	11.58	4.73
Feed Temperature	K	32.63	13.48
Feed Pressure	atm	13.203	8.053
Product Temperature	K	22.82	7.52
Product Pressure	atm	3.881	1.139
Mass Flow	g/s	225.5	187.9
Adiabatic Fluid Head	kJ/kg	66.7	33.8
Adiabatic Efficiency		77	75

Heat Exchange								
		HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06
UA (Calculated)	W/C	104976	135653	3419	83152	0	40990	36139
Minimum Approach	K	1.85	1.86	0.80	0.08	0.10	0.10	1.03
Heat Leak	W*	203	234	10	152	5	147	59
		HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC
UA (Calculated)	W/C	37966	3933	6868	581	508	984	1416
Minimum Approach	K	0.10	1.42	0.10	0.10	0.41	0.10	0.08
Heat Leak	W*	76	6	27	5	5	5	0

Streams HP													
		HP_13a	HP_13b	HP_13e	HP_12c	HP_12b	HP_11b	HP_10	HP_11a	HP_09b	HP_08b	HP_08a	HP_05b
Temperature	K	5.56	5.56	4.55	5.80	5.80	7.43	7.60	7.43	14.15	18.09	18.05	76.33
Pressure	atm	3.231	3.231	3.200	3.231	3.231	13.19	13.19	13.19	13.19	13.19	13.25	13.27
Mass Flow	g/s	84.9	84.9	36.3	84.9	128.5	128.5	128.5	128.5	128.5	316.4	316.4	542.0
		HP_03a	HP_00b	HP_07a	HP_02b	HP_01a	HP_01b	HP_01bb	HP_01ab	HP_02a	HP_13c	HP_03c	HP_07b
Temperature	K	79.75	310.00	32.63	81.63	310.03	310.03	310.03	310.03	81.63	4.55	79.82	32.63
Pressure	atm	13.46	14.00	13.26	13.46	13.50	13.50	13.48	13.48	13.46	3.231	13.29	13.26
Mass Flow	g/s	542.0	561.1	542.0	312.5	229.5	312.5	312.5	229.5	229.5	84.9	542.0	316.4
		HP_13d	HP_05a	HP_02	HP_00a	HP_03b	HP_12a	HP_04	HP_00c	HP_01	HP_06a	HP_09a	
Temperature	K	4.55	76.33	81.63	707.34	79.81	6.89	76.33	310.03	310.03	56.88	14.15	
Pressure	atm	3.231	13.27	13.46	14.00	13.30	13.19	13.27	13.50	13.50	13.27	13.19	
Mass Flow	g/s	36.3	542.0	542.0	561.1	542.0	128.5	542.0	561.1	542.0	542.0	316.4	

Streams LPR													
		LPR_07	LPR_06a	LPR_05	LPR_06c	LPR_03a	LPR_06b	LPR_04b	LPR_01b	LPR_01a	LPR_04a	LPR_03b	LPR_00
Temperature	K	29.25	55.85	76.23	55.93	79.74	55.85	76.08	306.4	306.4	76.23	79.78	306.4
Pressure	atm	3.858	3.850	1.148	1.148	1.136	3.850	1.148	1.050	1.100	1.148	1.129	1.050
Mass Flow	g/s	225.2	225.2	113.6	113.6	225.2	113.6	225.2	225.2	225.2	113.6	225.2	225.2

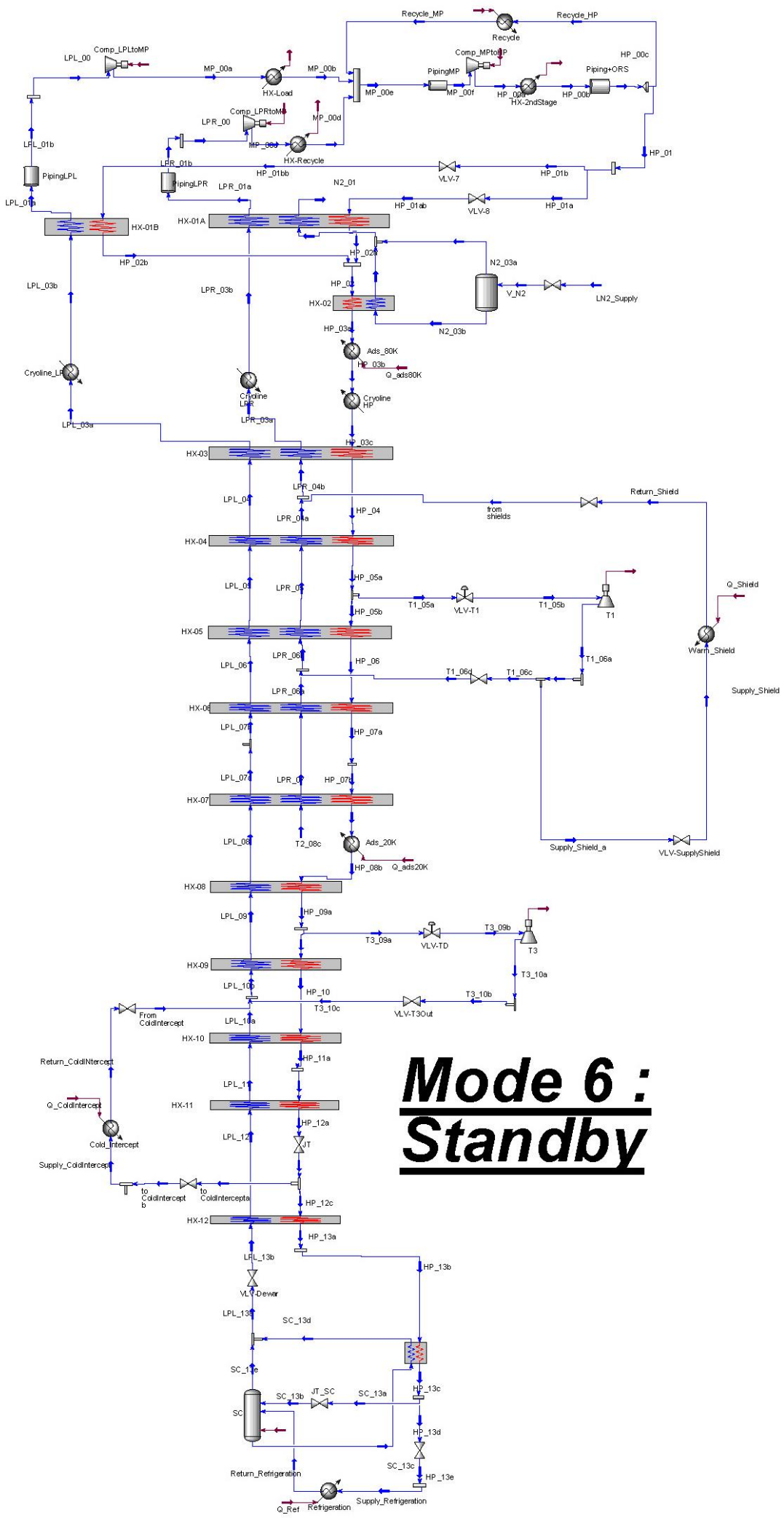
Streams MP							
		MP_00d	MP_00e	MP_00f	MP_00c	MP_00b	MP_00a
Temperature	K	310.0	310.0	310.0	498.3	310.0	497.8
Pressure	atm	2.750	2.750	2.600	2.750	2.750	2.750
Mass Flow	g/s	225.2	561.1	561.1	225.2	325.9	325.9

Streams LPL												
		LPL_13a	LPL_10b	LPL_09	LPL_08a	LPL_07a	LPL_07b	LPL_06a	LPL_05a	LPL_05b	LPL_08b	LPL_06b
Temperature	K	4.47	7.50	11.41	16.67	29.25	29.25	55.85	76.23	76.23	16.67	49.77
Pressure	atm	1.250	1.124	1.122	1.122	1.120	1.120	1.118	1.117	1.117	1.122	1.118
Mass Flow	g/s	48.6	279.6	279.6	279.6	279.6	279.6	279.6	315.9	315.9	0.0	315.9
		LPL_08c	LPL_03a	LPL_13b	LPL_01b	LPL_10a	LPL_11	LPL_12	LPL_01a	LPL_00	LPL_04	LPL_03b
Temperature	K	16.67	79.74	4.35	306.01	7.50	7.02	5.70	306.01	306.04	76.23	79.76
Pressure	atm	1.122	1.110	1.124	1.050	1.124	1.124	1.124	1.100	1.050	1.117	1.105
Mass Flow	g/s	279.6	315.9	48.6	315.9	48.6	48.6	48.6	315.9	325.9	315.9	315.9

Streams Subcooler							
		SC_13a	SC_13b	SC_13c	SC_13d	SC_13e	SC_13f
Vapour Fraction		0.0000	0.0335	0.0000	0.9980	1.0000	
Temperature	K	4.55	4.47	4.47	4.47	4.47	
Pressure	atm	3.231	1.250	1.250	1.250	1.250	
Mass Flow	g/s	48.6	48.6	36.5	36.5	12.1	

Streams Nitrogen								
		N2_02b	N2_02a	N2_03a	N2_03b	N2_01	N2_02c	LN2_Supply
Temperature	K	78.95	78.95	78.95	78.95	306.40	78.95	91.41
Pressure	atm	1.200	1.200	1.200	1.200	1.050	1.200	4.000
Mass Flow	g/s	27.1	4.2	31.4	27.1	31.4	31.4	31.4
Vapour Fraction		1.0000	1.0000	0.1341	0.0000	1.0000	1.0000	0.0000

A.1.2 TURBINE 2 AND TURBINE 4 OFF



Mode 6 : Standby

Heat Loads						
		Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	10100	900	500	0	0
Feed Temperature	K	34.80	5.52	4.55	4.55	4.55
Feed Pressure	atm	3.700	3.000	3.200	3.200	3.200
Product Temperature	K	55.00	7.50	4.47	300.00	30.00
Product Pressure	atm	2.700	1.230	1.250	1.100	1.220
Mass Flow	g/s	95.7	29.7	27.1	0.0	0.0

Warm Compression Station				
		Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)	ACT_m3/h	4784	3925	4030
Feed Pressure	atm	1.050	1.050	2.350
Feed Temperature	K	306.9	307.0	310.0
Product Pressure	atm	2.500	2.500	12.450
Mass Flow	g/s	221.7	181.8	413.5

