JSC Building 32 Facility
Fault Tolerance

Kenneth Anderle

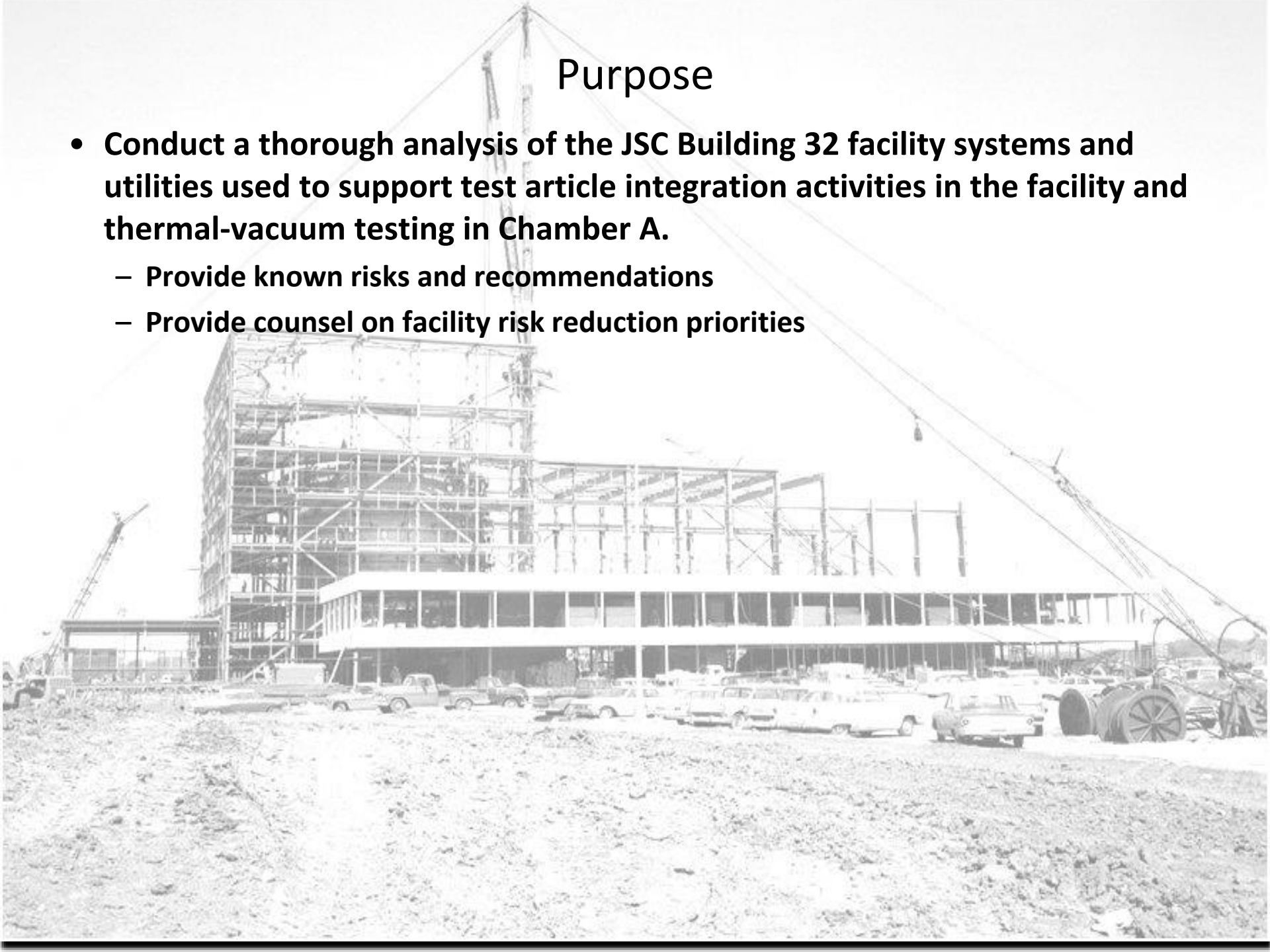
September 20, 2016

Agenda

- Purpose
- Background
- Methodology
- Findings/Lessons Learned
- Actions Taken
- Summary
- Questions

Purpose

- **Conduct a thorough analysis of the JSC Building 32 facility systems and utilities used to support test article integration activities in the facility and thermal-vacuum testing in Chamber A.**
  - **Provide known risks and recommendations**
  - **Provide counsel on facility risk reduction priorities**



Background

- Why did we conduct this review?

