STAR Failure Mode and Effects Analysis (FMEA)

Component #	Component Name	Failure:	Failure Effect:
C-1	Compressor 1	Stops	Recirculation flow stops, pressure down
			stream of compressor falls, pressure in TPC
			rises until > 2 mbar causing vent valve to
			open
C-2	Compressor 2	Stops	Not normally operating. If operating in place
			of C-1 then: Recirculation flow stops,
			pressure down stream of the compressor
			falls, pressure in TPC rises until > 2 mbar
			causing vent valve to open
CV-6	Compressor non return valve	Stuck Open	If C-2 is running gas backflows through C-1.
			There would be a pressure rise in the 1 mbar
			section of piping. (upstream of the com-
			pressors) Decreased flow to TPC.
		Stuck Closed	If C-2 is running recirculation flow stops,
			pressure downstream of compressor falls,
			pressure in TPC rises until > 2 mbar causing
			vent valve to open
CV-7	Compressor non return valve	Stuck Open	If C1 is running gas backflows through C2 and
			pressure rises in the 1 mbar section of piping.
			(upstream of the compressors)
		Stuck Closed	Only a problem if C-2 is in operation.
			Recirculation flow stops, pressure down
			stream of compressor falls, pressure in TPC
			rises until > 2 mbar causing vent valve to
			open
SV-4	Purifier Isolation Valve	Fails to open	wouldn't be able to remove excess 02 from
			gas.
		Fails to close	No effect, the purifier is left open during

Component #	Component Name	Failure:	Failure Effect:
			normal operation. Redundant to SV-3 during
			bake-out of the dryer.
MV-3	Purifier Regeneration Valve	Left Open	Output capped, no effect.
Purifier	Purifier	Low	wouldn't be able to remove excess O2 from
		temperature	gas.
PSV-2	Purifier Safety Valve	Stuck Closed	Could Damage Purifier during a bake-out
			only if MV-3 was not opened.
		Stuck Open	Small pressure drop in the system, and O2
			increase.
SV-3	Purifier Isolation Valve	Fails to open	wouldn't be able to remove excess O2 from
			gas.
		Fails to close	Wouldn't be able to regenerate the dryer
			off-line by itself. Would also have
			to take the purifier off-line to regen dryer.
SV-2	Dryer Isolation Valve	Fails to open	Wouldn't be able to remove excess H2O from
			the recirculation gas.
		Fails to close	Wouldn't be able to regenerate the Dryer
			off-line.
			Would get a burst of water vapor in the
			system during a bake-out of the dryer and
			Argon purge gas would get into and dilute the
			recirculation gas.
SV-2	Dryer Isolation Valve		

Component #	Component Name	Failure:	Failure Effect:
MV-2	Dryer Regeneration Valve	Left Closed	The dryer would pressurize until the relief
			valve opened.
		Left Open	• Normally capped-no effect, if left uncapped:
			Wouldn't be able to get the pressure in the
			lines up to 100 mbar while using the dryer
			and wouldn't be able to remove water.
			• P10 released into vent line (flows out of bldg.)
Dryer	Dryer	Saturated	No decrease in water vapor while operating
			the dryer.
MV-1	Dryer Regeneration Valve	Stuck Closed	• No flow of purge gas during regeneration
		Left Open	• Normally capped-no effect, if uncapped:
			Pressure Drop in system and 02 increase.
			If uncapped, gas released to room.
PSV-1	Dryer Pressure Relief Valve	Stuck Closed	Over pressurize the dryer.
		Stuck Open	Pressure Drop in system.
			• P10 released into vent line (flows out of bldg.)
SV-1	Dryer Isolation Valve	Fails to open	• No decrease in water vapor while operating
			the dryer.
			• If the purifier was also running then,
			wouldn't be able to remove excess 02 from
			gas.
		Fails to close	• Pressure increase in the recirculation
			system during regeneration of the dryer due
			to flowing purge gas.
			• Excess Argon could flow into the

Component #	Component Name	Failure:	Failure Effect:
			recirculating gas.
F-3	10 micron filter	Full	Reduced flow of gasses through the dryer or
			purifier/dryer loop.
		Blown Element	Reduced/no filtering of the recirculation gas
			immediately after the dryer/purifier. F-4
			would have a reduced life.
PT-9	10 micron filter differential	Broken	•No direct warning that the 10 micron filter
	pressure transducer		is filling up.
CV-13	Purifier loop check valve	Stuck Closed	The dryer or purifier/dryer will appear
			not to work.
		Stuck Open	Could get back-flow through the 10 micron
			filter.
SV-5	Sample line shut-off valve	Fails to open	Wouldn't be able to sample the dried/purified
			gasses.
		Fails to close	Confuses sampling of fresh and recirculating gas.
Ref Mixture P1(	Ref. Mixture P10	Empty	No reading at M-3a or M4 gas analyzers
PCV-3	P10 Dual stage regulator	Stuck Closed	No reading at M-3a or M4 gas analyzers
		Diaphram	Gas pressure rises locally, vents at regulator
		breaks	bonnet and reg. mounted relief valve.
			Relief valve, PSV15, opens venting gas to
			atmosphere.
PI-17	P10 ref. mix. pressure ind.	Broken	No pressure reading
MV-43b	P10 ref. mix. shut off valve	Left Closed	No reading at M-3a or M4 gas analyzers

Component #	Component Name	Failure:	Failure Effect:
Ref Mixture P2(	Ref. Mixture P20	Empty	No reading at M-3a gas analyzer
PCV-10	P20 Dual stage regulator	Left Closed	No reading at M-3a gas analyzer
		Diaphram	Gas pressure rises locally, vents at regulator
		breaks	bonnet and reg. mounted relief valve.
			Relief valve, PSV15, opens venting gas to
			atmosphere.
PI-16	P20 ref. mix. pressure ind.	Broken	No pressure reading
MV-43a	P20 ref. mix. shut off valve	Left Closed	No reading at M-3a gas analyzer
MV-47	P10/P20 three way valve	Wrong gas	No reading at M-3a gas analyzer
		selected	
SV-15	Reference mixture shut-off	Fails to open	No reading at M-3a gas analyzer.
		Fails to close	Possible false reading at the analyzers.
MV-17a	Ref. mix to compressor #2	Left Closed	No reading at M-4 gas analyzer.
	manual valve	Left Open	Possible false reading when trying to
			measure gas from mixer.
SC-2	Make-up gas sm. compressor	Stops	M4 won't get gas - no monitor of the P10 mixture
			except through M3a.
MV-18	Compressor 4 by pass valve	Left Closed	SC-2 will not be operating in a
			throttled configuration.
PSV-3	SC2 pressure relief valve	Stuck Closed	Could damage M-4, CH4 Analyzer
		Stuck Open	Gas won't flow through M-4
PI-8a	SC-2 exit pressure indicator	Broken	No pressure reading for the exit of SC-2

Component #	Component Name	Failure:	Failure Effect:
MV-19	M-4 entrance valve	Left Closed	M-4 analyzer will be blocked
FI-2a	M4 flowmeter	Broken	No flow reading for the M-4 analyzer
M-4	CH4 analyzer, make up gas	Broken	No reading of %CH4 when there is gas flow.
HE-3	C1&2 Heat Exchanger	No coolant flow	No Cooling of recirculation gas
M-5	Oxygen Analyzer	Broken	No reading of O2 build up unless gas sampling
PI-1	Compressor 1&2 exit	Broken	No pressure reading
	pressure indicator		
FI-7	Mixture circulation flow	Broken	No flow reading
	indicator		
PCV-1	Recirculating flow pressure	• Stuck/Left	No recirculating gas flow, high flow through
	reducing valve.	Closed	vent (FI-1, PT-11) Low pressure at TPC.
		Diaphragm	Pressure in the 30 mbar line will rise to
		burst	100 mbar, the bypass check valve on PCV-4
			will open. May relieve some of the pressure
			through the bubbler.
PI-3	30 mbar supply pressure	Broken	No pressure reading
	indicator		
SC-1	Sample line sm. compressor	Stopped	Won't be able to use the gas sampler
			analyzers.
MV-16	SC-1 bypass valve	Left Closed	SC-1 will not be operating in a
			throttled configuration.
PI-2	SC-1 exit pressure	Broken	No pressure reading
	indicator		