Cryogenic Expanders					
		T1	T2	T3	T4
Power	kW	13.11	0.00	1.95	0.00
Feed Temperature	K	48.38	30.00	9.96	6.35
Feed Pressure	atm	11.667	3.939	5.129	11.605
Product Temperature	K	34.80	23.04	6.31	5.43
Product Pressure	atm	3.745	1.500	1.132	3.239
Mass Flow	g/s	182.1	0.0	144.9	0.0
Adiabatic Fluid Head	kJ/kg	93.5	50.1	19.5	6.9
Adiabatic Efficiency		77	72	69	70

Heat Exchange								
		HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06
UA (Calculated)	W/C	90216	102301	2055	66491	1675	15738	18940
Minimum Approach	K	1.96	1.96	0.80	0.73	2.77	0.10	0.10
Heat Leak	W*	203	234	10	152	5	147	59
		HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC
UA (Calculated)	W/C	29826	3248	2272	486	428	1100	24
Minimum Approach	K	0.26	1.70	0.10	0.10	0.24	0.10	0.08
Heat Leak	W*	76	6	27	5	5	5	0

Streams HP													
		HP_00a	HP_00b	HP_00c	HP_01	HP_01a	HP_01b	HP_01bb	HP_01ab	HP_02	HP_02a	HP_02b	HP_03a
Temperature	K	702.08	310.00	310.03	310.03	310.03	310.03	310.03	310.03	81.12	81.12	81.12	79.75
Pressure	atm	12.45	12.45	11.95	11.95	11.95	11.95	11.93	11.93	11.91	11.91	11.91	11.91
Mass Flow	g/s	413.5	413.5	413.5	394.8	184.0	210.8	210.8	184.0	394.8	184.0	210.8	394.8
		HP_03b	HP_03c	HP_04	HP_05a	HP_05b	HP_06	HP_07a	HP_08a	HP_07b	HP_08b	HP_09a	HP_09b
Temperature	K	79.83	79.84	50.94	48.37	48.37	34.86	32.04	16.21	32.04	16.27	11.25	11.25
Pressure	atm	11.76	11.75	11.74	11.74	11.74	11.73	11.73	11.73	11.73	11.67	11.67	11.67
Mass Flow	g/s	394.8	394.8	394.8	394.8	212.7	212.7	212.7	212.7	212.7	212.7	212.7	67.8
		HP_10	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13d	HP_13e		
Temperature	K	6.59	6.35	6.35	5.89	5.59	5.59	4.56	4.56	4.55	4.55		
Pressure	atm	11.67	11.67	11.67	11.67	3.231	3.231	3.231	3.231	3.231	3.200		
Mass Flow	g/s	67.8	67.8	67.8	67.8	67.8	38.1	38.1	38.1	27.1	27.1		

Streams LPR												
		LPR_00	LPR_01a	LPR_01b	LPR_03b	LPR_03a	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_06b	LPR_07
Temperature	K	307.0	307.0	307.0	79.16	79.11	48.17	51.79	44.72	34.76	34.77	31.77
Pressure	atm	1.050	1.100	1.050	1.129	1.136	1.143	1.143	1.143	1.146	1.146	1.146
Mass Flow	g/s	181.8	181.8	181.8	181.8	181.8	86.13	181.8	86.13	1.000e-006	86.13	1.000e-006

Streams MP					
		MP_00b	MP_00d	MP_00e	MP_00f
Temperature	K	310.0	310.0	310.0	310.0
Pressure	atm	2.500	2.500	2.500	2.350
Mass Flow	g/s	221.7	181.8	413.5	413.5

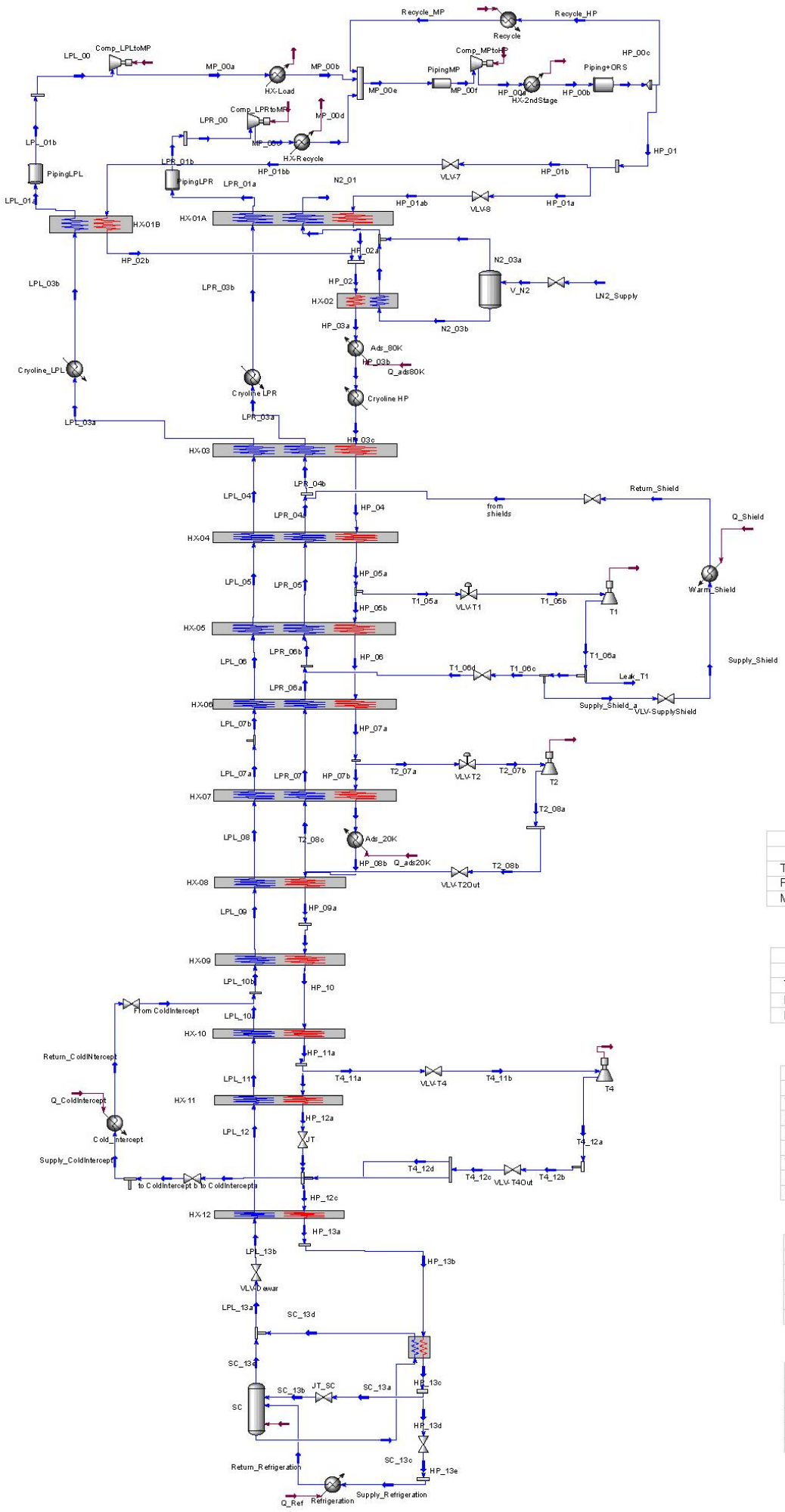
Streams LPL										
		LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a
Temperature	K	306.89	306.88	306.88	79.11	79.16	48.17	44.72	34.76	31.77
Pressure	atm	1.050	1.100	1.050	1.110	1.105	1.112	1.112	1.114	1.115
Mass Flow	g/s	221.7	212.2	212.2	212.2	212.2	212.2	212.2	212.2	212.2
		LPL_07b	LPL_08	LPL_09	LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a	LPL_13b
Temperature	K	31.77	14.57	8.39	6.49	6.49	6.11	5.49	4.47	4.34
Pressure	atm	1.115	1.117	1.117	1.117	1.117	1.117	1.117	1.250	1.117
Mass Flow	g/s	212.2	212.2	212.2	38.1	212.2	38.1	38.1	38.1	38.1

Streams Subcooler						
		SC_13a	SC_13b	SC_13c	SC_13d	SC_13e
Vapour Fraction		0.0000	0.0334	0.0000	0.9980	1.0000
Temperature	K	4.55	4.47	4.47	4.47	4.47
Pressure	atm	3.231	1.250	1.250	1.250	1.250
Mass Flow	g/s	11.0	11.0	0.1	0.1	38.0

Streams Nitrogen								
		N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b	LN2_Supply
Temperature	K	306.97	78.95	78.95	78.95	78.95	78.95	91.41
Pressure	atm	1.050	1.200	1.200	1.200	1.200	1.200	4.000
Mass Flow	g/s	16.7	2.2	14.5	16.7	16.7	14.5	16.7
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.1341	0.0000	0.0000

A.1.3 TURBINE 3 OFF

Mode 6 : Standby
T3 off, T1, T2 and T4 on



Heat Loads						
		Warm_Shield	Cold_Intercept	Refrigeration	Liquefaction	Sub_atm
DUTY	W*	10100	900	500	0	0
Feed Temperature	K	35.01	6.20	4.55	4.55	4.55
Feed Pressure	atm	3.700	3.000	3.200	3.200	3.200
Product Temperature	K	55.00	7.50	4.47	300.00	30.00
Product Pressure	atm	2.700	1.230	1.250	1.100	1.220
Mass Flow	g/s	96.7	55.2	27.1	0.0	0.0

Warm Compression Station				
		Comp_LPLtoMP	Comp_LPRtoMP	Comp_MPtoHP
Capacity (act feed vol flow)	ACT_m3/h	3327	5444	4058
Feed Pressure	atm	1.050	1.050	2.350
Feed Temperature	K	307.6	306.6	310.0
Product Pressure	atm	2.500	2.500	12.320
Mass Flow	g/s	153.8	252.6	416.4

Cryogenic Expanders					
		T1	T2	T3	T4
Power	kW	12.86	1.81	0.00	0.58
Feed Temperature	K	48.51	19.95	9.96	7.99
Feed Pressure	atm	11.524	3.308	5.132	6.685
Product Temperature	K	35.01	15.09	6.31	6.33
Product Pressure	atm	3.745	1.165	1.132	3.239
Mass Flow	g/s	179.6	73.6	0.0	140.3
Adiabatic Fluid Head	kJ/kg	93.0	35.1	19.5	6.4
Adiabatic Efficiency		77	70	69	64

Heat Exchange								
		HX-01A	HX-01B	HX-02	HX-03	HX-04	HX-05	HX-06
UA (Calculated)	W/C	113418	76294	2188	66779	1658	19391	19685
Minimum Approach	K	2.10	2.04	0.80	0.70	2.79	0.10	0.47
Heat Leak	W*	203	234	10	152	5	147	59
		HX-07	HX-08	HX-09	HX-10	HX-11	HX-12	HX-SC
UA (Calculated)	W/C	10095	0	10021	1976	0	1691	1550
Minimum Approach	K	0.10	0.10	0.10	0.24	2.16	0.23	0.08
Heat Leak	W*	76	6	27	5	5	5	0