Primary: Identify risk to the James Webb Space Telescope program and provide recommendations on risk-reduction measures

Secondary: Validate and update the facility Failure Modes and Effects Analysis (FMEA) in an effort to understand the facility's fault tolerance

Methodology

- **Step 1**: Identify all major facility systems & utilities
  - Helium refrigeration plant(s)
  - Liquid Nitrogen storage and distribution system
  - Rough vacuum system
  - High vacuum system(s)
  - Chamber airflow management system
  - Facility heating, ventilation, & air conditioning (HVAC)
  - Normal & emergency power
  - Data acquisition, recording, & controls system
  - Facility steam system
  - Facility chilled water system
  - Cooling tower
  - Closed loop cooling water
  - Etc…

Methodology

- **Step 2**: Break systems down into components and/or sub-systems and populate into a matrix with supporting utilities.

JOHNSON SPACE CENTER - BLDG 32 - CHAMBER A SUPPORT SYSTEMS AND UTILITY MATRIX

JSC DIVISION	JA					BLDG 32 SYSTEMS															
MAIN UTILIITES OR BACKUP SYSTEMS	*BLDG 24*			*CITY*	*GRID*													*B32 BACK UP SYSTEMS*			
COMPRESSED AIR (SITE)																					
STEAM (SITE)																					
CHILLED WATER (SITE)																					
POTABLE WATER (SITE)																					
NORMAL POWER (SITE)																					
EMERGENCY POWER (B32)																					
UPS (B32)																					
UTILITIES X = UTILIZED UTILITY 1 = PERSONNEL INJURY/DEATH (CRITICALITY 1) 2R = BACKUP SYSTEM (CRITICALITY 2R) (R=REDUNDANT) 2 = VULNERABLE COMPONENT (CRITICALITY 2) 3 = LOST/COMPRIMISED TEST OBJECTIVE (CRITICALITY 3) 4 = NEGLIGIBLE EFFECT (CRITICALITY 4)	COMPRESSED AIR	STEAM	CHILLED WATER	POTABLE WATER	NORMAL POWER	LIQUID NITROGEN	NITROGEN	CHAMBER REPRESS (GN2)	HELIUM	VACUUM	DEIONIZIED WATER	COOLING TOWER WATER	CLOSED LOOP COOLING (CHILLER CARTS)	3RD FLOOR CLOSED LOOP P-115, P-116	CH A PIT CLOSED LOOP COOLING WATER (P-117, P-118)	RM 1904 CLOSED LOOP COOLING WATER (B24 CHILLED WATER)	HOT WATER	EMERGENCY POWER (B32 GENERATOR)	UPS	TEMPORARY ENVIORNMENTAL CONTROL SYSTEM	BACKUP COMPRESSED AIR & ACCUMULATOR
VACUUM SYSTEM																					
MAIN BACKING PUMPS & PROCESS VALVES																					
MAIN BLOWER VACUUM PUMPS & PROCESS VALVES																					
MAIN CONTROLS FOR ROUGHING																					
MAIN ROUGHING CRYOBAFFLE																					
HI-VAC -TMP VACUUM BACKING PUMPS & VALVES																					
HI-VAC - CONTROLS FOR TURBO PUMP BACKING																					
HI-VAC - CONTROL SYSTEM PLC																					
HI-VAC TURBOPUMPS																					
HI-VAC CRYOPUMPS																					
HI-VAC TMP CRYOBAFFLE																					
HI-VAC GATE VALVE S(TMP'S AND CMP'S)																					

Methodology

- **Step 3**: Identify system and utility dependencies and populate into the matrix.
  - Dependencies should be identified and evaluated for individual system components and/or subsystems to the extent possible
  - Start off by simply marking with an “X” if there is a dependency