Component #	Component Name	Failure:	Failure Effect:
PS-1	Gas sampling Pressure	Broken	If output is zero, get alarm.
	switch and transmitter		
PSV-7	Gas sampling pressure relief	Stuck close	The gas sampling analyzers could be
	valve		subjected to a higher than designed pressure.
SV-6	Oxygen analyzer shutoff valve	Failed to open	Increasing reading from the oxygen analyzer
		Failed to close	gas is analyzed
FI-2	Oxygen analyzer flow indicat.	Broken	No flow reading
MV-46a	M-1 isolation valve	Left closed	no reading from the oxygen analyzer
M-1	Oxygen analyzer	Broken	No reading of O2
MV-46b	M-1 isolation valve	Left closed	Increasing reading from the oxygen analyzer
CV-3	Oxygen analyzer check valve	Stuck closed	Increasing reading of O2 from M-1 analyzer
SV-7	H2O analyzer shutoff valve	Failed to open	Increasing reading from the H2O analyzer
		Failed to close	gas is analyzed
FI-3	H2O analyzer flow indicat.	Broken	No flow reading
M-2	H2O analyzer	Broken	No reading of H2O
CV-4	H2O analyzer check valve	Stuck closed	Increasing reading of H2O from M-2 analyzer
SV-8	CH4/C2H6 analyzer shutoff	Failed to open	no reading from the CH4 or C2H6 analyzer
	valve.		
		Failed to close	gas is analyzed

Component #	Component Name	Failure:	Failure Effect:
FI-4	CH4/C2H6 analyzer flow	Broken	No flow reading
	Indicator		
MV-48	Three way valve	Left closed	No CH4 or C2H6 readings
		Wrong gas	No CH4/C2H6 reading
		selected	
M-3a	CH4 analyzer	Broken	No reading of CH4
M-3b	C2H6 analyzer	Broken	No reading of C2H6
CV-5	CH4/C2H6 ana. check valve	Stuck closed	No reading of CH4/C2H6 from M-3 analyzers
SV-17	Monitoring chamber/	Failed to open	No sampling gas will pass through the
	compressor SC1 valve		monitoring chamber.
		Failed to close	sampling gas could mix with recirculation
			gas prior to entering the monitoring
			chamber giving a false reading
FI-9	Monitoring chamber/	Broken	No flow reading
	compressor SC1 flow meter		
SV-14	sampling valve from	Failed to open	No sampling of recirculation gases
	big compressors 1 & 2 inlets	Failed to close	Erroneous data from the gas analyzers
MV-9	Compressors 1&2 manual	Left Open	It could become difficult or impossible to
	bypass valve		control the TPC gas exit pressure to within
			the limits required.
		Left closed	Normal position
FCV-1	Compressors 1&2 controlled	Broken	Would not be able to control the TPC gas
	bypass valve		exit pressure to within the limits required.

Component #	Component Name	Failure:	Failure Effect:
PI-7	Return manifold pressure ind.	Broken	No pressure reading
PT-6	Return manifold pressure	Broken	Would not be able to control the TPC gas
	transmitter		exit pressure to within the limits required.
PT-5	Alarm pressure transmitter	Broken	No alarm at out of tolerance pressure
CNT-1	Return manifold pressure	Broken	Would not be able to control the TPC gas
	controller		exit pressure to within the limits required.
PT-11	Pressure transducer, for	Broken	No pressure reading, resulting in no exhaust
	exhaust gas		flow reading
FI-1	Exhaust gas flow indicator	Broken	Wouldn't be able to read the vent line flow
			rate below 4.8 liters/min. Between 4.8 and
			24 liters/min., would only be able to read it
			on FI-1a which has a coarser scale.
FI-1a	Exhaust gas flow indicator	Broken	Wouldn't be able to read the vent line flow
			rate above 24 liters/min. Between 4.8 and
			24 liters/min., would only be able to read it
			on FI-1.
BPCV-1	Vent line back pressure	Stuck open	Lose pressure in the 100 mbar section of the
	regulator		recirculating gas circuit.
CV-1	Back pressure regulator	Stuck Closed	Wouldn't be able to bleed off some of the
	check valve		recirculating gas.
		Stuck Open	None
F-4	1.2 micron filter	Full	Reduced flow of gasses through the
			recirculating gas loop.
		Blown element	No filtering of the recirculating gas.

Component #	Component Name	Failure:	Failure Effect:
PT-10	F-4 differential pressure	Broken	No advanced warning that the 1.2 micron
	transducer		filter is filling up.
SV-16	Monitoring chamber inlet	Fails to Open	Can't use monitoring chamber
	valve from recirculation loop	Fails to Close	May get erroneous results when trying to run
			the gas from the sampling loop through the
			monitoring chamber.
FI-8	Monitoring chamber flow	Broken	Won't be able to determine if there is gas
	indicator		flow from the recirculation loop.
Monitoring	Monitoring Chamber	Broken	Won't be able to evaluate the quality of the
Chamber			gas going to the TPC.
TT-1	monitoring chamber	Broken	The temperature of the gas in the monitoring
	temperature transmitter		chamber will be unknown. Won't be able to
			evaluate the quality of the gas going to the TPC
PT-3	monitoring chamber pressure	Broken	The pressure of the gas in the monitoring
	transmitter		chamber will be unknown. Won't be able to
			evaluate the quality of the gas going to the TPC
SV-9	Monitoring chamber	Fails to Open	Can't use the monitoring chamber
	exhaust valve	Fails to Close	None - normal position
MV-10	Monitoring chamber purge	Left Open	Lose recirculation gas out the vent.
	valve		
PSV-3a	Monitoring chamber relief	Stuck Open	Lose recirculation gas out the vent.
	valve		
		Stuck Closed	The pressure in the lines upstream of
			compressors 1 & 2 would rise.
PCV-4	Recirculating flow, pressure	Stuck open	The TPC's upstream pressure would rise,

Component #	Component Name	Failure:	Failure Effect:
	reducing regulator.		2.4 mbar section rises to 30 mbar.
		Stuck closed	TPC pressure would be low.
			No recirculating gas flow, high flow through
			vent (FI-1, PT-11) Low pressure at TPC.
CV-14	PCV-4 bypass/relief valve	Stuck Open	The TPC's upstream pressure would rise.
		Stuck Closed	If PCV-1 failed open then,
			The pressure in the 25-30 mbar section of
			the recirculation loop would rise, and
			possibly damage PCV-4, & leak P10 to room.
PI-4	TPC supply manifold	Broken	No pressure reading
	pressure indicator		
PT-2	TPC supply manifold	Broken	No pressure reading, no direct warning of
	pressure transmitter		when the TPC supply manifold pressure is
			above normal.
Bubbler	Bubbler	High fluid	Excess supply pressure relieved at a higher/
		level	lower pressure.
		Low fluid level	Excessive P10 gas loss, low TPC pressure
MV-14a	Bubbler bypass valve	Left Open	The TPC's upstream pressure would drop.
			Gas in the recirculating loop would vent.
		Left Closed	Wouldn't be able to bypass the bubbler
			Impure gas in supply line stub.
TT-2	TPC temperature transmitter	Broken	No temperature reading
HE-1	East Heat Exchanger	No water	No cooling of gasses entering the east side of

Component #	Component Name	Failure:	Failure Effect:
			the TPC.
HE-2	West Heat Exchanger	No water	No cooling of gasses entering the west side of
			the TPC.
TT-3	TPC temperature transmitter	Broken	No temperature reading
PT-7	TPC differential pressure	Broken	No pressure reading - possible TPC/gap
	transmitter		pressure imbalance.
PI-5	TPC differential pressure	Broken	No pressure reading
	indicator		
TT-4	TPC temperature transmitter	Broken	No temperature reading
PI-6	TPC pressure indicator	Broken	No pressure reading
PT-8	TPC pressure transmitter	Broken	No pressure reading
TT-5	TPC exit temp. transmitter	Broken	No temperature reading
SV-18	Vent line shut off valve	Fails to close	Lose recirculation gas out the vent.
		Fails to open	Won't be able to vent the TPC
MV-17	Gas supply to SC2, M4	Left Closed	Won't be able to check the mix of the supply
			gas with the M4 analyzer
		Left Open	Could produce errors in calibrating M4
SV-10	Supply to recirc. loop, valve	Fails to close	additional supply gas to the recirculation
			loop when not needed, less flow to where the
			supply gas is supposed to go, analyzers or the
			monitoring chamber/M4.
		Fails to open	No addition of gas to the recirculation loop.