Streams HP													
		HP_00a	HP_00b	HP_00c	HP_01	HP_01a	HP_01b	HP_01bb	HP_01ab	HP_02	HP_02a	HP_02b	HP_03a
Temperature	K	698.70	310.00	310.03	310.03	310.03	310.03	310.03	310.03	81.27	81.27	81.27	79.75
Pressure	atm	12.32	12.32	11.82	11.82	11.82	11.82	11.80	11.80	11.78	11.78	11.78	11.78
Mass Flow	g/s	416.4	416.4	416.4	393.5	254.5	139.0	139.0	254.5	393.5	254.5	139.0	393.5
		HP_03b	HP_03c	HP_04	HP_05a	HP_05b	HP_06	HP_07a	HP_08a	HP_07b	HP_08b	HP_09a	HP_09b
Temperature	K	79.83	79.84	51.09	48.51	48.51	33.62	20.64	15.31	20.64	15.40	15.40	15.40
Pressure	atm	11.63	11.62	11.61	11.61	11.61	11.61	11.61	11.61	11.61	11.55	11.55	11.55
Mass Flow	g/s	393.5	393.5	393.5	393.5	213.9	213.9	213.9	140.3	140.3	140.3	140.3	140.3
		HP_10	HP_11a	HP_11b	HP_12a	HP_12b	HP_12c	HP_13a	HP_13b	HP_13d	HP_13e		
Temperature	K	10.65	8.79	8.79	8.26	6.33	6.33	5.65	5.65	4.55	4.55		
Pressure	atm	11.54	11.54	11.54	11.54	3.231	3.231	3.231	3.231	3.231	3.200		
Mass Flow	g/s	140.3	140.3	0.0	0.0	0.0	84.2	84.2	84.2	27.1	27.1		

Streams LPR												
		LPR_00	LPR_01a	LPR_01b	LPR_03b	LPR_03a	LPR_04a	LPR_04b	LPR_05	LPR_06a	LPR_06b	LPR_07
Temperature	K	306.6	306.6	306.6	79.17	79.14	48.29	50.88	44.80	33.15	34.12	19.28
Pressure	atm	1.050	1.100	1.050	1.129	1.136	1.136	1.136	1.136	1.145	1.145	1.154
Mass Flow	g/s	252.6	252.6	252.6	252.6	252.6	155.8	252.6	155.8	73.22	155.8	73.22

Streams MP					
		MP_00b	MP_00d	MP_00e	MP_00f
Temperature	K	310.0	310.0	310.0	310.0
Pressure	atm	2.500	2.500	2.500	2.350
Mass Flow	g/s	153.8	252.6	416.4	416.4

Streams LPL										
		LPL_00	LPL_01a	LPL_01b	LPL_03a	LPL_03b	LPL_04	LPL_05	LPL_06	LPL_07a
Temperature	K	307.59	307.65	307.66	79.14	79.20	48.29	44.80	33.15	19.28
Pressure	atm	1.050	1.100	1.050	1.110	1.105	1.110	1.110	1.111	1.112
Mass Flow	g/s	153.8	139.5	139.5	139.5	139.5	139.5	139.5	139.5	139.5
		LPL_07b	LPL_08	LPL_09	LPL_10a	LPL_10b	LPL_11	LPL_12	LPL_13a	LPL_13b
Temperature	K	19.28	15.30	15.30	10.41	9.22	6.10	6.10	4.47	4.34
Pressure	atm	1.112	1.113	1.115	1.115	1.115	1.115	1.115	1.250	1.115
Mass Flow	g/s	139.5	139.5	139.5	84.2	139.5	84.2	84.2	84.2	84.2

Streams Subcooler						
		SC_13a	SC_13b	SC_13c	SC_13d	SC_13e
Vapour Fraction		0.0000	0.0335	0.0000	0.9980	1.0000
Temperature	K	4.55	4.47	4.47	4.47	4.47
Pressure	atm	3.231	1.250	1.250	1.250	1.250
Mass Flow	g/s	57.1	57.1	44.7	44.7	39.5

Streams Nitrogen								
		N2_01	N2_02a	N2_02b	N2_02c	N2_03a	N2_03b	LN2_Supply
Temperature	K	306.57	78.95	78.95	78.95	78.95	78.95	91.41
Pressure	atm	1.050	1.200	1.200	1.200	1.200	1.200	4.000
Mass Flow	g/s	18.5	2.5	16.0	18.5	18.5	16.0	18.5
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.1341	0.0000	0.0000

ANNEX 2 : FMEA OTHER EQUIPMENTS

A.2.1 HEAT EXCHANGERS

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
1	**Heat Exchanger**							
	LN2/LPR/HP Heat Exchanger	HX-1A	4	Fails: Rupture of Heat Exchanger	Leak in the Vacuum Enclosure Loss of Helium inventory Loss of Performance	Safe	Vacuum pressure in the CB enclosure is monitored by the Control System	Vacuum Enclosure is protected by a 7 psig relief pressure device
			2	Clogged/Blocked Heat Exchanger	Increased pressure drop in the process line (Water, Oil): Loss of Performance Isolation of a volume: Pressure increase	Safe	HP Stream pressure difference is monitored by the control system. Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	HP pressure drop alarm: PT22402 - PT22413 > 0.3 atm: HX-1A HP pressure drop High Pressure upstream HX-1A is controlled by the compressors (no increase if HX-1A clogged) GN2 upstream volume protected against overpressure by PSV-22510
	LPL/HP Heat Exchanger	HX-1B	4	Fails: Rupture of Heat Exchanger	Leak in the Vacuum Enclosure Loss of Helium inventory Loss of Performance	Safe	Vacuum pressure in the CB enclosure is monitored by the Control System	Vacuum Enclosure is protected by a 7 psig relief pressure device
			2	Clogged/Blocked Heat Exchanger	Increased pressure drop in the process line (Water, Oil): Loss of Performance Isolation of a volume: Pressure increase	Safe	HP Stream pressure differences is monitored by the control system. Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	HP pressure drop alarms: PT22401 - PT22413 > 0.3 atm: HX-1B HP pressure drop High Pressure upstream HX-1B is controlled by the compressors (no increase if HX-1B clogged)
	LN2 Heat Exchanger	HX2	4	Fails: Rupture of Heat Exchanger	Leak in the LN2phase separator Loss of Helium inventory Loss of Performance	Safe	Pressure in HP stream and in LN2 phase separator is monitored by the Control System	LN2 phase separator is protected by a PSV. LN2 supply is interlocked if pressure PT-22510 > 5 atm.
			2	Clogged/Blocked Heat Exchanger	Increased pressure drop in the process line (Water, Oil): Loss of Performance Isolation of a volume: Pressure increase	Safe	If LN2 streams clogged, HX2 temperature outlet (80K adsorber inlet) is monitored by the control system. Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	LN2 stream clogged (Increase of HP outlet temperature): Interlock PV-22421 open if: TP-22415B > 100K AND PV-22415B and PV-22420B open at 100% TP-22415A > 100K AND PV-22415A and PV-22420A open at 100% Pressure upstream HX-2 is controlled by the compressors (no increase if Hx-2 clogged)
	LPL/LPR/HP Heat Exchanger	HX-3-4	4	Fails: Rupture of Heat Exchanger	Leak in the Vacuum Enclosure Loss of Helium inventory Loss of Performance	Safe	Vacuum pressure in the CB enclosure is monitored by the Control System	Vacuum Enclosure is protected by a 7 psig relief pressure device
			2	Clogged Heat Exchanger (no complete blocking shall be envisaged at this stage)	Increased pressure drop in the process line (Water, Oil): Loss of Performance	Safe	Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	
	LPL/LPR/HP Heat Exchanger	HX-5	4	Fails: Rupture of Heat Exchanger	Leak in the Vacuum Enclosure Loss of Helium inventory Loss of Performance	Safe	Vacuum pressure in the CB enclosure is monitored by the Control System	Vacuum Enclosure is protected by a 7 psig relief pressure device
			2	Clogged Heat Exchanger (no complete blocking shall be envisaged at this stage)	Increased pressure drop in the process line (Air): Loss of Performance	Safe	Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	
	LPL/LPR/HP Heat Exchanger	HX-6-7	4	Fails: Rupture of Heat Exchanger	Leak in the Vacuum Enclosure Loss of Helium inventory Loss of Performance	Safe	Vacuum pressure in the CB enclosure is monitored by the Control System	Vacuum Enclosure is protected by a 7 psig relief pressure device
			2	Clogged Heat Exchanger (no complete blocking shall be envisaged at this stage)	Increased pressure drop in the process line (Air): Loss of Performance	Safe	Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	LPL/HP Heat Exchanger	HX-8-12	4	Fails: Rupture of Heat Exchanger	Leak in the Vacuum Enclosure Loss of Helium inventory Loss of Performance	Safe	Vacuum pressure in the CB enclosure is monitored by the Control System	Vacuum Enclosure is protected by a 7 psig relief pressure device
			2	Clogged Heat Exchanger (no complete blocking shall be envisaged at this stage)	Increased pressure drop in the process line (Air): Loss of Performance	Safe	Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	
	Subcooler Heat Exchanger	HX-SC	4	Fails: Rupture of Heat Exchanger	Leak in the LHe phase separator Loss of Performance	Safe	Pressure in HP stream and in LHe phase separator is monitored by the Control System	LHe phase separator is protected by a PSV. LHe phase separator Heaters as well as LHe supply valve are interlocked closed if pressure PT-22195 >1.5 atm.
			2	Clogged Heat Exchanger (no complete blocking shall be envisaged at this stage)	Increased pressure drop in the process line (Air): Loss of Performance	Safe	Progressive increasing of pressure difference to be monitored by operators for maintenance plan.	