Methodology

It should look something like this…

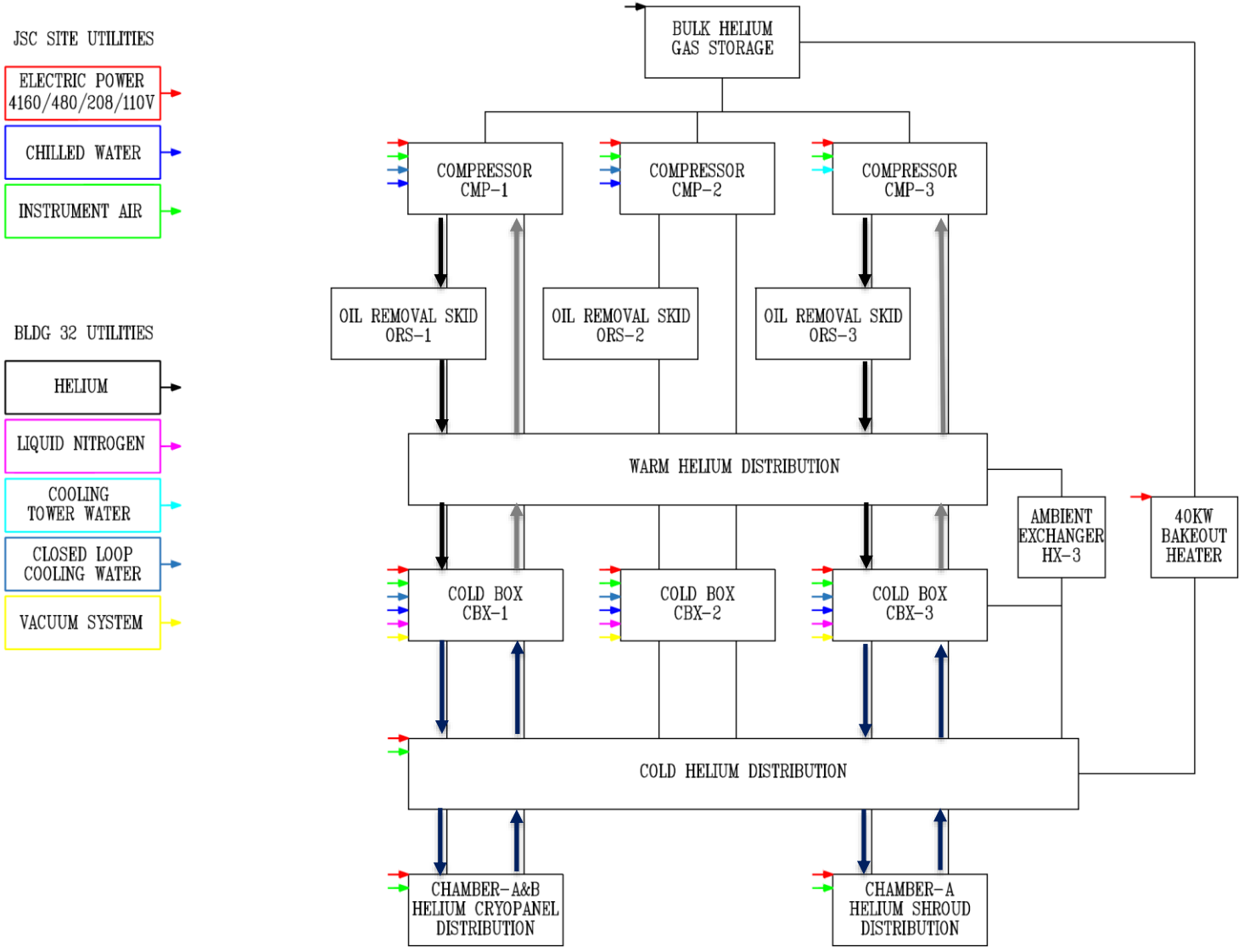
JOHNSON SPACE CENTER - BLDG 32 - CHAMBER A SUPPORT SYSTEMS AND UTILITY MATRIX																					
JSC DIVISION	**JA**					**BLDG 32 SYSTEMS**															
MAIN UTILIITES OR BACKUP SYSTEMS	***BLDG 24***			***CITY***	***GRID***													***B32 BACK UP SYSTEMS***			
COMPRESSED AIR (SITE)		X	X	X		X	X	X	X	X		X	X	X	X	X	X				
STEAM (SITE)							X										X				
CHILLED WATER (SITE)									X	X		X	X	X	X	X					
POTABLE WATER (SITE)		X	X						X	X	X	X	X	X	X	X	X				
NORMAL POWER (SITE)	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
EMERGENCY POWER (B32)						X	X	X	X	X	X	X	X	X	X	X	X				
UPS (B32)						X	X	X		X											
UTILITIES X = UTILIZED UTILITY 1 = PERSONNEL INJURY/DEATH (CRITICALITY 1) 2R = BACKUP SYSTEM (CRITICALITY 2R) (R=REDUNDANT) 2 = VULNERABLE COMPONENT (CRITICALITY 2) 3 = LOST/COMPRIMISED TEST OBJECTIVE (CRITICALITY 3) 4 = NEGLIGIBLE EFFECT (CRITICALITY 4)	COMPRESSED AIR	STEAM	CHILLED WATER	POTABLE WATER	NORMAL POWER	LIQUID NITROGEN	NITROGEN	CHAMBER REPRESS (GN2)	HELIUM	VACUUM	DEIONIZIED WATER	COOLING TOWER WATER	CLOSED LOOP COOLING (CHILLER CARTS)	3RD FLOOR CLOSED LOOP P-115, P-116	CH A PIT CLOSED LOOP COOLING WATER (P-117, P-118)	RM 1904 CLOSED LOOP COOLING WATER (B24 CHILLED WATER)	HOT WATER	EMERGENCY POWER (B32 GENERATOR)	UPS	TEMPORARY ENVIORNMENTAL CONTROL SYSTEM	BACKUP COMPRESSED AIR & ACCUMULATOR
VACUUM SYSTEM																					
MAIN BACKING PUMPS & PROCESS VALVES	X				X							X			X						X
MAIN BLOWER VACUUM PUMPS & PROCESS VALVES	X				X							X			X						X
MAIN CONTROLS FOR ROUGHING					X																
MAIN ROUGHING CRYOBAFFLE					X		X											X			
HI-VAC -TMP VACUUM BACKING PUMPS & VALVES	X			X	X					X		X		X	X			X			X
HI-VAC - CONTROLS FOR TURBO PUMP BACKING					X													X	X		
HI-VAC - CONTROL SYSTEM PLC					X			X		X								X			
HI-VAC TURBOPUMPS				X	X					X			X					X			
HI-VAC CRYOPUMPS					X	X	X			X								X			
HI-VAC TMP CRYOBAFFLE					X	X				X								X			
HI-VAC GATE VALVE S(TMP'S AND CMP'S)	X				X			X		X								X			X