Component #	Component Name	Failure:	Failure Effect:
SV-13	Supply to gas sampling loop	Fails to close	gas flow in the sampling loop. Less gas flow
			where the gas is supposed to be going, recirc.
			loop or the monitoring chamber/M4.
		Fails to open	No sampling of the supply gas
Gas Mixer	Gas Mixer	None	No moving parts
FI-5	Mixing block flow ind., Ar	Left closed	Purging will be limited to less than half the
			design flow rate.
			If FI-6 is also closed or set too low, in an
			emergency condition (system power off)
			there will be insufficient flow to compensate
			for atm. pressure changes. Possible air
			intrusion into the TPC.
		Left open	Condition during normal operation
		Adjusted low	If FI-6 is also closed or set too low, in an
			emergency condition (system power off)
			there will be insufficient flow to compensate
			for atm. pressure changes. Possible air
			intrusion into the TPC.
FI-6	Mixing block flow ind., CH4	Left closed	Purging will be limited to less than 2/3 the
	(used for inert gas only)		design flow rate.
			If FI-5 is also closed or set too low, in an
			emergency condition (system power off)
			there will be insufficient flow to compensate
			for atm. pressure changes. Possible air
			intrusion into the TPC.
		Left open	Condition during normal operation
		Adjusted low	If FI-5 is also closed or set too low, in an
			emergency condition (system power off)
			there will be insufficient flow to compensate
			for atm. pressure changes. Possible air
			intrusion into the TPC.
CV-12	FM-5 check valve	Stuck open	None, MV-4 closed during normal operation.

Component #	Component Name	Failure:	Failure Effect:
		Stuck closed	None, MV-4 closed during normal operation
CV-11	FM-4 check valve	Stuck open	None, SV-10 always open, not possible to
			have back flow through FM-4, due to lower
			downstream pressure.
		Stuck closed	No Ar flow.
CV-8	FM-2 check valve	Stuck open	None, MV-7 closed during normal operation
		Stuck closed	None, MV-7 closed during normal operation
CV-10	FM-1 check valve	Stuck open	None, SV-10 always open, not possible to
			have back flow through FM-1, due to lower
			downstream pressure.
			No CH4 flow.
FM-5 (3lpm)	Mixing blk mass flow control.	Broken	Make up flow too low.
	for Ar		
FM-4 10lpm	Mixing block mass flow meter	• Loss of power	• FM-4 & FM-1 are slaved, resulting in no
	for Ar	closed valve	added gas to the system. Flow through FT-1
			• If FM-4 & FM-1 don't remain slaved then,
			Decrease in flow through FM-1, PT-11
			would show a decreased pressure differential,
			%CH4 in the system would increase.
		• loss of meter-	• wide open flow of Ar
		ing function	• no flow of Ar
FM-3	Mixing block mass flow meter	• loss of power	No flow reading. Only a problem during
(500 lpm)	for Ar	closed valve	start-up and purging. No flow of N2 or Ar.
		• loss of meter-	• wide open flow of Ar during startup
		ing function	• no flow of Ar during startup
FM-2	Mixing block mass flow meter	Loss of	No flow reading. This will make it very

Component #	Component Name for CH4	Failure: metering	Failure Effect: difficult to adjust the Ar to CH4 mixture to the correct concentrations.
FM-1	Mixing block mass flow meter for CH4	Loss of Power (closed valve)	Decrease in % CH4
		Loss of metering	flow meter valve goes wide open, then increase in % CH4
			flow meter valve closes, zero % CH4 in the mixer, and low % CH4 in recirculation loop
MV-4	FM-5 shut off valve	Left open	May have a small amount of Ar leak through the Mass flow controller #5. Effect negligible.
		Left closed	Possibly too small makeup flow.
MV-5	FM-4 shut off valve	Left open	Normal operating position, except during start-up, effect none.
		Left closed	No Ar flow during operation.
MV-6	FM-3 shut off valve	Left open	May have a small amount of Ar leak through the Mass flow controller #3. Effect negligible.
		Left closed	Normal operating position
MV-7	FM-2 shut off valve	Left open	A small amount of CH4 may flow through FM-2, this could make it difficult to achieve the correct flow with FM-1.
		Left closed	No flow of CH4 during start-up, otherwise normal operating position.
MV-8	FM-1 shut off valve	Left open	Normal operating position. During start-up CH4 flow through FM-1 when there should only be flow through FM-2.
		Left closed	No flow of CH4 during operation.
SV-11	Inert gas inlet to mixing blk	Left closed	• Normal operating position.
			• Purging will be limited to less than half the

Component #	Component Name	Failure:	Failure Effect:
			design flow rate.
			If FI-6 is also closed or set too low, in an
			emergency condition (system power off)
			there will be insufficient flow to compensate
			for atm. pressure changes. Possible air
			intrusion into the TPC.
		Opens	The gas system/TPC will be purged with
			Ar
SV-12	Methane inlet to mixing blk	Left closed	• Normal operating position.
			• Purging will be limited to less than half the
			design flow rate.
			If FI-5 is also closed or set too low, in an
			emergency condition (system power off)
			there will be insufficient flow to compensate
			for atm. pressure changes. Possible air
			intrusion into the TPC.
		Opens	The gas system/TPC will be purged with
			CH4
F-1	Inert gas inlet filter	Full	Reduced flow of Ar.
		Blown element	Reduced or no filtering of Ar supply gas,
			may shorten the life of the mass flow
			controller #4.
F-2	Methane inlet filter	Full	Reduced flow of CH4
		Blown element	Reduced or no filtering of CH4 supply gas,
			may shorten the life of the mass flow
			controller #1.
SV-22	Inert gas cross-over SV	Fails to open	Wouldn't be able to purge the CH4 side of the
			mixing block.
		Fails to close	If the CH4 supply pressure is greater than
			the inert gas
			then it could be possible to get CH4 in inert

Component #	Component Name	Failure:	Failure Effect:
			gas lines.
SV-21	CH4 supply line isolation SV	Fails to open	No CH4 supplied to the gas recirculation syst.
		Fails to close	Only a problem if SV-21a also fails to close
			during a purge. The gas system would not be
			purged of CH4 in that case.
PI-9	CH4 supply pressure indicat.	Broken	No pressure reading
MV-25	CH4 supply isolation	Left open	None
		Left closed	No CH4 supplied to the gas recirculation syst.
PSV-4	CH4 supply relief valve	Fails to open	? Not likely to ever need to open, PSV-4a
			has a lower set pressure & would open first.
		Fails to close	Gas vented to atmosphere on pad.
SV-21a	CH4 supply isolation @ pad	Fails to open	No CH4 supplied to the gas recirculation syst.
		Fails to close	Only a problem if SV-21 also fails to close
			during a purge. The gas system would not be
			purged of CH4 in that case.
PSV-4a	CH4 supply relief valve	Fails to open	If SV-21a open then PSV-4 will open at 25
			psi, otherwise the supply line could only
			pressurize up to 30 psi if PCV-6 was set
			wrong and then PSV-4b would open at 30 psi.
		Fails to close	Gas vented to atmosphere on pad.
PCV-6	CH4 supply regulator	Left closed	No CH4 supplied to the gas recirculation syst.
		Set low	Insufficient CH4 supplied to gas recirc. sys.
		Set high	Higher than wanted pressure in the CH4
			supply line. If to high, PSV-4a will open.

Component #	Component Name	Failure:	Failure Effect:
PSV-4b	CH4 supply relief valve	Fails to open	Possible blowout of PCV6 - then PSV4a or
			PSV4 will open.
		Fails to close	Methane vents to atmosphere.
CV-19	CH4 supply check valve, 1st	Stuck open	None
	6-pack	Stuck closed	No CH4 supplied to the gas recirculation syst.
CV-20	CH4 supply check valve, 2nd	Stuck open	None
	6-pack	Stuck closed	Only a problem if the 2nd 6pk is in use,
			No CH4 supplied to the gas recirculation syst.
MV-41	CH4 isolation valve, 1st 6pk	Left open	None, duplicate valve.
		Left closed	No CH4 supplied to the gas recirculation syst.
MV-42	CH4 isolation valve, 2nd 6pk	Left open	None, redundant valve.
		Left closed	Only a problem if the 2nd 6pk is in use,
			No CH4 supplied to the gas recirculation syst.
PCV-6a	CH4 sup. regulator, 1st 6pk	Left closed or	No CH4 supplied to the gas recirculation syst.
		Adjusted low	
		Adjusted high	Relief valve PSV-4b will open
PCV-6b	CH4 sup. regulator, 2nd 6pk	Left closed	No CH4 supplied to the gas recirculation syst.
		Adjusted low	None, to insufficient pressure CH4 supplied to
			the gas recirculation system.
		Adjusted high	Relief valve PSV-4b will open
MV-26a	CH4 manif. isolation, 1st 6pk	Left open	None, duplicate valve.
		Left closed	No CH4 supplied to the gas recirculation syst.