A.2.2 CONTROL VALVES

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
2	**Control Valves**							
	HX-1B HP inlet valve	PV-22400	2	Shut down	Loss of performance and subcooling of LPL outlet line	Safe	Valve position is defined by the 4.5K CB PLC logic.	TP-22101 low alarms and interlocks. Alarm "HX-1B HP pressure drop High" will indicate a too high pressure drop and drive operator to investigate.
			2	Blocked Open	Loss of performance and increase of LN2 consumption if too much flow through HX-1B	Safe	Valve position is defined by the 4.5K CB PLC logic.	TP-22505 low alarms and message: "GN2 outlet temperature Low." TP-22201 low alarms and message: "LPR outlet temperature Low." TP-22411 high alarm, message "HX-1B HP Temperature High"
	HX-1A HP inlet valve	PV-22402	2	Shut down	Loss of performance and subcooling of LPR and N2 outlet lines	Safe	Valve position is defined by the 4.5K CB PLC logic.	TP-22201 low alarms and interlocks. Alarm "HX-1B HP pressure drop High" will indicate a too high pressure drop and drive operator to investigate.
			2	Blocked Open	Loss of performance and increase of LN2 consumption if too much flow through HX-1A	Safe	Valve position is defined by the 4.5K CB PLC logic.	TP-22101 low alarms and message: "LPL outlet temperature Low." TP-22412 high alarm, message "HX-1A HP Temperature High"
	Bearing Gas Tank Supply Valve	PV-22405	2	Shut down	Loss of pressure in Turbines bearings	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbines are self-protected
			1	Blocked Open	Unnecessary increase of Helium HP flow consumption	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	Cooldown valve - 300K stage	PV-22110	2	Shut down	Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190
			2	Blocked Open	Loss of performance due to unrecovered cold flow from 2K Cold Box	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	Cooldown valve - 80K stage	PV-22115	2	Shut down	Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190. TD-22190 will enventually warm-up (no flow) which will open PV-22110
			2	Blocked Open	Loss of performance due to cold flow from 2K CB recovered at wrong temperature level. Subcooling of HX-1B	Safe	Valve position is defined by the 4.5K CB PLC logic.	TP-22411 - TP-22111 > 35K: Alarm message and Interlock Cool Down Line control (Will close open valves and open PV-22110)
	80K adsorber A inlet valve	PV-22415A	2	Shut down	Isolate Adsorber and block HP Line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Detection of Hign pressure drop across the Adsorber will occure: PDT-22414 > 2 bar will Interlock PV-22421 opened at 100%
			1	Blocked Open	Pressure will not decrease during Adsorber regeneration by Operator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Adsorber regeneration procedure for Operator
	80K adsorber B inlet valve	PV-22415B	2	Shut down	Isolate Adsorber and block HP Line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Detection of Hign pressure drop across the Adsorber will occure: PDT-22414 > 2 bar will Interlock PV-22421 opened at 100%
			1	Blocked Open	Pressure will not decrease during Adsorber regeneration by Operator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Adsorber regeneration procedure for Operator
	80K adsorber A outlet valve	PV-22420A	2	Shut down	Isolate Adsorber and block HP Line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Detection of Hign pressure drop across the Adsorber will occure: PDT-22414 > 2 bar will Interlock PV-22421 opened at 100%
			1	Blocked Open	Pressure will not decrease during Adsorber regeneration by Operator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Adsorber regeneration procedure for Operator
	80K adsorber B outlet valve	PV-22420B	2	Shut down	Isolate Adsorber and block HP Line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Detection of Hign pressure drop across the Adsorber will occure: PDT-22414 > 2 bar will Interlock PV-22421 opened at 100%
			1	Blocked Open	Pressure will not decrease during Adsorber regeneration by Operator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Adsorber regeneration procedure for Operator

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	80K adsorbers bypass valve	PV-22421	2	Shut down	Loss of pressure in downstream HP Line (if both adsorbers are closed)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
			2	Blocked Open	Air in Helium my by-pass the 80K adsorbers and freeze in Turbines	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbines protected against pressure drop increase in the distributor (where air may freeze), via wheel pressure information
	LN2 supply valve	PV-22520	2	Shut down	Loss of performance (LN2 level decrease)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
			2	Blocked Open	Over-filling of LN2 in LN2 phase separator	Safe	Valve position is defined by the 4.5K CB PLC logic.	High alarm if LT-22510 > 90% and message "LN2 Level High"
	CD VALVE - 60K STAGE	PV-22135	2	Shut down	Loss of performance if 2K CB return flow at 60K. Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190. TD-22190 will enventually warm-up (no flow) which will open PV-22115
			2	Blocked Open	Loss of performance due to cold flow from 2K CB recovered at wrong temperature level. Subcooling of HX-4. Turbine 1 inlet Temperature will decrease	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	CD VALVE / SUB-ATMO - 35K STAGE	PV-22140	2	Shut down	Loss of performance if 2K CB return flow at 35K. Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190. TD-22190 will enventually warm-up (no flow) which will open PV-22135
			1	Blocked Open	No major impact on the performance since normal return temperature should be 30K	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	CD VALVE / SUB-ATMO - 30K STAGE	PV-22150	2	Shut down	Loss of performance if 2K CB return flow at 30K. Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190. TD-22190 will enventually warm-up (no flow) which will open PV-22140
			1	Blocked Open	No impact on the performance since normal return temperature should be 30K	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	CD VALVE - 18K STAGE	PV-22160	2	Shut down	Loss of performance if 2K CB return flow at 18K. Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190. TD-22190 will enventually warm-up (no flow) which will open PV-22150
			2	Blocked Open	Loss of performance since it will warm-up HX-7 if Cold box return Temperature is >20K	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	CD VALVE - 7.5K STAGE	PV-22180	2	Shut down	Loss of performance if 2K CB return flow at 7.5K. Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190. TD-22190 will enventually warm-up (no flow) which will open PV-22160
			2	Blocked Open	Loss of performance since it will warm-up HX-9 if Cold box return Temperature is >10K	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	CD VALVE - 5K STAGE	PV-22190	2	Shut down	Loss of performance if 2K CB return flow at 5K. Increase pressure in Cool down line	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22190. TD-22190 will enventually warm-up (no flow) which will open PV-22190
			2	Blocked Open	Loss of performance since it will warm-up HX12 if Cold box return Temperature is >5K	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	COLD INTERCEPT RETURN VALVE	PV-22191	2	Shut down	Isolation of cold intercept and pressure rise	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22191
			1	Blocked Open	Normal state for the valve, no issue in Normal operation.	Safe	Valve position is defined by the 4.5K CB PLC logic.	-

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	COLD INTERCEPT COOL DOWN VALVE	PV-22192	2	Shut down	Isolation of cold intercept and pressure rise (during intercept cool down only)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22191
			1	Blocked Open	Loss of performance sinc part of the 6K flow from Cold shields will be lost in Cool down line (Although Cool down line temperature TD-22190 will decrease and adjust returning valves opening)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	LHE SUBCOOLER RETURN VALVE	PV-22193	2	Shut down	Loss of performance, Isolation of subcooler and pressure rise	Safe	Valve position is defined by the 4.5K CB PLC logic.	Subcooler protected by PSV-22195
			1	Blocked Open	Normal state for the valve, no issue in Normal operation.	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	DEWAR VAPOR RETURN VALVE	PV-22194	2	Shut down	Isolation of dewar pressure return line (pressure rise in the dewar)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Dewar pressure return line protected by PSV-22194
			2	Blocked Open	Pressure decrease in Dewar, no transfer of Lhe from Dewar to LHe phase separator (Level decrease in phase separator) which may result in Temperature increase at 4.5K supply interface	Safe	Valve position is defined by the 4.5K CB PLC logic.	TD-22390 High alarm and message: "Temperature to 4.5K Supply High"
	LHE FROM DEWAR	PV-22195	2	Shut down	LHe level decrease in subcooler, potential temperature increase at 4K supply	Safe	Valve position is defined by the 4.5K CB PLC logic.	Alarm message if TD-22390 >6K and CB in nominal operation
			2	Blocked Open	Liquid level increase in LHe phase separator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Sub-cooler Heaters will control the level in the LHe phase separator. LT-22195 > 90% : High alarm and message: "Level in LHe subcooler High" LT-22195 > 95% : Interlock PV-22390 closed
	WARM SHIELDS CD VALVE	PV-22220	2	Shut down	Isolation of warm shields and pressure rise (during shields cool down only)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22248
			2	Blocked Open	Increase pressure in Cool down line and possible returned temperature at wrong temperature level	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	WARM SHIELDS RETURN AT 80K	PV-22225	2	Shut down	Isolation of warm shields and pressure rise (during shields cool down only)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22248
			1	Blocked Open	Low impact since only HX-3 is by passed (no major process difference)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	TURBINE 1 OUTLET VALVE (SHIELDS)	PV-22242	2	Shut down	Isolation of Turbine 1 discharge line, pressure increase downstram Turbine 1	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 1 trip if PT-22332 too high
			2	Blocked Open	Decreased flow in Warm Shields	Safe	Valve position is defined by the 4.5K CB PLC logic.	ZSH-22242 actif when Valve position <100% = Alarm on information discrepency
	WARM SHIELDS SUPPLY VALVE (FROM T1)	PV-22245	2	Shut down	Stop warm shields supply from T1	Safe	Valve position is defined by the 4.5K CB PLC logic.	Pressure difference in shields will tend to decrease (No Flow), DPIC-22240 will force flow from Tubine 2 by closing PV-22246
			1	Blocked Open	Normal state for this valve	Safe	Valve position is defined by the 4.5K CB PLC logic.	ZSH-22245 actif when Valve position <100% = Alarm on information discrepency

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	TURBINE 2 OUTLET VALVE (SHIELDS)	PV-22246	2	Shut down	Limit flow in Turbine 2 discharge line, pressure increase downstram Turbine 2	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 2 trip if PT-22352 too high
			1	Blocked Open	Decreased flow in Warm Shields if flow from Turbine 2 is required (not identified in process cases)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	WARM SHIELDS SUPPLY VALVE (FROM T2)	PV-22248	2	Shut down	Stop warm shields supply from T2 (but still supplied by T1 line) Potential pressure increase downstream T2	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 2 trip if PT-22352 too high
			2	Blocked Open	Normal state for this valve	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	WARM SHIELDS RETURN VALVE	PV-22249	2	Shut down	Isolation of warm shields and pressure rise	Safe	Valve position is defined by the 4.5K CB PLC logic.	Line protected by PSV-22248
			1	Blocked Open	Normal state for this valve	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	TURBINE 2 OUTLET VALVE	PV-22358	2	Shut down	Pressure increase downstram Turbine 2	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 2 trip if PT-22352 too high
			1	Blocked Open	Normal state for this valve	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	TURBINE 3 OUTLET VALVE	PV-22378	2	Shut down	Pressure increase downstram Turbine 3	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 3 trip if PT-22372 too high
			1	Blocked Open	Normal state for this valve	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	TURBINE 4 OUTLET VALVE	PV-22388	2	Shut down	Pressure increase downstram Turbine 4	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if PT-22382 too high
			1	Blocked Open	Normal state for this valve	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	COLD END BYPASS VALVE	PV-22389	1	Shut down	Limit flow during cool down	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
			2	Blocked Open	Decrease pressure downstream Turbine 4	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if PT-22382 too Low
	JT VALVE (SC SUPPLY)	PV-22390	2	Shut down	Pressure increase downstream Turbine 4	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if PT-22382 too high
			2	Blocked Open	Decrease pressure downstream Turbine 4. Level increase in the LHe phase separator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if PT-22382 too Low LT-22195A High alarm and message: "Level in LHe subcooler High"
	4.5K LOADS SUPPLY VALVE	PV-22391	1	Shut down	No flow to 4.5K suplly line	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
			1	Blocked Open	Normal state for this valve	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	COLD INTERCEPT SUPPLY VALVE	PV-22392	1	Shut down	No flow to Cold intercepts	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
			1	Blocked Open	Too much flow in the Cold intercepts (if not regulated on Cold intercepts side by JLAB)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	DEWAR SUPPLY VALVE	PV-22393	2	Shut down	Pressure increase downstream Turbine 4	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if PT-22382 too high
			2	Blocked Open	Decrease pressure downstream Turbine 4.	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	TURBINE 1 INLET VALVE	PV-22432	2	Shut down	No flow in Turbine 1, Loss of performance	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 1 trip if ST-22432 too low
			2	Blocked Open	No speed control on Turbine 1, risk of Turbine failure (if overspeed)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 1 trip if ST-22432 too High, but the valve will not close so this will not stop the Turbine (failure risk)