Methodology

- **Step 4**: Evaluate systems for component/subsystem loss to determine those that result in system shut down/failure.
  - This is in line with your Failure Modes & Effects Analysis (FMEA)
  - This needs to be evaluated for each phase of your test/operation (as applicable). For example:
    - Chamber @ rough vacuum, ambient temp
    - Chamber @ high vacuum, ambient temp
    - Chamber @ 80K (LN2 shrouds full cold)
    - Chamber < 80K, but > 32K (helium shrouds cooling)
    - Chamber < 32K (helium shrouds full cold)

Methodology: Helium Systems

Nominal Operations



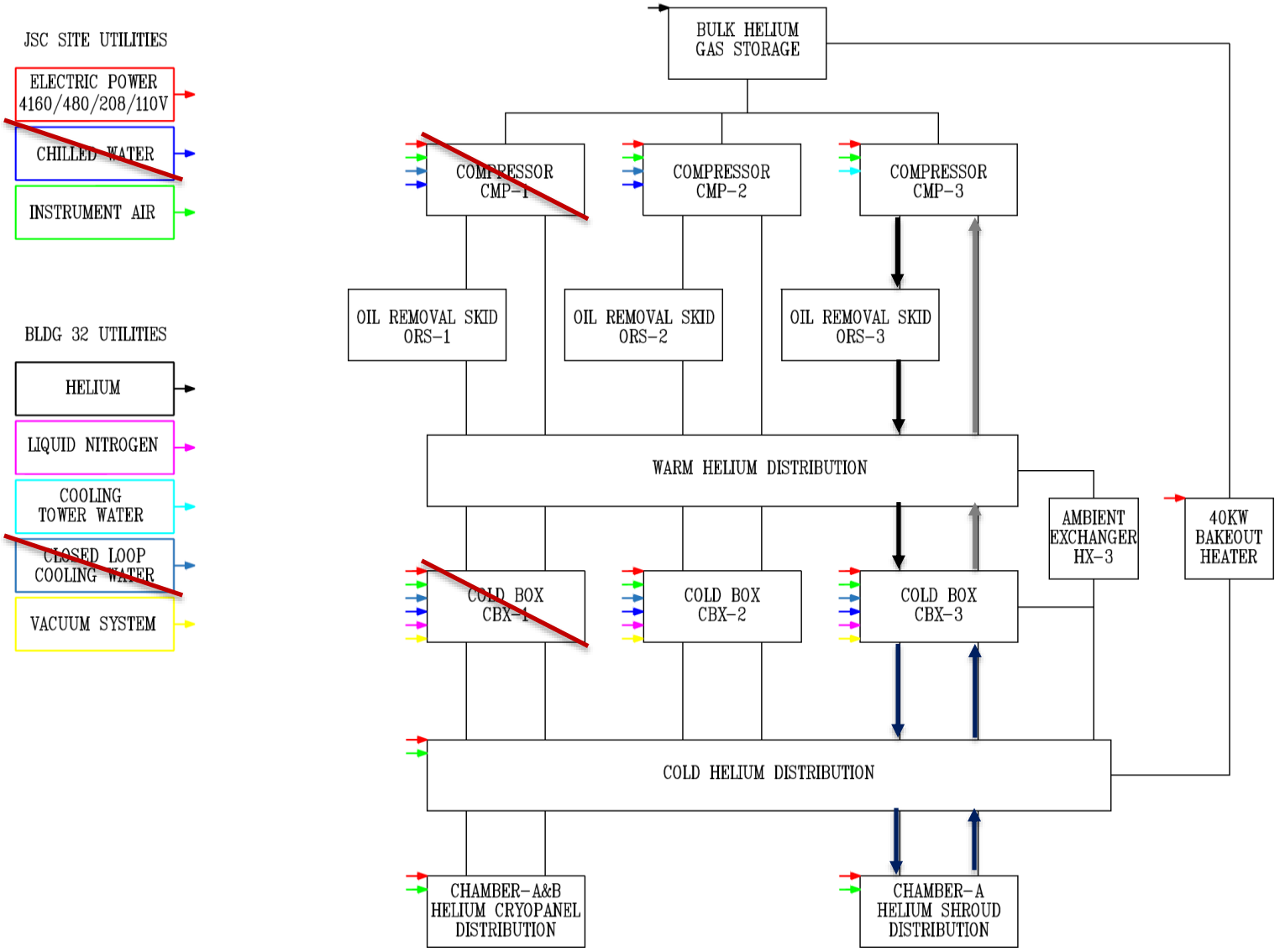
Methodology: Helium Systems

Off-Nominal Operations

Off-Nominal Ops	Criticality	Failure Mode	Cause	Effects
Mode #1	2/3	Helium Train 1	Subsystem Single Point Failure: CMP1, CBX1 Loss of Utility	Loss of Refrigeration to Helium CryoPumping Panels (CPP)
Mode #2	2R	Compressor 3	Single Point failure Loss of Utility	Loss of Refrigeration to main Helium shroud/TA Zones
Mode #3	2R	Coldbox 3	Single Point failure	Loss of Refrigeration to main Helium shroud/TA Zones
Mode #4	2	Helium Zones	Zone Leakage, Zone Control Valve Failure	Loss of thermal control of Helium Zone
Mode #5	2R	DARAC	Single Point failure	Loss of sub-system data monitoring and HMI control screens
Shutdown	2	Helium Plant	Loss of Utility	Loss of Refrigeration to Helium CPP, main Helium shroud/TA Zones

Methodology: Helium Systems

Off-Nominal #1: Loss CW, CLCW, on Train 1



Methodology: Helium Systems

- Effect: Loss of Refrigeration to the Helium CryoPumping Panels
- Test Impacts: Criticality 2 / 3
  - Cooldown / Warm-Up: Released of Condensed Gas (“Burp”) from CPP
  - Steady State: Condensed Gas transfers to the main Helium Shrouds
- Controls:
  - System designed for 24-7 operations
  - TGL22 Turbine
    - MTBF: 190,500 hrs
    - MTTR: 3 hrs with spare
- Recommendation:
  - Re-commission Helium Train 2 (inactive) as back-up

Methodology

- **Step 5**: Define system categories & use your failure mode analysis in previous step to determine what utility or component losses result in you realizing one of these category levels
  - Examples:
    - Category 1 – Loss of system could result in personnel injury or loss of life
    - Category 2 – Loss of system could result in damage to test article or other critical facility hardware and ground support equipment
    - Category 3 – Loss of system could result in loss of test objective or schedule delay
  - Update matrix to show Category numbers in lieu of an “X” where applicable