Component #	Component Name	Failure:	Failure Effect:
MV-26b	CH4 manif. isolation, 2nd 6pk	Left open	None, redundant valve.
		Left closed	Only a problem if the 2nd 6pk is in use,
			No CH4 supplied to the gas recirculation syst.
MV-26	3-way valve, CH4 manifold	Wrong manif.	Incorrect pressure reading
	selector for PI-14	selected	
PI-14	CH4 manifold Press. Indicator	Broken	No pressure reading
RO-1	CH4 press. reducer, 1st 6pk	Clogged	No flow of CH4 into system
RO-2	CH4 press. reducer, 2nd 6pk	Clogged	No flow of CH4 into system IF 2nd 6pk is
			in use.
MV-24a	High press. CH4 manifold	Left open	Normal operating position
		Left closed	Back up 6-pack of CH4 will be emptied while
			the primary 6-pack still has pressure.
MV-24c	High press. CH4 manifold	Left open	Normal operating position
		Left closed	No CH4 supplied to the gas recirculation syst.
MV-24b	High press. CH4 manifold	Left open	CH4 would flow out the purge line.
		Left closed	won't be able to purge the CH4 manifold
MV-24d	High press. CH4 manifold	Left open	CH4 would flow out the purge line.
		Left closed	won't be able to purge the CH4 manifold
PI-8	Inert gas supply press. indic.	Broken	No pressure reading

Component #	Component Name	Failure:	Failure Effect:
Q-3	Inert gas supply heater	Left off	None - not used during normal running.
MV-21	Inert gas sup. heater bypass	Left Open	Normal operating position
		Left Closed	Reduced flow of purge gases, will take longer
			to purge the TPC upon start-up.
SV-20	Inert gas sup. heater SV	Fail to open	None - heater not normally used.
		Fail to close	None - parallel path.
HE-5	Inert gas heat exchanger	Leak	Inert gas vents to mixing room
CV-16	Ar supply line check valve	Stuck open	N2 from the N2 supply could get into the
			Ar supply lines. The N2 would be flushed out
			when the Ar supply is started.
		Stuck closed	No flow of Ar to the TPC gas system
			TPC data could be skewed.
F-7	Ar supply line filter	Full	Reduced flow of Ar, if Ar pressure decreases
			enough the inert gas supply will switch over
			to N2 and the TPC data will be skewed.
PI-12	Ar supply line pressure ind.	Broken	No pressure reading
PCV-5	HI flow regulator, Ar supply	Left closed or	No flow of Ar. N2 will flow instead of Ar to
		adjusted too low	the TPC gas system, thus skewing TPC data

Component #	Component Name	Failure:	Failure Effect:
		Adjusted High	Higher than normal pressure in the inert
			gas line up to the mass flow controllers.
PI-13	Ar supply line pressure ind.	Broken	No pressure reading
MV-30	Ar supply isolation valve	Left Open	Normal position.
		Left Closed	No flow of Ar from the dewars, Ar will start
			flowing from a 6-pack
MV-34	Ar supply purge valve	Left Open	No flow of Ar. N2 will flow instead of Ar to
			the TPC gas system, thus skewing the TPC data
		Left Closed	Unable to purge Ar supply line.
HE-4	Ar vaporizer		
PSV-8	Ar vaporizer relief valve	Stuck Open	No flow of Ar. N2 will flow instead of Ar to
			the TPC gas system, thus skewing the TPC data
		Stuck Closed	PSV-14 would relieve the pressure instead
MV-39	Liquid Ar manifold exit	Left Open	None, redundant valve
		Left Closed	No flow of Ar from the dewars, Ar will start
			flowing from a 6-pack
PSV-14	Ar manifold pressure relief	Stuck Open	No flow of Ar. N2 will flow instead of Ar to
			the TPC gas system, thus skewing the TPC data
		Stuck Closed	The pressure relief valves on one of the Ar
			dewars would relieve the pressure
MV-37a,b,c	Liquid Ar manifold inlet valve	Stuck Open	Air in the manifold during replacement of
			dewar
		Stuck Closed	No flow of Ar from the dewars, Ar will start
			flowing from a 6-pack

Component #	Component Name	Failure:	Failure Effect:
PT-4	Backup Ar Press. transducer	Broken	No Pressure Reading
CV-15b	Backup Ar check valve	Stuck Open	Ar from the back up 6-pack will be depleted
		Stuck Close	No back-up Ar will flow when needed, N2 will
			flow instead of Ar to the TPC gas system, thus
			skewing the TPC data.
MV-32	Backup Ar isolation valve	Left Open	Normal operating position
		Left Closed	No back-up Ar will flow when needed, N2 will
			flow instead of Ar to the TPC gas system, thus
			skewing the TPC data.
PSV-9	Backup Ar relief valve	Stuck open	All the Ar from the 6-pack will vent
		Stuck closed	Check valve 15b will open and Ar from the
			6-pack will flow with Ar from the dewars. If
			the line is constantly over pressure this could
			lead to using up the back up Ar.
MV-33	Backup Ar purge valve	Left open	All the Ar from the 6-pack will vent
		Left closed	Won't be able to purge the 6-pack manifold line
MV-32a	Backup Ar isolation valve	Left Open	May get air in the backup Ar line when
			changing out the 6-pack
		Left Closed	No back-up Ar will flow when needed, N2 will
			flow instead of Ar to the TPC gas system, thus
			skewing the TPC data.
PCV-7	Backup Ar 6-pack regulator	Adjusted to hi	PSV-9 will open
		Adjusted to low	No back-up Ar will flow when needed, N2 will

Component #	Component Name	Failure:	Failure Effect:
		or closed	flow instead of Ar to the TPC gas system, thus
			skewing the TPC data.
CV-15	N2 supply line check valve	Stuck closed	No purging of the TPC gas system with N2
		Stuck open	N2 would mix with the Ar, thus skewing the
			TPC data.
F-6	N2 supply filter	Full	No/reduced purging of the TPC gas sys w/N2
PSV-5	N2 supply line press. relief	Stuck open	Loose a lot of N2 to atmosphere
		Stuck closed	Could get N2 in the Ar lines to the TPC thus
			skewing the TPC data.
PI-11	N2 supply line press. indicat.	broken	No pressure reading
PCV-2	N2 supply regulator	Left closed	No N2 for purging the TPC gas system or
			analyzer manifolds
		Adjusted low	No N2 for purging the TPC and reduced
			flow of purge gas to the analyzer cases
		Adjusted high	Could prevent Ar from flowing to the TPC
			Gas system.
PI-10	N2 supply press. indicator	Broken	No pressure reading
MV-28	N2 supply isolation valve	Left Open	Normal operating position
		Left Closed	No N2 for purging the TPC gas system or
			analyzer manifolds
MV-35	N2 supply purge valve	Left Open	No N2 for purging the TPC gas system or
			analyzer manifolds
		Left Closed	Won't be able to purge the N2 supply manifold
MV-36	LN manifold exit	Left Open	Normal operating position

Component #	Component Name	Failure:	Failure Effect:
		Left Closed	No N2 for purging the TPC gas system or
			analyzer manifolds
PSV-10	LN manifold press. relief	Stuck Open	No N2 for purging the TPC gas system or
			analyzer manifolds
		Stuck Closed	The pressure relief valves on the individual
			dewars will open.
MV-38a,b,c	LN manifold inlet valves	Left open	Normal operating position
		Left closed	No N2 for purging the TPC gas system or
			analyzer manifolds
CV-15a	Backup N2 check valve	Stuck open	Will use up the backup N2 before it is needed
		Stuck closed	There will be no backup N2 to purge the TPC
			and/or the monitors when the LN dewars go
			dry.
MV-27	Backup N2 isolation valve	Left open	Normal operating position
		Left closed	There will be no backup N2 to purge the TPC
			and/or the monitors when the LN dewars go
			dry.
PSV-6	Backup N2 pressure relief	Stuck open	Will use up the backup N2 before it is needed
		Stuck closed	Nothing, to leak N2 into the N2 lines that are
			being supplied from the LN dewars thus using
			up the backup N2 before its time.
MV-29	Backup N2 purge valve	Left open	Will use up the backup N2 before it is needed
		Left closed	Would not be able to purge the backup N2 line
MV-27a	N2 backup cyl. isolation v.	Left open	May get air in the line when changing out the
			N2 cylinder-will need to purge line
		Left closed	There will be no backup N2 to purge the TPC
			and/or the monitors when the LN dewars go