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	WARM SHIELDS SUPPLY (T1 BYPASS)	PV-22441	2	Shut down	No flow in Warm shields (only during cool down or if Turbine 1 stopped)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
			2	Blocked Open	Warm temperature sent in Warm Shields which may decrease the thermal performance of Customers cavities	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
	TURBINE 2 INLET VALVE	PV-22452	2	Shut down	No flow in Turbine 2, Loss of performance	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 2 trip if ST-22452 too low
			2	Blocked Open	No speed control on Turbine 2, risk of Turbine failure (if overspeed)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 2 trip if ST-22452 too High, but the valve will not close so this will not stop the Turbine (failure risk)
	20K ADSORBER BYPASS VALVE	PV-22460	2	Shut down	Loss of pressure in downstream HP Line (if 20K adsorber closed)	Safe	Valve position is defined by the 4.5K CB PLC logic.	-
			2	Blocked Open	Flow will by-pass 20K adsorber, resulting in some impurities not being trapped in adsorber but in Turbine 3 or Turbine 4	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbines protected against pressure drop increase in the distributor (where air may freeze), via wheel pressure information
	20K ADSORBER INLET VALVE	PV-22461	2	Shut down	Isolation of HP Line (No flow).	Safe	Valve position is defined by the 4.5K CB PLC logic.	Interlock will force PV-22460 opened at 100% (based on pressure difference across 20K Adsorber)
			1	Blocked Open	Pressure will not decrease during Adsorber regeneration by Operator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Adsorber regeneration procedure for Operator
	20K ADSORBER OUTLET VALVE	PV-22466	2	Shut down	Isolation of HP Line (No flow).	Safe	Valve position is defined by the 4.5K CB PLC logic.	Interlock will force PV-22460 opened at 100% (based on pressure difference across 20K Adsorber)
			1	Blocked Open	Pressure will not decrease during Adsorber regeneration by Operator	Safe	Valve position is defined by the 4.5K CB PLC logic.	Adsorber regeneration procedure for Operator
	TURBINE 3 INLET VALVE	PV-22472	2	Shut down	No flow in Turbine 3, Loss of performance	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 3 trip if ST-22472 too low
			2	Blocked Open	No speed control on Turbine 3, risk of Turbine failure (if overspeed)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 3 trip if ST-22472 too High, but the valve will not close so this will not stop the Turbine (failure risk)
	TURBINE 4 INLET VALVE	PV-22482	2	Shut down	No flow in Turbine 4, Loss of performance	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if ST-22482 too low
			2	Blocked Open	No speed control on Turbine 4, risk of Turbine failure (if overspeed)	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if ST-22482 too High, but the valve will not close so this will not stop the Turbine (failure risk)
	TURBINE 4 BYPASS VALVE	PV-22485	2	Shut down	Limit flow during cool down	Safe	Valve position is defined by the 4.5K CB PLC logic.	
			2	Blocked Open	Pressure increase downstream Turbine 4	Safe	Valve position is defined by the 4.5K CB PLC logic.	Turbine 4 trip if ST-22482 too High, but the valve will not close so this will not stop the Turbine (failure risk)

A.2.3 HEATERS

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
3	**Heaters**							
	80K Adsorber A regeneration heater	EH-22418A-A	1	No Heating	No warm-up possible during 80K Adsorber A regeneration operation	Safe	Heater power is defined by the 4.5K CB PLC logic.	Operator can swith to the redundant Heater
	80K Adsorber A regeneration heater	EH-22418A-B	1	No Heating	Not connected in baseline conditions	Safe	Heater power is defined by the 4.5K CB PLC logic.	
	80K Adsorber B regeneration heater	EH-22418B-A	1	No Heating	No warm-up possible during 80K Adsorber B regeneration operation	Safe	Heater power is defined by the 4.5K CB PLC logic.	Operator can swith to the redundant Heater
	80K Adsorber B regeneration heater	EH-22418B-B	1	No Heating	Not connected in baseline conditions	Safe	Heater power is defined by the 4.5K CB PLC logic.	
	LHe Subcooler Heater A	EH-22195A	1	No Heating	Decreased power capacity in LHe Subcooler	Safe	Heater power is defined by the 4.5K CB PLC logic.	Heaters B and C are sufficient to operate the Cold Box
	LHe Subcooler Heater B	EH-22195B	1	No Heating	Decreased power capacity in LHe Subcooler	Safe	Heater power is defined by the 4.5K CB PLC logic.	Heaters A and C are sufficient to operate the Cold Box
	LHe Subcooler Heater C	EH-22195C	1	No Heating	Decreased power capacity in LHe Subcooler	Safe	Heater power is defined by the 4.5K CB PLC logic.	Heaters A and B are sufficient to operate the Cold Box
	LHe Subcooler Heater D	EH-22195D	1	No Heating	Not connected in baseline conditions	Safe	Heater power is defined by the 4.5K CB PLC logic.	
	20K Adsorber regeneration heater	EH-22465A	1	No Heating	No warm-up possible during 20K Adsorber regeneration operation	Safe	Heater power is defined by the 4.5K CB PLC logic.	Operator can swith to the redundant Heater
	20K Adsorber regeneration heater	EH-22465B	1	No Heating	Not connected in baseline conditions	Safe	Heater power is defined by the 4.5K CB PLC logic.	

A.2.4 PRESSURE TRANSDUCERS

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
4	**Pressure Transducers**							
	COMPRESSOR SIDE LPL PRESSURE	PT-22100	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1B LPL OUTLET PRESSURE	PT-22101	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1B LPL INLET PRESSURE	PT-22111	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	COMPRESSOR SIDE LPR PRESSURE	PT-22200	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1A LPR OUTLET PRESSURE	PT-22201	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1A LPR INLET PRESSURE	PT-22211	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HP WARM INLET PRESSURE	PT-22400	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1B HP INLET PRESSURE	PT-22401	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1A HP INLET PRESSURE	PT-22402	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1A HP OUTLET PRESSURE	PT-22413	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADSORBERS UPSTREAM PRESSURE	PT-22415	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADSORBER A PRESSURE	PT-22417A	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADSORBER B PRESSURE	PT-22417B	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADS OUTLET PRESSURE	PT-22422	1	Fails High / Low	Misleading alarm	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1AGN2 OUTLET PRESSURE	PT-22505	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	LN2 PHASE SEPARATOR PRESSURE	PT-22510	2	Fails High	Interlock will close PV-22520 (No LN2 supply) Loss of performance	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
			1	Fails Low	None	Safe		
	LN2 INLET PRESSURE	PT-22520	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-3 LPL OUTLET PRESSURE	PT-22125	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	HX-4 LPL INLET PRESSURE	PT-22130	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-5 LPL INLET PRESSURE	PT-22140	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-7 LPL INLET PRESSURE	PT-22160	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-3 LPR OUTLET PRESSURE	PT-22225	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-4 LPR INLET PRESSURE	PT-22230	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-5 LPR INLET PRESSURE	PT-22240	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	WARM SHIELDS SUPPLY PRESSURE	PT-22245	2	Fails High	Warm Shields Pressure drop control wrong operation DPIC-22240 = PT-22245-PT-22249 PV-22242 will open at 100% which will stop the supply flow in the shields	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure to disconnect Pressure diffence controller and allow fixed position for the control valves?
			2	Fails Low	Warm Shields Pressure drop control wrong operation DPIC-22240 = PT-22245-PT-22249 Differential pressure will become negative PV-22242 and PV-22246 will close to force flow in the shields	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure or of Negative differential pressure information to disconnect Pressure diffence controller and allow fixed position for the control valves?
	HX-6/7 LPR OUTLET PRESSURE	PT-22247	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	WARM SHIELDS RETURN PRESSURE	PT-22249	2	Fails High	Warm Shields Pressure drop control wrong operation DPIC-22240 = PT-22245-PT-22249 Differential pressure will become negative PV-22242 and PV-22246 will close to force flow in the shields	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure or of Negative differential pressure information to disconnect Pressure diffence controller and allow fixed position for the control valves?
			2	Fails Low	Warm Shields Pressure drop control wrong operation DPIC-22240 = PT-22245-PT-22249 PV-22242 will open at 100% which will stop the supply flow in the shields	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure to disconnect Pressure diffence controller and allow fixed position for the control valves?
	HX-4 HP OUTLET PRESSURE	PT-22430	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-5 HP OUTLET PRESSURE	PT-22440	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	20K ADSORBER UPSTREAM PRESSURE	PT-22460	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	20K ADSORBER PRESSURE	PT-22463	1	Fails High	An interlock will not allow using Heater EHTR 22465	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Operator will have to replace the Pressure transmitter so as to regenerate the 20K Adsorber
			1	Fails Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-9 LPL INLET PRESSURE	PT-22180	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	COOL DOWN / SUB ATMOSPHERIC RETURN LINE PRESSURE	PT-22190	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	COLD INTERCEPT RETURN PRESSURE	PT-22191	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-12 LPL INLET PRESSURE	PT-22193	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	LHE PHASE SEPARATOR (SUBCOOLER) PRESSURE	PT-22195	2	Fails High	Misleading alarm "High Pressure in LHe phase separator" This will interlock closed PV-22390 and this will interlock Heaters EHTR-22195	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
			2	Fails Low	If implemented by JLAB, pressure controller in LHe subcooler (PIC-22195) will close PV-22193	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 4 OUTLET PRESSURE	PT-22389	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	4.5K SUPPLY LINE PRESSURE	PT-22391	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	COLD INTERCEPT SUPPLY LINE PRESSURE	PT-22392	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-12 HP OUTLET PRESSURE	PT-22393	2	Fails High	Controller of the pressure downstream Turbine 4 will open Sub-cooler supply valve (PV-22390) or Dewar Supply valve (PV-22393) depending on the controller in operation. This will drop the pressure downstream Turbine 4	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Turbine 4 is protected against pressure variations downstream using other Pressure transmitter: PT-22382. Detection of Pressure transmitter failure to disconnect Pressure controller and allow fixed position for the control valves
			2	Fails Low	Controller of the pressure downstream Turbine 4 will close Sub-cooler supply valve (PV-22390) or Dewar Supply valve (PV-22393) depending on the controller in operation This will increase the pressure downstream Turbine 4	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Turbine 4 is protected against pressure variations downstream using other Pressure transmitter: PT-22382. Detection of Pressure transmitter failure to disconnect Pressure controller and allow fixed position for the control valves
	HX-3 INLET PRESSURE	PT-22425	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	TURBINE 1 FILTER INLET PRESSURE	PT-22432	2	Fails High	Will trip Turbine 1	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure to disconnect Trip action
			1	Fails Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 2 FILTER INLET PRESSURE	PT-22452	2	Fails High	Will trip Turbine 2	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure to disconnect Trip action
			1	Fails Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 3 FILTER INLET PRESSURE	PT-22472	2	Fails High	Will trip Turbine 3	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure to disconnect Trip action
			1	Fails Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 4 FILTER INLET PRESSURE	PT-22482	2	Fails High	Will trip Turbine 3	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Pressure transmitter failure to disconnect Trip action
			1	Fails Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 4 BYPASS UPSTREAM PRESSURE (used to be PT-22485, redundant with Turbine 4 TAG)	PT-22484	1	Fails High / Low	None	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINES BEARINGS SUPPLY PRESSURE	PT-22405	2	Fails High	Turbines bearing Pressure regulator will close the bearings supply valve PV-22405	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	Turbines will trip if pressure in their bearings are not high enough. Detection of Pressure transmitter failure to disconnect Pressure controller and allow fixed position for the control valves
			2	Fails Low	Turbines bearing Pressure regulator will open the bearings supply valve PV-22405	Safe	Pressure information and associated control and alarms are defined by the 4.5K CB PLC logic.	No impact on Turbines. Detection of Pressure transmitter failure to disconnect Pressure controller and allow fixed position for the control valves