Methodology

And you get something like this…

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JSC DIVISION	JA					BLDG 32 SYSTEMS															
MAIN UTILIITES OR BACKUP SYSTEMS	*BLDG 24*			*CITY*	*GRID*													*B32 BACK UP SYSTEMS*			
COMPRESSED AIR (SITE)		X	X	X		X	X	X	X	X		X	X	X	X	X	X				
STEAM (SITE)							X										X				
CHILLED WATER (SITE)									X	X		X	X	X	X	X					
POTABLE WATER (SITE)		X	X						X	X	X	X	X	X	X	X	X				
NORMAL POWER (SITE)	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
EMERGENCY POWER (B32)						X	X	X	X	X	X	X	X	X	X	X	X				
UPS (B32)						X	X	X		X											
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VACUUM SYSTEM																					
MAIN BACKING PUMPS & PROCESS VALVES	2				2							2			2						X
MAIN BLOWER VACUUM PUMPS & PROCESS VALVES	2				2							2			2						X
MAIN CONTROLS FOR ROUGHING					2																
MAIN ROUGHING CRYOBAFFLE					2		X											X			
HI-VAC -TMP VACUUM BACKING PUMPS & VALVES	2			2	2					X		X		X	X			X			X
HI-VAC - CONTROLS FOR TURBO PUMP BACKING					2													X	X		
HI-VAC - CONTROL SYSTEM PLC					2			X		X								X			
HI-VAC TURBOPUMPS				2	2					X			X					X			
HI-VAC CRYOPUMPS					2	X	X			X								X			
HI-VAC TMP CRYOBAFFLE					2	X				X								X			
HI-VAC GATE VALVE S(TMP'S AND CMP'S)	2				2			X		X								X			X

Methodology

- **Step 6**: Eliminate or Mitigate your Risk
  - All Category 1 must be eliminated
  - All Category 2 should be eliminated or must be controlled/mitigated through redundancy
  - Category 3 can be eliminated/controlled if schedule & budget allow