Component #	Component Name	Failure:	Failure Effect:
			dry.
PCV-8	Backup N2 regulator	Adjusted to hi	PSV-6 will relieve the excess pressure. If
			not fixed the backup N2 will be used up before
			its need.
PCV-8	Backup N2 regulator	Adjusted to low	There may be no backup N2 to purge the TPC
			and/or the monitors when the LN dewars go
			dry.
		Left Closed	There will be no backup N2 to purge the TPC
			and/or the monitors when the LN dewars go
			dry.
N2 cylinder	N2 Cylinder, backup N2	Closed/empty	There will be no backup N2 to purge the TPC
			and/or the monitors when the LN dewars go
			dry.
MV-43	Laser N2 isolation valve	Left closed	Could eventually damage laser optics
FI-16	Laser N2 flow indicator	Left closed	Could eventually damage laser optics
MV-22a	CH4 purge line isolation v.	Closed	No purging of M3a, M4 analyzer cases
FI-12	M4 case purge flow indicator	Closed	No purging of the M4 analyzer case
FI-13	M3a case purge flow indicator	Closed	No purging of the M3a analyzer case
SV-24	vent line purge valve	Closed	May get some air into the TPC gas recirc. sys.
FI-15	Vent line purge flow indicator	Closed	May get some air into the TPC gas recirc. sys.
MV-14	Vent line purge isolation v.	Closed	May get some air into the TPC gas recirc. sys.
MV-22	M4 ref. gas isolation valve	Closed	No flow of N2 to M4 analyzer for use in
			calibrating. Incorrect calibration of the
			analyzer possible.
FI-14	M4 ref.gas flow indicator	Closed	No flow of N2 to M4 analyzer for use in

Component #	Component Name	Failure:	Failure Effect:
			calibrating. Incorrect calibration of the
			analyzer possible.
MV-23	3 way valve, insulation gas	Incorrect gas	Insulation gas may stop.
	selector	selected	
F-5	Insulation gas filter	Full	Reduced or no flow on N2 to the insulation
			gas rack. Could spark down between the inner
			and outer field cages.
PI-15	N2 gas sup. line	Broken	No Pressure reading
PSV-11	Insulation gas sup. line relief	Stuck closed	If SV-23 is open, then PSV-50 will open,
			otherwise PSV-5 will open.
		Stuck open	May get air in the insulation gas line
SV-23	Insulation gas sup. SV	Stuck closed	No flow of N2 to the insulation gas rack.
		Stuck open	During a power failure some of the N2 used
			for purging the TPC would be redirected to the
			insulation gas rack.
FI-10	Insulation gas sup. flow indic.	Broken	No flow reading for the insulation gas supply
PSV-50	Insulation gas pres. relief	Stuck closed	PSV-11 will open
	rack 4	Stuck open	May get air in the insulation gas line
MV-50	Insulation gas isolation valve	Left closed	No flow of N2 to the insulation gas rack.
		Left open	Normal operating position
FI-50	Insulation gas flow indicator	Left closed	May have insufficient flow on insulating gas
			to the TPC.
		Adjusted too high	May be possible to over pressurize the TPC
			insulation gap.
FI-51	Insulation gas flow indicator	Left closed	May have insufficient flow on insulating gas

Component #	Component Name	Failure:	Failure Effect:
			to the TPC.
		Adjusted too high	May be possible to over pressurize the TPC
			insulation gap.
PSV-51	He insulation gas press. relief	Not used	
MV-51	He insulation gas isolation v.	Not used	
FI-52	He insulation gap flow indic.	Not used	
FI-53	He insulation gap flow indic.	Not used	
MV-52	Insulation gas analyzers	Left closed	Would not be able to analyze the insulation
	isolation valve		gas with M6,M7
		Left open	Would not be able to analyze the insulation gas
			property.
MV-53	Ref. N2 isolation valve	Not used	
MV-54	Used insulation gas return to	Left closed	Would not be able to analyze the insulation
	analyzers isolation valve		gas with M6,M7 & the spark gap
		Left open	
			• Fresh gas and used gas would mix, possibly
			giving erroneous data on the condition of the
			insulating gas if MV52 is open.
SC-3	Insul. gas sampling sm. comp.	Off/broken	Would not be able to analyze the insulation
			gas with M6,M7 & the spark gap
MV-55	SC-3 bypass valve	Left Closed	Would not be able to throttle the sm.
			compressor #3.
FI-54	Spark gap flow indicator	Not used	
Spark Gap	Spark Gap	No Voltage	Would not be able to use the spark gap to

Component #	Component Name	Failure:	Failure Effect: evaluate the insulation properties of the gases
FI-55	Insulating gas monitors FI	Left Closed	Would not be able to use M6, M7 to evaluate
			the quality of the insulation gas.
		Left Open	Normal operating position
M6	02 analyzer	Broken	Can't detect 02 in the insulation gas, if 02
			present could cause premature breakdown
			of TPC insulator gap.
M7	H20 analyzer	Broken	Can't detect H20 in the insulation gas, if H20
			present could cause premature breakdown
			of TPC insulator gap.
M8	Flammable gas detector	Broken	Could delay the warning of a flammable gas
			leak.

Failure Detection	Affected Components
FI-7 , 1, 1a would show decreased flow.	C2, TPC, PI7, PT6,
PI-7 may show an increase in pressure.	PT5, CNT1, FCV1,
PT-5 would sound an alarm.	PI1, FI7, SV-18
SV-18 would open upon PT-5 reaching	
2 mbar.	
PI-1 would show a decrease in pressure.	C2, TPC, PI7, PT6,
FI-7 , 1, 1a would show decreased flow.	PT5, CNT1, FCV1,
PI-7 would show an increase in pressure.	PI1, FI7, SV-18
PT-5 would sound an alarm.	
SV-18 would open upon PT-5 reaching	
2 mbar.	
PI-7 would show a pressure rise.	Compressor-1, PI1, FI7
PT-6 would see a pressure rise	C2, TPC, PI7, PT6,
PT-5 would sound a pressure alarm	PT5, CNT1, FCV1,
	SV-18
FI-7 , 1, 1a would show decreased flow.	
PI-7 may show an increase in pressure.	
PT-5 would sound an alarm.	
SV-18 would open upon PT-5 reaching	
2 mbar.	
PI-7 would show a pressure rise.	Compressor-2, PI1, FI7
PT-5 would sound a pressure alarm	C2, TPC, PI7, PT6,
	PT5, CNT1, FCV1,
FI-7 , 1, 1a would show decreased flow.	SV-18
PI-7 may show an increase in pressure.	
PT-5 would sound an alarm.	
SV-18 would open upon PT-5 reaching	
2 mbar.	
The M-5 Oxygen Analyzer would show no	TPC, purifier, M5, M1,
decrease in O2. If sampling the recir-	PI1, BPCV1
culating flow, the M-1 Oxygen Analyzer will	
also show no decrease in O2.	
None.	Purifier.