A.2.5 TEMPERATURE SENSORS

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
5	**Temperature Sensors**							
	HX-1B LPL OUTLET TEMPERATURE	TP-22101-A	2	Fails	Warm HP flow repartition controller (DTIC-22400) impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller and allow fixed position for the control valves
	HX-1B LPL OUTLET TEMPERATURE	TP-22110-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1B LPL INLET TEMPERATURE	TP-22111-A	2	Fails	Interlock on PV-22115 based on TP-22411 - TP-22111 > 35K information impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	TEMPERATURE AT PV-22115 OUTLET	TP-22115-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1A LPR OUTLET TEMPERATURE	TP-22201-A	2	Fails	Interlock on PV-22400 based on TP-22201 < 240 K information impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	HX-1A LPR INLET TEMPERATURE	TP-22211-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HP WARM INLET TEMPERATURE	TP-22400-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1B HP OUTLET TEMPERATURE	TP-22411-A	2	Fails	Interlock on PV-22115 based on TP-22411 - TP-22111 > 35K information impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	HX-1A HP OUTLET TEMPERATURE	TP-22412-A	2	Fails	Interlock on PV-22402 based on TP-22412 - TP22511 > 40K information impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	HX2 HP INTLET TEMPERATURE	TP-22413-A	2	Fails	Interlock on PV-22400 and PV-22402 based on TP-22413 - TP-22511 > 40K information impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	80K ADS A INLET TEMPERATURE	TP-22415A-A	2	Fails	Interlock on PV-22421 allowing by-passing 80K Adsorber A impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	80K ADS B INLET TEMPERATURE	TP-22415B-A	2	Fails	Interlock on PV-22421 allowing by-passing 80K Adsorber B impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	80K ADS A TEMPERATURE	TP-22416A-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADS B TEMPERATURE	TP-22416B-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADS A HEATER TEMPERATURE	TP-22418A-A-A TP-22418A-A-B TP-22418A-A-C TP-22418A-A-D	1	Fails	Interlock on EH-22418A impacted. No impact on system in operation (Regeneration is a Manual Operation)	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	80K ADS B HEATER TEMPERATURE	TP-22418B-A-A TP-22418B-A-B TP-22418B-A-C TP-22418B-A-D	1	Fails	Interlock on EH-22418B impacted. No impact on system in operation (Regeneration is a Manual Operation)	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADS A OUTLET TEMPERATURE	TP-22420A-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADS B OUTLET TEMPERATURE	TP-22420B-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	80K ADS OUTLET TEMPERATURE	TP-22422-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-1A GN2 OUTLET TEMPERATURE	TP-22505-A	2	Fails	Interlock on PV-22400 based on TP-22505 < 240 K information impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	HX-1A GN2 INLET TEMPERATURE	TP-22511-A	2	Fails	Interlock on PV-22400 and PV-22402 based on TP-225113 - TP-22511 > 40K information impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	LN2 INLET TEMPERATURE	TP-22520-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	LN2 TANK TEMPERATURE	TP-22525-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-3 LPL OUTLET TEMPERATURE	TD-22125-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-4 LPL INLET TEMPERATURE	TD-22130-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-5 LPL INLET TEMPERATURE	TD-22140-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-6 LPL OUTLET TEMPERATURE	TD-22147-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-7 LPL INLET TEMPERATURE	TD-22160-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 3 + COLD INTERCEPT RETURN TEMPERATURE	TD-22180-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	COLD END BY-PASS OUTLET TEMPERATURE	TD-22189-A	1	Fails	Controller of Cool Down line Not in Nominal Operation using TD-22189 will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	SUB-ATMOSPHERIC RETURN TEMPERATURE	TD-22190-A	2	Fails	Controller of Cool Down line in Nominal Operation using TD-22190 will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	COLD INTERCEPT RETURN TEMPERATURE	TD-22191-A	2	Fails	Controller of Cold Intercepts return temperature (controlling the Flow) will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	LHE PHASE SEPARATOR (SUBCOOLER) OUTLET TEMPERATURE	TD-22193-A	1	Fails	TD-22193 used during Cool Down of the Cold Box Only. The sequence will be impacted if the Temperature probe TD-22193 fails.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	DEWAR LIQUID RETURN TEMPERATURE	TD-22194-A	2	Fails	Interlock of PV-22194 based on condition TD-22194 > 7K and PV-22194 >10% will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	DEWAR VAPOR RETURN TEMPERATURE	TD-22195-A	2	Fails	Interlock of PV-22194 based on condition TD-22195 > 7K and PV-22195 >10% will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	HX-3 LPR OUTLET TEMPERATURE	TD-22225-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-4 LPR INLET TEMPERATURE	TD-22230-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-5 LPR INLET TEMPERATURE	TD-22240-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	WARM SHIELDS SUPPLY TEMPERATURE	TD-22245-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-6 LPR OUTLET TEMPERATURE	TD-22247-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	WARM SHIELDS RETURN TEMPERATURE	TD-22249-A	1	Fails	Warm Shields return temperature control using TD-22249 will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	TURBINE 1 OUTLET TEMPERATURE	TD-22332-A	2	Fails	Turbine 1 discharge temperature control (TIC-22332) will be impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	TURBINE 2 OUTLET TEMPERATURE	TD-22352-A	2	Fails	Turbine 2 discharge temperature control (TIC-22352) will be impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	TURBINE 3 OUTLET TEMPERATURE	TD-22372-A	2	Fails	Turbine 3 discharge temperature control (TIC-22372) will be impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	TURBINE 4 OUTLET TEMPERATURE	TD-22382-A	2	Fails	Turbine 4 discharge temperature control (TIC-22382) will be impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	PV-22485 OUTLET TEMPERATURE	TD-22386-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-12 HP INLET TEMPERATURE	TD-22389-A	1	Fails	Cold End by pass control (TIC-22389) will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	SUBCOOLER HX OUTLET TEMPERATURE	TD-22390-A	1	Fails	Alarm on TD-22390 (4.5K Supply) may appear	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	COLD INTERCEPT SUPPLY TEMPERATURE	TD-22392-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-12 HP OUTLET TEMPERATURE	TD-22393-A	1	Fails	TD-22393 used during Cold Box Cool Down sequence only.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	20K ADSORBER OUTLET TEMPERATURE	TD-22466-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-3 HP INLET TEMPERATURE	TD-22425A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-4 HP OUTLET TEMPERATURE	TD-22430-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 1 INLET TEMPERATURE	TD-22432-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-5 HP OUTLET TEMPERATURE	TD-22440-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-6/7 REDISTRIBUTION TEMPERATURE	TD-22450-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 2 INLET TEMPERATURE	TD-22452-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	20K ADSORBER INLET TEMPERATURE	TD-22461-A	1	Fails	Interlock closing PV22461 if (TD-22466 - TD-22461) > 15K will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	20K ADSORBER INLET TEMPERATURE	TD-22464-A	1	Fails	Interlock on PV-22460 allowing by-passing 20K Adsorber impacted.	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	20K ADSORBER OUTLET TEMPERATURE	TD-22466-A	1	Fails	Interlock closing PV22461 if (TD-22466 - TD-22461) > 15K will be impacted	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	Detection of Temperature sensor failure should be implemented to disconnect associated controller interlock
	HX-8/9 REDISTIBUTION TEMPERATURE	TD-22470-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 3 INLET TEMPERATURE	TD-22472-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	HX-10 HP OUT TEMPERATURE	TD-22480-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 4 INLET TEMPERATURE	TD-22482-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	TURBINE 4 BY-PASS TEMPERATURE	TD-22487-A	1	Fails	None	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	20K ADS HEATER TEMPERATURE	TP-22465-A-A TP-22465-A-B TP-22465-A-C TP-22465-A-D TP-22465-A-E TP-22465-A-F	1	Fails	Interlock on EH-22465 impacted. No impact on system in operation (Regeneration is a Manual Operation)	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	LHE SUBCOOLER HEATER A TEMPERATURE	TP-22195A-A TP-22195A-B TP-22195A-C TP-22195A-D	1	Fails	Interlock on EH-22195A impacted. Refer to EH-22195A Failure analysis	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	LHE SUBCOOLER HEATER B TEMPERATURE	TP-22195B-A TP-22195B-B TP-22195B-C TP-22195B-D	1	Fails	Interlock on EH-22195B impacted. Refer to EH-22195B Failure analysis	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	LHE SUBCOOLER HEATER C TEMPERATURE	TP-22195C-A TP-22195C-B TP-22195C-C TP-22195C-D	1	Fails	Interlock on EH-22195C impacted. Refer to EH-22195C Failure analysis	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	
	LHE SUBCOOLER HEATER D TEMPERATURE	TP-22195D-A TP-22195D-B TP-22195D-C TP-22195D-D	1	Fails	Interlock on EH-22195D impacted. Refer to EH-22195D Failure analysis	Safe	Temperature information and associated control and alarms are defined by the 4.5K CB PLC logic.	