Methodology

- **Step 7**: Evaluate for existing redundancy & update matrix
  - Does the redundant system have same capacity as the primary?
  - Does the redundant system fully meet requirements?
  - Is the redundant system fully operational?
  - Does the redundant system require reconfiguration to be employed?
    - Are procedures in place?
    - Are people trained?
    - How long does it take to reconfigure?

Methodology

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STEAM (SITE)							X										X				
CHILLED WATER (SITE)									X	X		X	X	X	X	X					
POTABLE WATER (SITE)		X	X						X	X	X	X	X	X	X	X	X				
NORMAL POWER (SITE)	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
EMERGENCY POWER (B32)						X	X	X	X	X	X	X	X	X	X	X	X				
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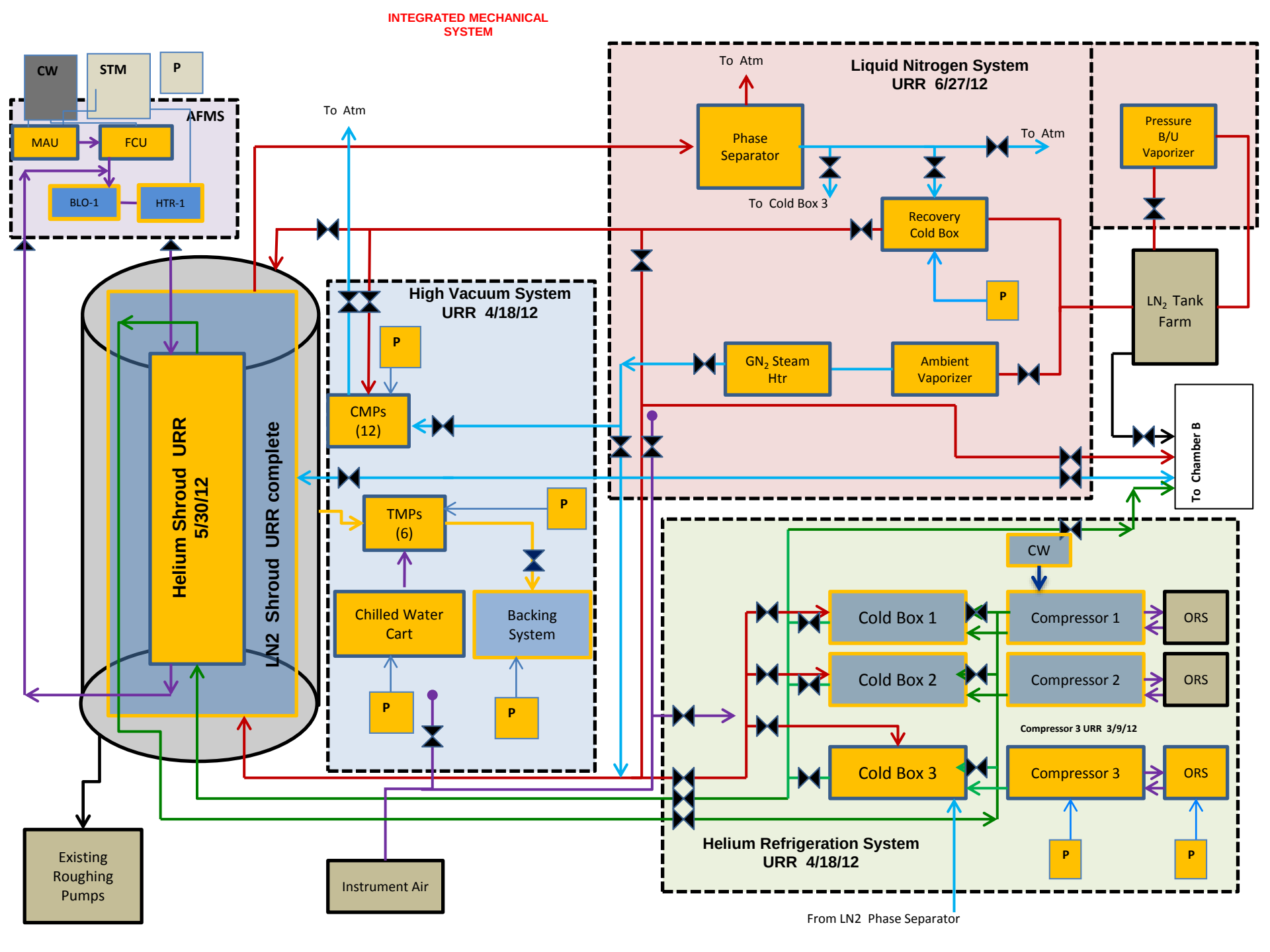
VACUUM SYSTEM																					
MAIN BACKING PUMPS & PROCESS VALVES	2R				2							2			2						X
MAIN BLOWER VACUUM PUMPS & PROCESS VALVES	2R				2							2			2						X
MAIN CONTROLS FOR ROUGHING					2																
MAIN ROUGHING CRYOBAFFLE					2R		X											X			
HI-VAC -TMP VACUUM BACKING PUMPS & VALVES	2R			2R	2R					X		X		X	X			X			X
HI-VAC - CONTROLS FOR TURBO PUMP BACKING					2R													X	X		
HI-VAC - CONTROL SYSTEM PLC					2R			X		X								X			
HI-VAC TURBOPUMPS				2R	2R					X			X					X			
HI-VAC CRYOPUMPS					2R	X	X			X								X			
HI-VAC TMP CRYOBAFFLE					2R	X				X								X			
HI-VAC GATE VALVE S(TMP'S AND CMP'S)	2R				2R			X		X								X			X
LIQUID NITROGEN (80 KELVIN)																					