Failure Detection	Affected Components
None.	none
The M-5 Oxygen Analyzer would show no decrease in O2. If sampling, the M-1 Oxygen Analyzer will also show no decrease in O2 .	TPC, M5, M1,
The O2 level would be the same as it was prior to the bakeout. The M-5 Oxygen Analyzer would measure an increase in O2. If sampling, M-1 Oxygen Analyzer will also measure the increase in O2. The control system system may sense an imbalance of the gas flowing out vs. flowing in.	TPC, M5, M1, Purifier, P11
The M-5 Oxygen Analyzer would show no decrease in O2. If gas sampling, the M-1 Oxygen Analyzer will also show no decrease in O2, and M-2 will show no decrease in H2O. The dryer will saturate sooner than normal.	TPC, purifier, dryer, M5, M1
There would be no decrease in water vapor in the system. The M-2 H2O analyzer would show this, if sampling gas. The water vapor would be detected by the ppm H2O analyzer if gas sampling. PT11 would increase in pressure and F11 flow will increase. M3 & M4 analyzers would measure a decrease in the %CH4. The control system would sense an imbalance of the gas flowing out vs. flowing in. The monitoring chamber would detect a	TPC, M2, Purifier, Dryer, PT11, F11

Failure Detection	Affected Components
mixture imbalance.	
The dryer relief valve would open.	PSV2, PI1, M2, Dryer,
	TPC, Purifier
PI-1 would show a pressure drop, and	
If gas sampling then the M-2 ppm H2O	
analyzer would show no improvement in	
water removal.	
gas monitor	
If gas sampling then the M-2 ppm H2O	TPC, M2, Purifier
analyzer would show no improvement in	
water removal.	
No flow of purge gas during regeneration	TPC, Dryer, Purifier,
The M-5 Oxygen Analyzer would measure	M5, M1
an increase in O2. If gas sampling, the	
M-1 Oxygen Analyzer will also measure the	
increase in O2. PI-1 would show a lower	
than normal pressure.	
Gas monitor	
None, to spring a leak.	TPC, Dryer, Purifier,
PI-1 would show a lower than normal	M5, M1, PI1
pressure.	
If gas sampling then the M-2 ppm H2O	TPC, Dryer, Purifier,
analyzer would show no improvement in	M2, M5, M1, PI3, M3a,
water removal.	
The M-5 Oxygen Analyzer would measure	
any increase in O2. If gas sampling, the	
M-1 Oxygen Analyzer will also measure the	
increase in O2.	
The pressure indicator PI-3 may show a	
change in pressure	
The M-3a Methane Analyzer would show a	

Failure Detection	Affected Components
decrease in the percentage of Methane if	
gas sampling. The monitoring chamber would	
detect a gas mix imbalance.	
PT-9, pressure transmitter on the filter	PT9, F4
would show a larger pressure differential.	
PT-9 would show a lower than normal	
pressure differential.	
No pressure reading or an impossible	10 micron filter,
pressure reading recorded.	
The M-5 Oxygen Analyzer would show no	TPC, Dryer, Purifier,
change in O2. If gas sampling, the	M5, M1, M2
M-1 Oxygen Analyzer will also show no	
change in O2, and M2 the lack of change in	
the H20 reading.	
none	
Flow indicators FI-2,3,4, &9 would read	M1, M2, M3, FI-2, FI-3
zero. Low pressure at PS1 causes alarm.	FI-4, FI-9, PS1
M1, oxygen monitor and M2, water monitor show	M1, M2
abnormally high readings.	
Regulator on the gas cylinder reads low.	M3a, M4, PI-17
Flow indicators FI-2,3,4,& 9 show zero flow.	M3a, M4, PI-17, PS-1
Low pressure on PS-1 causes alarm.	
Pressure at indicator PI-17 exceeds 10psi,	PI-16, PSV-15,
gas escapes from PSV-15	MV43b, MV47,
	PCV-9
No pressure reading	None, indicator only
Flow indicators FI-2,3,4,& 9 show zero flow.	M3a, FI-2,3,4, &9

Failure Detection	Affected Components
PS1 alarms.	
Regulator on the gas cylinder reads low.	M3b, PI-16, FI-2,3,4,
	& 9.
Flow indicators FI-2,3,4,& 9 show zero flow.	M3b, PI-16, FI-2,3,4,
PS1 alarm	& 9.
Pressure at indicator PI16 exceeds 10psi,	PI16, PSV15,
gas escapes from PSV15	MV43a, MV47,
	PCV-9
No pressure reading	None, indicator only
Flow indicators FI-2,3,4,& 9 show zero flow.	M3b, FI-2,3,4, & 9
PS1 alarm.	
No reading at M-3a gas analyzer	M3
Flow indicators FI-2,3,4,& 9 show zero flow.	M3, FI-2,3,4,& 9
PS1 alarm	
None	
Flow indicator FI-2a shows zero flow.	M4, FI-2a, PI-8a, SC2
PI-8a will indicate a pressure higher than	
expected from the gas mixer.	
FI-2a will indicate zero flow, PI8a reads zero.	TPC, FI-2a, PI-8a, M4
PI-8a will show a high pressure reading	SC-2, M4, PI-8a
PI-8a will register a high pressure reading	M4, FI-2a, PI-8a
FI-2a will indicate zero flow	
No reading on the pressure indicator	None, indicator only

Failure Detection	Affected Components
FI-2a will indicate zero flow	M4, FI-2a
zero reading when there is a known flow	None, indicator only
FI-2a indicates flow, M-4 doesn't read	TPC
TT-2 will show the gas entering the TPC	TPC, TT-2
heat exchanger as being hotter than normal	
No reading, or conflicting reading when using	TPC
the gas sampling Analyzers. TPC won't work.	
No pressure reading	Interlock system alarm
Alarm sounds	
No flow reading	None, indicator only
FI-1 will indicate no flow, PT-5,8 will	TPC, FI-7, PI-1,3,4
sound an alarm.	PT-2,5,8, PCV-4,
PI-3, PI-4, PT-2 read 100 mbar. PT-2	CV-14, Bubbler.
sounds an alarm.	
No pressure reading	None, indicator only
PI-2 will show a low pressure reading,P61 will	M1,2,3, FI-2,3,4,88
alarm. Also, get alarm if M3a reading is low.	PI-2
PI-2 will show a high pressure reading	SC-1, PI-2, M1,2,3
No pressure reading	MV-16

Failure Detection	Affected Components
No pressure reading, alarm	M1,M2, M3a, Monitor
	Chamber
PS-1 and PI-2 will indicate a pressure	M1,2,3, PS-1, PI-2
reading above the set relief pressure.	
FI-2 would show no flow to the O2 analyzer	M1, FI-2
FI-2 would show flow when there should be	
none.	
No flow reading	M1
FI-2 would show no flow to the O2 analyzer	M1, FI-2
No reading, or conflicting reading with	TPC
the M-5 Analyzer.	
FI-2 would show no flow to the O2 analyzer	M1, FI-2
Increasing reading of O2 from M-1 analyzer,	M1, FI-2
FI-3 would show no flow to the H2O analyzer	M2, FI-3
FI-3 would show flow when there should be	
none.	
No flow reading	M2
No reading	TPC
Increasing reading of H2O from M-2 analyzer	M2, FI-3
FI-4 would show no flow to the CH4/C2H6	M3a,b, FI-4
analyzers. Alarm from low methane content	
FI-4 would show flow when there should be	
none.	

Failure Detection	Affected Components
No flow reading	M3a,b
FI-4 would show no flow to the CH4/C2H6	M3a,b, FI-4
analyzers. Alarm from low methane content.	
No CH4/C2H6 reading	
No reading, or conflicting reading with	TPC
the M-4 Analyzer. Alarm if out of normal range.	
No reading of C2H6.	TPC
No reading of CH4/C2H6 from M-3 analyzers	M3a,b, FI-4
and M-4 analyzer is reading CH4.	
FI-9 will show zero flow	Monitoring Chamber,
	FI-9
FI-9 will show flow where there should be	
none & PT-3 should show a higher than	
expected pressure.	
No flow reading	Monitoring chamber
No readings from the gas analyzers M-1,2,3	M1,2,3, monitoring
PS1 alarm	
more than one valve open to the gas sampling	chamber, FI-2,3,4,9
system.	
controller-1 will detect an out of tolerance	C1&2, PI-7, CNT-1
pressure condition	
controller-1 will detect an out of tolerance	TPC, C1&2, PT-5,6,
pressure condition, alarm will go off	PI-7

Failure Detection	Affected Components
No pressure reading. Alarm if above or below red line trip.	TPC
Pressure alarm will sound	CNT-1, C1,2, TPC
PI-7, or controller-1 show an out of tolerance pressure and the alarm has not gone off.	TPC
Pressure alarm will sound	TPC, PT5
No pressure reading, zero flow indication from computer, high computed gas leakage	FI-1, FI-1a
No reading	PT-11
No reading	PT-11, FI-1
PI-1 would show the pressure drop. Alarm	TPC, FI-1,1a, PT-11
F1 and F1-a would show zero flow.	FI-1,1a, PT-11
None	
PT-10 will show a higher pressure drop	PT-10
PT-10 will show a lower than normal pressure drop.	