A.2.6 LEVEL TRANSMITTERS

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
6	**Level Transmitters**							
	LN2 level (Pressure difference)	LT-22510	2	Fails High	Impact LN2 level control: LIC-22510 will close PV-22520	Safe	Level information and associated control and alarms are defined by the 4.5K CB PLC logic.	Alarm message if LT-22510 > 90%
			2	Fails Low	Impact LN2 level control: LIC-22510 will open PV-22520	Safe	Level information and associated control and alarms are defined by the 4.5K CB PLC logic.	Alarm message if LT-22510 < 50%
	Superconductive probe - Lower LHe Level	LE-22195A / LT-22195A	2	Fails High	LT-22195 will wrongly indicate 85% which will make LIC-22195 controller boiling LHe to decrease the level	Safe	Level information and associated control and alarms are defined by the 4.5K CB PLC logic. Set point should be 60% of LE-22195A+LE-22195B sensor length. This corresponds to 82% of LE-22195A probe.	Alarm message if LT-22195 > 80%
			2	Fails Low	LT-22195 will wrongly indicate 0% which will make LIC-22195 controller opening PV-22195 to take more LHe from Dewar	Safe		Alarm if LT-22195 < 15% Subcooler heaters interlocked if LT-22195 < 5% Add a discrepancy Alarm: If LT-22195 < 90% while LT-22195B > 0%
	Superconductive probe - Higher LHe Level	LE-22195B / LT-22195B	1	Fails High	None	Safe	Level information and associated control and alarms are defined by the 4.5K CB PLC logic. Set point should be 60% of LE-22195A+LE-22195B sensor length. This corresponds to 82% of LE-22195A probe.	Add a discrepancy Alarm: If LT-22195A < 90% while LT-22195B > 0%
			1	Fails Low	None	Safe		
	LHe level (Pressure difference)	LT-22195C	1	Fails High	None	Safe	Level information and associated control and alarms are defined by the 4.5K CB PLC logic.	
			1	Fails Low	None	Safe	Level information and associated control and alarms are defined by the 4.5K CB PLC logic.	

A.2.7 RELIEF VALVES

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
7	**Relief Valves**							
	LPL Relief Valve	PSV-22104	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	LPR Relief Valve	PSV-22204	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Bearing Gas Tank Relief Valve	PSV-22403	1	Failed Closed	None - No source of pressure higher than design pressure where identified except temperature variation and volume isolated.	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	HP Relief Valve	PSV-22404	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Cryoduct HP Line Relief Valve	PSV-22421	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	LN2 Phase separator Relief Valve	PSV-22510	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	LN2 inlet interface Relief Valve	PSV-22520	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Valve Rack 1121 Relief Valve	PSV-23100	1	Failed Closed	None - No source of pressure higher than design pressure where identified except temperature variation and volume isolated.	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	Valve Rack 1120 Relief Valve	PSV-23200	1	Failed Closed	None - No source of pressure higher than design pressure where identified except temperature variation and volume isolated.	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	80K Ads A Relief Valve	PSV-23717A	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	80K Ads B Relief Valve	PSV-23717B	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Cool Down Line/Sub-atmo return interface PSV	PSV-22190	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Cold Intercepts return interface PSV	PSV-22191	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Dewar Liq return Interface PSV	PSV-22193	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Dewar VAP return Interface PSV	PSV-22194	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Lhe Phase separator (Subcooler) PSV	PSV-22195	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	Warm shields supply Interface PSV	PSV-22245	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	HX-6/7 LPR PSV	PSV-22247	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Warm shields return Interface PSV	PSV-22248	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	HX-SC PSV	PSV-22390	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	4.5K supply interface PSV	PSV-22391	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Cold Intercepts supply interface PSV	PSV-22392	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Dewar LHe supply Interface PSV	PSV-22393	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Turbine 1 PSV	PSV-22432	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
	Turbine 2 PSV	PSV-22452	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	HP Circuit downstream 20K Adsorber PSV	PSV-22465	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Turbine 3 PSV	PSV-22472	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	Turbine 4 PSV	PSV-22482	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	
	20K Adsorber PSV	PSV-23760	5	Failed Closed	Relief function is lost thus potential process line failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
			3	Failed Open	Loss of Helium Inventory	Safe	Periodic monitoring of helium inventory required	

A.2.8 CHECK VALVES

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
8	**Check Valves**							
	GN2 Exhaust check valve	CKV-22501	2	Failed Closed	No relief of Nitrogen boil-off possible, pressure will increase	Safe	"Warm" Check Valves to be inspected and tested periodically. Consequences of Check valve issue are managed in 4.5K cold box control logic. Safety relief Valves also protect lines against Check Valves failing closed.	Interlock on LN2 supply via PV-22520 if pressure too high. PSV-22510 will protect the lines against excessive pressure.
			1	Failed Open	Water from air can enter in the line when GN2 vent stops	Safe	"Warm" Check Valves to be inspected and tested periodically.	
	Turbines Bearings Supply Check Valve	CKV-22405	2	Failed Closed	No supply to Turbines bearings.	Safe	"Warm" Check Valves to be inspected and tested periodically. Consequences of Check valve issue are managed in 4.5K cold box control logic.	Turbines protected against low pressure in the bearings
			1	Failed Open	Act as a redundant safeguard with PV-22405 in case of compression station trip to avoid bearing gas to leave Bearing gas capacity.	Safe	"Warm" Check Valves to be inspected and tested periodically.	
	Warm Shield Supply	CKV-22248	1	Failed Closed	No supply to Warm Shields from Turbine 2 is possible.	Safe	Consequences of Check valve issue are managed in 4.5K cold box control logic.	
			1	Failed Open	Potential by pass of gas from T1 discharge to T2 discharge: degradation of Warm Shields supply control	Safe	Control Logic on the way to operate PV-22248 to be adjusted to this scenario: Close PV-22248 when flow from Turbine 2 to the shields is not required.	Could be implemented by JLAB if the check valves is blocked open with no possibility to repair.

A.2.9 FILTERS

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
9	**Filters**							
	HP inlet filters	F-22400A, F-22400B	2	Clogging	Loss of performance (increased pressure drop)	Safe	Filters pressure drop is monitored by the 4.5K CB PLC Logic. Maintenance procedures to be developed.	Alarm if PT22400 - PT22402 > 0.2 atm And PV-22402 open at 100%
	80K adsorbers Filters	F-22411A, F-22412A, F-22418A, F-22419A, F-22411B, F-22412B, F-22418B, F-22419B	2	Clogging	Loss of performance (increased pressure drop)	Safe	Filters pressure drop is monitored by the 4.5K CB PLC Logic. Maintenance procedures to be developed.	Alarm if PV-22420A open AND (PT-22417A - PT-22422) > 1,5 atm Alarm if PV-22420B open AND (PT-22417B - PT-22422) > 1,5 atm
	20K adsorbers Filters	F-22461, F-22462, F-22468, F-22469	2	Clogging	Loss of performance (increased pressure drop)	Safe	Filters pressure drop is monitored by the 4.5K CB PLC Logic. Maintenance procedures to be developed.	Alarm if PV-22461 and PV-22466 open AND DPT-22461 > 1.5 atm

A.2.10 COOLING WATER

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
10	**Cooling Water**							
	Cooling Water Valves	MV-23420, MV-23431, MV-23438, MV-23439, MV-23451, MV-23458, MV-23459, MV-23471, MV-23478, MV-23479, MV-23481, MV-23488, MV-23489, MV-23499	2	1/ Loss of cooling water 2/ Closed manual valves during normal operation	1/ Turbines and Diffusion pumps cooling issue 2/ Turbines and Diffusions pumps will trip if over-heating	Safe	Operator training and operating procedure required	
	Cooling Water Relief Valves		1		Water leakage	Safe	Periodic monitoring of Water leakage required	
		PSV-23431, PSV-23451, PSV-23471, PSV-23481	2	Failed Closed	Turbine cooling water Exchanger failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	Flow Switch indication on each Turbine cooling water circuit. Turbine Brake temperature: - Alarm if Temperature > 370K - Trip if Temperature > 375K
	Temperature sensors	TI-23420, TI-23438, TI-23458, TI-23478, TI-23488	1	Failed High or Low	Loss of diagnostic	Safe		Used only for diagnostics and not for process control
	Flow indicators	FI-23428, FI-23438, FI-23458, FI-23478, FI-23488	1	Failed High or Low	Loss of diagnostic	Safe		Used only for diagnostics and not for process control

A.2.11 INSTRUMENT AIR

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
11	**Instrument Air**							
	Instrument Air isolation valves	MV-23500, MV-23501, MV-23502, MV-23503, MV-23504, MV-23505, MV-23506, MV-23507, MV-23508, MV-23509, MV-23510, MV-23541, MV-23550, MV-23551, MV-23552, MV-23553, MV-23554, MV-23555, MV-23556, MV-23557, MV-23558, MV-23559, MV-23560, MV-23561, MV-23562, MV-23563, MV-23564, MV-23565, MV-23566, MV-23567, MV-23568, MV-23569, MV-23570, MV-23571, MV-23572, MV-23573, MV-23574, MV-23575, MV-23576, MV-23577, MV-23578, MV-23579, MV-23580, MV-23581, MV-22582, MV-22583, MV-22584, MV-22591, MV-22592, MV-22593, MV-22594	2	1/ Loss of Instrument air 2/ Closed manual valves during normal operation	1/ The control valves will close 2/ Refer to Control Valves failed close	Safe	Operator training and operating procedure required	
	Instrument Air Filters	F-23500, F-23550	2	1/ Loss of Instrument air 2/ Closed manual valves during normal operation		Safe	Operator training and Maintenance procedure required	
	Air Instrumentation Pressure switch (low)	PSL-23500, PSL-23550	1	Fails High	Loss of Diagnostic	Safe	Air Instrument Pressure switches are managed by the 4.5K CB PLC logic	Redundant Pressure switch: 1 on UCB and 1 on LCB
			2	Fails Low	General Trip of the Cold Box	Safe	Air Instrument Pressure switches are managed by the 4.5K CB PLC logic	Cold Box general Trip if Instrument Air PSL activated