Methodology

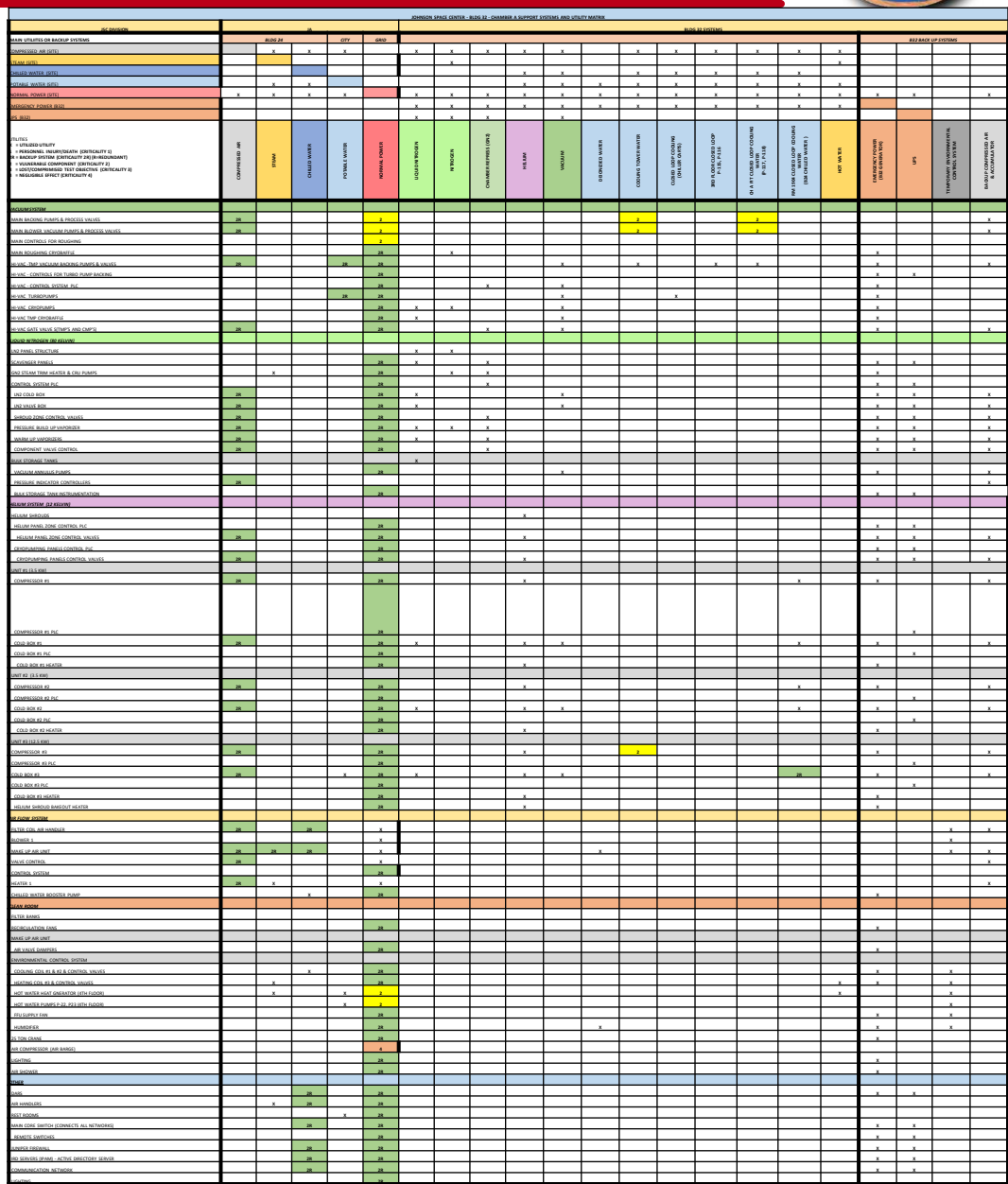
- **Step 8**: Address remaining critical areas and develop controls and/or system redundancy in order to reduce risk to an acceptable level