Failure Detection	Affected Components
No pressure reading	F-4
FI-8 reads zero flow.	monitoring chamber,
FI-8 reads positive flow when it should be	FI-8
zero.	
No flow reading with SV-16 open	monitoring chamber
No reading.	TPC
No temperature reading.	monitoring chamber?
No pressure reading.	monitoring chamber?
No flow reading from FI-8, or FI9. PT3 alarm	monitoring chamber,
	fi-8, 9, TPC
The controller would detect that there is more	CNT-1
gas leaving the system than is entering the	
system.	
The controller may detect that there is more	monitoring chamber,
gas leaving the system than is entering the	CNT-1, PI-7, PT-5
system.	
PI-7 would show the increased pressure,	
PT-5 would sound the alarm.	
PI-4 would show the increased pressure,	TPC, PI-4, PT-2,5,8

Failure Detection	Affected Components
PT-2,5,8 would show the increased pressure	bubbler
and sound an alarm. SV18 opens.	FI-7, PI-1,3,4
Excess gas would flow through the bubbler.	
FI-1 will indicate no flow, PT-5,8 will	
sound an alarm.	
PI-4 would show the increased pressure,	TPC, PCV-4, PI-4,3
PT-2 would show the increased pressure.	PT-2
Excess gas would flow through the bubbler.	
PI-3 would show the increased pressure.	
No pressure reading	None, indicator only
No pressure reading	TPC
PI-4, PT-2 will show the TPC supply	PI-4, PT-2,5,8,11, TPC
pressure.	FI-1
PT-5,8 would sound an alarm, PI-4 would	
read low, No flow through FI-1, PT-11,	
excess leakage calculated by monitoring prog.	
PI-4, PT-2 will show a pressure drop	bubbler, TPC, PI-4,
	PT-2
High oxygen, water readings.	
No temperature reading	TPC
TT-4, TT-5 will show a higher than normal	TPC, TT-4,5

Failure Detection	Affected Components
temperature.	
TT-4, TT-5 will show a higher than normal	TPC, TT-4,5
temperature.	
No temperature reading	TPC
No pressure reading - cross check with	TPC, Insulation gap
PI5	
No pressure reading - cross check with PT7	None, indicator only
No temperature reading	TPC
No pressure reading	TPC
No pressure reading, high or low pressure	TPC
alarm	
No temperature reading	TPC
The controller would detect that there is more	CNT-1, PI-7, PT-5,6
gas leaving the system than is entering the	
system.	
No pressure drop upstream of compressors	
1&2-measured by PI-7, PT-6, PT-5.	
FI-2a would show zero flow	
	M4, FI-2a
none	
FI-2a or FI-2,3,4,9 would indicate a lower	FI-1,2a,2,3,4,5,6,9
than expected flow rate.	
FI1 would show increased gas flow.	
FI-1 would show no increase of gas leaving	
the recirculation loop.	

Failure Detection	Affected Components
FI-5 and 6 would show no flow of supply gas	
FI-2,3,4,9 would show gas flow when there	FI-2,3,4,9
should be none.	
FI-2,3,4,9 would show no flow. PSI alarm	
-	None
FI-5 would show no flow, longer than normal	M1, M2, M5
time to reduce oxygen and water levels.	
-	
FI-5 would show low flow,	
FI-6 would show no flow, longer than normal	TPC
time to reduce oxygen and water levels.	
-	
FI-6 would show low flow,	
-	-

Failure Detection	Affected Components
-	
-	M3a, M4
% CH4 to Ar will increase, M4 will read	
100% CH4, M3a will show the increase - alarm	
-	
-	M3a, M4
% Ar to CH4 will increase, M4 will read	
0% CH4, M3a will show the decrease - alarm	
Water,oxygen slowly rise.	TPC, M1, M2
Flow thorough FI-1 would approach zero,	TPC, FI-1, PT-11, M4
PT-11 would show zero, PT-11, No reading	M3a
in pressure drop across FM-4	
FM-1,PT-11 would show decreased flow to	
vent line. M4, M3a would show increase in	
%CH4 - alarm	
%CH4 low on M4, M3a. FI-1 & PT-11 hi -alarm	
%CH4 hi on M4, M3a. FI-1 & PT-11 low-alarm	
No flow reading. %CH4 rising on M3a, M4	TPC, M3a, M4, PT-11
FI-1 & PT-11 would show low readings	FI-1,2,3,4,9
during startup. During purging FI-2,3,4,9	
will show no flow.	
%CH4 low on M4, M3a. FI-1 & PT-11 hi	
%CH4 hi on M4, M3a. FI-1 & PT-11 low	
No flow reading	TPC, M3a, M4

Failure Detection	Affected Components
No flow reading, M4 would show low %CH4,	TPC, M3a, M4, FI-1,
M3a would show a falling %CH4 - alarm	PT-11
M4 would show high % CH4, M3a would	
should a rising %CH4. FI-1 and PT-11	
would have high values - alarm	
No flow reading, M4 would show low %CH4,	
M3a would show a falling %CH4 - alarm	
None	FM-5
-	
None	FM-4
FM-4 would read zero flow.	
None	FM-3
-	
Unable to get the correct ratio of Ar to CH4	FM-2, FM-1
by adjusting FM-1	
FM-2 would read zero flow.	
FM-1 reads flow when it should be zero.	FM-1, FM-2
FM-1 reads zero flow.	
-	TPC, FI-5, M4, M3a
FI-5 would show no flow, longer than normal	

Failure Detection	Affected Components
time to reduce oxygen and water levels.	
FI-5 would show flow. M4 & M3a would	
show decreasing % CH4 - alarm	
-	TPC, FI-6, M4, M3a
FI-6 would show no flow, longer than normal	
time to reduce oxygen and water levels.	
FI-6 would show flow. M4 & M3a would	
show increasing % CH4	
FM-4 would show a decreasing flow rate.	FM-4
FM-4 would show an increased flow rate	
FM-1 would show a decreasing flow rate.	FM-1
FM-1 would show an increased flow rate	
FI-6, FM1&2 would show zero flow.	FI-6, FM-1,2
	Inert gas supply lines.
M4 would detect high methane and alarm.	

Failure Detection	Affected Components
FM-2 or FM-1 would show no flow, M3a &	FM1,2, M3a, M4, TPC
M4 would show zero % CH4.	
M3a & M4 would show CH4 in the system.	
No pressure reading	-
-	-
FM-2 or FM-1 would show no flow, M3a &	FM1,2, M3a, M4, TPC
M4 would show zero % CH4.	
-	
Excess usage of methane.	
FM-2 or FM-1 would show no flow, M3a &	FM1,2, M3a, M4, TPC
M4 would show zero % CH4.	
M3a & M4 would show CH4 in the system.	
The PI on the PCV-6 regulator would indicate	PI on PCV-6, PSV-4,
the pressure was above the set point on	PSV-4b
PSV-4a	
Excess usage of methane	
FM-2 or FM-1 would show no flow, M3a &	FM1,2, M3a, M4, TPC
M4 would show zero % CH4.	PI-9, PSV-4a
The PI on the regulator & PI-9 will show low	
pressure - alarm.	
The PI on the regulator & PI-9 will show hi	
pressure.	