A.2.12 3 ATM HE GAS DISTRIBUTION SYSTEM

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
12	**3 ATM He gas distribution system**							
	He distribution isolation valves	MV-23200, MV-23206, MV-23207, MV-23209, MV-23231, MV-23232, MV-23265, MV-23718A, MV-23718B	2	Open during operation	Helium Loss	Safe	Operator training and operating procedure required	PSV-23200 protects the Pumping Rack
	Pressure gauge	PI-23205	1	Failed High or Low	Loss of diagnostic	Safe	Operator training and operating procedure required	Used only for diagnostics and not for process control
	Check Valves	CKV-23718A, CKV-23718B, CKV-23207, CKV-23766	1	Failed Open or closed	Difficulties to fill lines with Helium	Safe	Operator training and operating procedure required	Used only during manual operation and not for process control operations

A.2.13 COOL DOWN/CLEAN UP DISTRIBUTION SYSTEM

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
13	**Cool down/clean up distribution system**							
	Pumping valves	MV-23100, MV-23102, MV-22106, MV-23110, MV-22206, MV-22306, MV-22405, MV-22406, MV-23101	2	Open during operation	Helium Loss	Safe	Operator training and operating procedure required	PSV-23100 protects the Pumping Rack
	Pressure gauge	PI-23100	1	Failed High or Low	Loss of diagnostic	Safe	Operator training and operating procedure required	Used only for diagnostics and not for process control
	Pumping Panel Vent Check Valve	CKV-23101	1	Failed Open or closed	Difficulties to vent lines to the atmosphere	Safe	Operator training and operating procedure required	Used only during manual operation and not for process control operations

A.2.14 VACUUM SYSTEM

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-1	**Vacuum Pumps**							
	Primary Vacuum Pump: Rotary Pump	VP-23610	2	Fails / Stop	No more dynamic vacuum on the Cold Box enclosure	Safe	Vacuum pumps are managed by 4.5K CB PLC Logic	Interlock Vacuum logic and close vacuum valves PV-23616, PV-23614 and PV-23611 if Pump failure is detected
	Secondary Vacuum: Diffusion Pump	DP-23610	2	Fails / Stop	No more dynamic vacuum on the Cold Box enclosure	Safe	Vacuum pumps are managed by 4.5K CB PLC Logic	Interlock Vacuum logic and close vacuum valve PV-23611 if Pump failure is detected
	Primary Vacuum Pump: Rotary Pump	VP-23630	2	Fails / Stop	No more dynamic vacuum on the Cold Box enclosure	Safe	Vacuum pumps are managed by 4.5K CB PLC Logic	Interlock Vacuum logic and close vacuum valves if PV-23636, PV-23634 and PV-23631 Pump failure is detected
	Secondary Vacuum: Diffusion Pump	DP-23630	2	Fails / Stop	No more dynamic vacuum on the Cold Box enclosure	Safe	Vacuum pumps are managed by 4.5K CB PLC Logic	Interlock Vacuum logic and close vacuum valve PV-23631 if Pump failure is detected

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-2	**Pneumatic Valves**							
	Gate Valve	PV-23611	1	Failed Open	Not possible to pump down the Vacuum chamber in operation	Safe	Gate Valve opening/closing managed by 4.5K CB PLC Logic. Gate Valve position feedback monitored by PLC Logic.	Alarm message if ZSH-23411 not energized after a delay of 4sec when PV-23611 open order given.
			1	Failed Closed	Not possible to isolate the Vacuum chamber from the Vacuum pumping system (If maintenance required)	Safe	Gate Valve opening/closing managed by 4.5K CB PLC Logic. Gate Valve position feedback monitored by PLC Logic.	Alarm message if ZSL-23411 not energized after a delay of 4sec when PV-23611 close order given.
	Diffusion Pump Isolation	PV-23614	1	Failed Open	Not possible to isolate the Diffusion pump	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	
			1	Failed Closed	Not possible toPump through the diffusion Pump	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	
	Diffusion Pump By-Pass	PV-23616	1	Failed Open	Not possible to benefit from diffusion pump for high vacuum	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	
			1	Failed Closed	No effect	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	
	Gate Valve	PV-23631	1	Failed Open	Not possible to pump down the Vacuum chamber in operation	Safe	Gate Valve opening/closing managed by 4.5K CB PLC Logic. Gate Valve position feedback monitored by PLC Logic.	Alarm message if ZSH-23431 not energized after a delay of 4sec when PV-23631 open order given.
			1	Failed Closed	Not possible to isolate the Vacuum chamber from the Vacuum pumping system (If maintenance required)	Safe	Gate Valve opening/closing managed by 4.5K CB PLC Logic. Gate Valve position feedback monitored by PLC Logic.	Alarm message if ZSL-23431 not energized after a delay of 4sec when PV-23631 close order given.
	Diffusion Pump Isolation	PV-23634	1	Failed Open	Not possible to isolate the Diffusion pump	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	
			1	Failed Closed	Not possible toPump through the diffusion Pump	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	
	Diffusion Pump By-Pass	PV-23636	1	Failed Open	Not possible to benefit from diffusion pump for high vacuum	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	
			1	Failed Closed	No effect	Safe	Valve opening/closing managed by 4.5K CB PLC Logic.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-3	**Cooling Water relief valves**							
	UCB Vacuum System Cooling water PSV	PSV-22411	2	Failed Open	Water leakage	Safe	Periodic monitoring of Water leakage required	
			2	Failed Closed	Diffusion pump cooling water tube failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	
	LCB Vacuum System Cooling water PSV	PSV-22431	2	Failed Open	Water leakage	Safe	Periodic monitoring of Water leakage required	
			2	Failed Closed	Diffusion pump cooling water tube failure	Safe	Relief System to be inspected and tested periodically per CGA requirements. Relief inspection procedure/schedule to be developed.	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-4	**Manual Valves**							
	UCB Vacuum System Cooling water valves	MV-23409 MV-23410 MV-23411 MV-23418 MV-23419	2	Cooling Water issue	Vacuum System may not be operational	Safe	Operator training and operating procedure required	Diffusion Pump interlocked if Water temperature switch TSH-23610 is reached (46 degC +/-3 degC)
	UCB Vacuum System Instrument Air Manual Valves	MV-23610 MV-23611 MV-23612 MV-23613 MV-23615 MV-23616	2	Vacuum lines isolation issue	Vacuum System may not be operational	Safe	Operator training and operating procedure required	
	LCB Vacuum System Cooling water valves	MV-23427 MV-23420 MV-23421 MV-23428 MV-23429	2	Cooling Water issue	Vacuum System may not be operational	Safe	Operator training and operating procedure required	Diffusion Pump interlocked if Water temperature switch TSH-23630 is reached (46 degC +/-3 degC)
	LCB Vacuum System Instrument Air Manual Valves	MV-23630 MV-23631 MV-23632 MV-23633 MV-23635 MV-23636	2	Vacuum lines isolation issue	Vacuum System may not be operational	Safe	Operator training and operating procedure required	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-5	**Vacuum Gauges**							
	UCB Vacuum gauges	PT-23610 PT-23615 PT-23618	2	Fails High or Fails Low	Vacuum System may not be operational	Safe	Vacuum gauges are monitored by the 4.5K CB PLC Logic	- Diffusion Pump isolation valve PV-23614 will not open and alarm will trigger if PT-23615 and PT-23618 have more than 100 mTorr difference. - Vacuum Shell Isolation valve PV-23611 will not open and alarm will trigger if PT-23610 and PT-23615 have more than 100 mTorr difference. - Diffusion Pump by-pass valve PV-23616 will not open and alarm will trigger if PT-23618 not lower than PT-23618.
	LCB Vacuum gauges	PT-23630 PT-23635 PT-23638	2	Fails High or Fails Low	Vacuum System may not be operational	Safe	Vacuum gauges are monitored by the 4.5K CB PLC Logic	- Diffusion Pump isolation valve PV-23634 will not open and alarm will trigger if PT-23635 and PT-23638 have more than 100 mTorr difference. - Vacuum Shell Isolation valve PV-23631 will not open and alarm will trigger if PT-23630 and PT-23635 have more than 100 mTorr difference. - Diffusion Pump by-pass valve PV-23636 will not open and alarm will trigger if PT-23638 not lower than PT-23638.

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-6	**Vacuum Temperature Switches**							
	UCB Diffusion Pump thermal switch	TSH-23610	2	Fails High	Vacuum System may not be operational	Safe	Thermal Switch monitored by 4.5K CB PLC Logic	Diffusion Pump will stop
			2	Fail Low	Diffusion Pump not protected against overheating (Heater could fail if no cooling water)	Safe	Thermal Switch monitored by 4.5K CB PLC Logic	
	UCB Diffusion Pump thermal switch	TSH-23630	2	Fails High	Vacuum System may not be operational	Safe	Thermal Switch monitored by 4.5K CB PLC Logic	Diffusion Pump will stop
			2	Fail Low	Diffusion Pump not protected against overheating (Heater could fail if no cooling water)	Safe	Thermal Switch monitored by 4.5K CB PLC Logic	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-7	**Vacuum Cooling Water Flow Switches**							
	UCB Vacuum Cooling Water Flow Switches	FSL-23418	1	Fails High or Low	Diagnostic of the cooling water Flow will be lost	Safe	Flow Switch monitored by 4.5K CB PLC Logic	
	LCB Vacuum Cooling Water Flow Switches	FSL-23428	1	Fails High or Low	Diagnostic of the cooling water Flow will be lost	Safe	Flow Switch monitored by 4.5K CB PLC Logic	

NO	Component	Tag	Severity	Failure Mode	Hazard/Effect	Hazard Class	To Be Implemented in Controls/Operating & Maintenance Procedures	Existing Safeguard
14-8	**Vacuum Cooling Water Temperature sensors**							
	UCB Vacuum Cooling Water Temperature	TE-23418	1	Fails High or Low	Diagnostic of the cooling water Temperature will be lost	Safe	Temperature monitored by 4.5K CB PLC Logic	
	LCB Vacuum Cooling Water Temperature	TE-23428	1	Fails High or Low	Diagnostic of the cooling water Temperature will be lost	Safe	Temperature monitored by 4.5K CB PLC Logic	