So, after completing this process for JSC Building 32, this is what we found…


INTEGRATED MECHANICAL SYSTEM
CW
STM
P
AFMS
MAU
FCU
BLO-1
HTR-1
To Atm
To Atm
Liquid Nitrogen System
URR 6/27/12
Phase Separator
To Atm
To Cold Box 3
Recovery Cold Box
P
Pressure B/U Vaporizer
LN2 Tank Farm
GN2 Steam Htr
Ambient Vaporizer
To Chamber B
High Vacuum System
URR 4/18/12
P
CMPs (12)
TMPs (6)
P
Chilled Water Cart
Backing System
P
P
Helium Shroud URR 5/30/12
LN2 Shroud URR complete
CW
Cold Box 1
Compressor 1
ORS
Cold Box 2
Compressor 2
ORS
Compressor 3 URR 3/9/12
Cold Box 3
Compressor 3
ORS
P
P
Helium Refrigeration System
URR 4/18/12
Existing Roughing Pumps
Instrument Air
From LN2 Phase Separator

Findings/Lessons Learned

- No Critical 1 areas identified
- Only a few Critical 2 areas were found
  - **Vacuum System**: Power & Cooling Water
  - **Helium Compressor (Train 3)**: Cooling Water
  - **Chamber A Environmental Control**: Cooling Water



Actions Taken: Vacuum System

- Placed chamber rough vacuum system & cooling tower pumps/fans on emergency power
  - Replaced power distribution
  - Installed new transfer switches & breaker panels
  - Rental generator (2MW) & diesel tank provide 5 days run-time

Actions Taken: Helium Compressor 3

- Placing cooling tower pumps/fan on emergency power eliminates failure mode due to loss of cooling water to compressor 3
- Additionally, identified operational method providing redundancy on train 3 using the compressor from train 1
  - Requires temporary shutdown and minor reconfiguration of valves
  - Replicated failure during test and observed no thermal or contamination concerns for time required to reactivate system
  - Although Compressor 1 is smaller, it demonstrated sufficient capacity to cool and maintain temperatures on GHe shrouds

Actions Taken: Chamber Airflow Management System

- Installed fully-redundant backup system run off a 1MW generator
  - Ties into system at makeup air unit on roof

Summary

- Although a time-consuming process, we gained a much better understanding of our facility systems and their level of fault tolerance

- We have a clear understanding of our risk and are confident that a facility system/utility failure will not negatively impact sensitive/critical hardware in the chamber

- Strongly recommend others take the time to implement this or a similar process prior to the next test of critical hardware

Questions