Failure Detection	Affected Components
The downstream pressure indicator on either	PI on PCV6a or 6b
PCV-6a or 6b will show a pressure above	
the relief pressure.	
-	FM1,2, M3a, M4, TPC
FM-2 or FM-1 would show no flow, M3a &	
M4 would show zero % CH4.	
-	FM1,2, M3a, M4, TPC
FM-2 or FM-1 would show no flow, M3a &	
M4 would show zero % CH4.	
-	FM1,2, M3a, M4, TPC
FM-2 or FM-1 would show no flow, M3a &	
M4 would show zero % CH4.	
-	FM1,2, M3a, M4, TPC
FM-2 or FM-1 would show no flow, M3a &	
M4 would show zero % CH4.	
FM-2 or FM-1 would show no flow, M3a &	FM1,2, M3a, M4, TPC
M4 would show zero % CH4. - alarm	
Excess methane usage.	
FM-2 or FM-1 would show no flow, M3a &	FM1,2, M3a, M4,
M4 would show zero % CH4.	PSV-4b
The downstream pressure gage on the	
regulator would show the low pressure	
Excess methane usage	
-	FM1,2, M3a, M4, TPC
FM-2 or FM-1 would show no flow, M3a &	

Failure Detection	Affected Components
M4 would show zero % CH4 - alarm	
-	FM1,2, M3a, M4, TPC
FM-2 or FM-1 would show no flow, M3a &	
M4 would show zero % CH4 - alarm	
If the appropriate valve were open, MV26a or	PI-14, PI-9
b, the upstream PI on the PCV-6 regulator	
could be used to check the pressure.	
PI9 alarm on low pressure.	
No pressure reading - alarm	None, indicator only
The pressure indicator on PCV-6a will show	PCV-6a, FM-1
insufficient pressure. FM-1 will show zero	
flow. PI9 alarm on low pressure.	
The pressure indicator on PCV-6b will show	PCV-6b, FM-1
insufficient pressure. FM-1 will show zero	
flow. PI9 alarm on low pressure.	
-	secondary 6-pack
The upstream PI on PCV-6a shows no	
pressure while the upstream	
PI on PCV-6b shows the secondary 6-pack	
is in use.	
-	FM1,2, M3a, M4, PI9
FM-2 or FM-1 would show no flow, M3a &	
M4 would show zero % CH4.PI9 alarm	
Excess methane usage.	
No gas out the purge line.	
Excess methane usage.	
No gas out the purge line.	
No pressure reading - alarm.	-

Failure Detection	Affected Components
-	FI-5, FI-6, TPC
FI-5, FI-6 may show reduced flow rate	
Low pressure alarm PI13, PI8	
None	TPC data
Insufficient decrease of Ar in the Ar dewars.	
Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
Insufficient decrease of Ar in the Ar dewars.	TPC data
Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
No pressure reading	-
Insufficient decrease of Ar in the Ar dewars.	TPC data, PI-8
Monitoring chamber may pick up	

Failure Detection	Affected Components
the discrepancy in the inert gas properties.	
PI-8 will show a high pressure reading	
No pressure reading - alarm.	-
	Ar 6-pack, PI-13
Insufficient decrease of Ar in the Ar dewars.	
The pressure gage on the Ar 6-pack will	
show a steady decrease in available gas.	
PI-13 would show low pressure, PI-12	PI-12,13
would show no pressure - alarm.	
No gas flowing out the purge line	
PI-13 would show low pressure, PI-12	PI-12,13, PSV-14
would show no pressure - alarm.	
None	
-	Ar 6-pack
Insufficient decrease of Ar in the Ar dewars.	
The pressure gage on the Ar 6-pack will	
show a steady decrease in available gas.	
PI-13 would show low pressure, PI-12	PI-12,13
would show no pressure.	
None	
-	Ar 6-pack
Insufficient decrease of Ar in the Ar dewars.	
The pressure gage on the Ar 6-pack will	
show a steady decrease in available gas.	

Failure Detection	Affected Components
No Pressure	-
The pressure gage on the Ar 6-pack will	PI on Ar 6 pk,
show a steady decrease in available gas.	
The pressure gage on the Ar 6-pack will not	
show a steady decrease in available gas.	
?Takes a higher voltage to spark across the	
spark gap. Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
-	PI on Ar 6 pk,
The pressure gage on the Ar 6-pack will not	
show a steady decrease in available gas.	
Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
The pressure gage on the Ar 6-pack will	PI on Ar 6 pk, CV-15
show a steady decrease in available gas.	
None, to the press. gage on the Ar 6-pack will	
show a steady decrease in available gas.	
The pressure gage on the Ar 6-pack will	PI on Ar 6 pk
show a steady decrease in available gas.	
No flow out the purge line	
None	PI on Ar 6 pk,
The pressure gage on the Ar 6-pack will not	
show a steady decrease in available gas.	
Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
gas venting from PSV-9	PSV-9, PI on Ar pk
The pressure gage on the Ar 6-pack will not	

Failure Detection	Affected Components
show a steady decrease in available gas.	
Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
FI-5,6 will show no flow	FI-5,6
Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
FI-5,6 will show no flow	FI-5,6
N2 dewars empty quicker, FI-12,13,14,15	N2 dewars, FI-12,13,
may show reduced flow rates	FI-14,15
Monitoring chamber may pick up	
the discrepancy in the inert gas properties.	
No pressure reading	-
FI-5,6, 12,13,14, 15 will show no flow	FI-5,6, 12,13,14,15
	PI-11
FI-12,13,14,15 will show low flow rate	
PI-11 would show high pressure, Pressure	
on Ar dewars would not decrease as expected.	
No pressure reading - alarm	-
-	FI-5,6, 12,13,14,15
FI-5,6, 12,13,14, 15 will show no flow - alarm	PI-11
FI-5,6, 12,13,14, 15 will show no flow	FI-5,6, 12,13,14,15
Alarm from PI15	PI-11
No gas flow out the vent line	
-	FI-5,6, 12,13,14,15

Failure Detection	Affected Components
FI-5,6, 12,13,14, 15 will show no flow	PI-11
Alarm from PI15	
FI-5,6, 12,13,14, 15 will show no flow	FI-5,6, 12,13,14,15
	PI-11
-	FI-5,6, 12,13,14,15
FI-5,6, 12,13,14, 15 will show no flow	PI-11
Alarm from PI15	
The PI on the N2 cylinder will show a	PI on N2 cylinder
decreasing pressure when there is still LN	TPC, M3a, M4, PI-10
PI-10 shows no pressure after the LN dewars	
run out.	
-	TPC, M3a, M4, PI-10
PI-10 shows no pressure after the LN dewars	
run out.	
The PI on the N2 cylinder will show a	PI on N2 cylinder
decreasing pressure when there is still LN	TPC, M3a, M4, PI-10
The PI on the N2 cylinder will show a	
decreasing pressure when there is still LN	
The PI on the N2 cylinder will show a	PI on N2 cylinder
decreasing pressure when there is still LN	TPC, M3a, M4, PI-10
No flow out the purge line	
None	TPC, M3a, M4, PI-10
PI-10 shows no pressure after the LN dewars	
run out.	

Failure Detection	Affected Components
N2 venting from PSV-6, and The PI on the N2	PSV-6, PI on PCV-8
cylinder will show a decreasing pressure	
when there is still LN	
PI on the regulator will show the pressure	
to low.	
PI on the regulator will show no decrease in	
the pressure in the cylinder	
PI on the regulator will show no decrease in	PI on PCV-8
the pressure in the cylinder	
FI-16 would read zero flow	Laser
FI-16 would read zero flow	Laser
FI-12, 13 will show no flow	M3a, 4
FI-12 reads zero flow	M4
FI-13 reads zero flow	M3a
FI-12 will read zero flow	TPC
FI-12 will read zero flow	TPC
FI-12 will read zero flow	TPC
FI-14 will read zero flow	M4, TPC
FI-14 will read zero flow	M4, TPC

Failure Detection	Affected Components
No flow in FT10, M6, M7 readings increase.	TPC, FT10, M6, M7,gap
FT-10 would read zero flow	TPC, FT-10, M6, M7
	gap
No Pressure reading - alarm	
PT-15 will read a high pressure	PT-15, PSV-5,50, M6
	M7,
M6 and M7 may will detect 02 and H20 in the	
line.	
FT-10 would read zero flow	FT-10
FT-10 would show flow	
No flow reading for the insulation gas supply	-
none	PSV-11, M6,M7
M6 and M7 may will detect 02 and H20 in the	
line.	
FT-10, 50,51,54,55 would read zero flow	FT-10,50,51,54,55
-	
FT-50 would show zero flow	FT-50, spark gap
	PT-5, PT-7
PT-5, PT-7 would show the pressure	
differential between the insulation gap and the	
drift volume as being to high.	
FT-51 would show zero flow, Spark gap would	FT-51, spark gap

Failure Detection	Affected Components
break down.	PI-5, PT-7
PI-5, PT-7 would show the pressure	
differential between the insulation gap and the	
drift volume as being to high.	
FI-54,55 would show no flow	FI-54, 55, M6,7
-	
FI-54,55 would show no flow	FI-54, 55, M6,7
None	
FI-54,55 would show no flow	FI-54, 55, M6,7
FI-54,55 would show the flow being to high	FI-54,55
?	TPC

Failure Detection	Affected Components
FI-55 would read zero flow	FI-55
No reading/ erroneous reading?	TPC
No reading/ erroneous reading?	TPC
	-