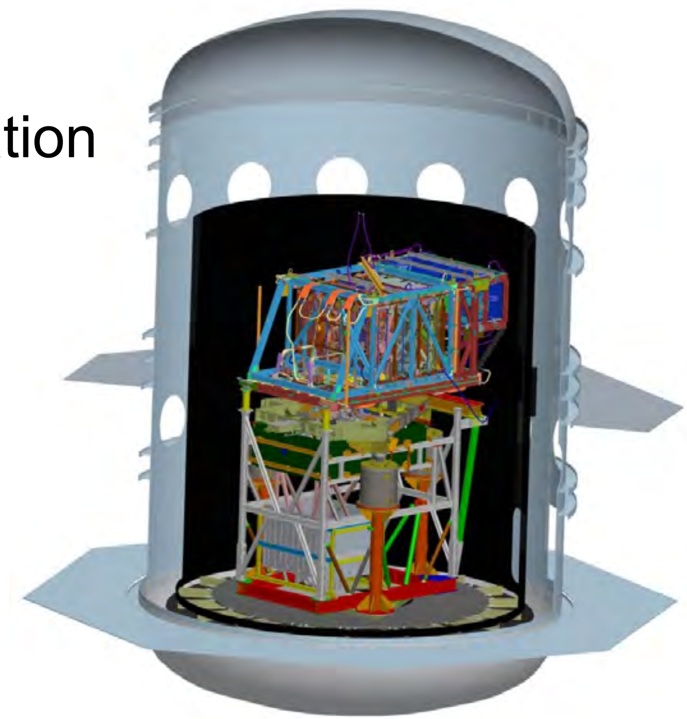
James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM) Cryo-Vac #3 (CV3) Thermal Vacuum Test

AIAA Working Group on Space Simulation
November, 2016

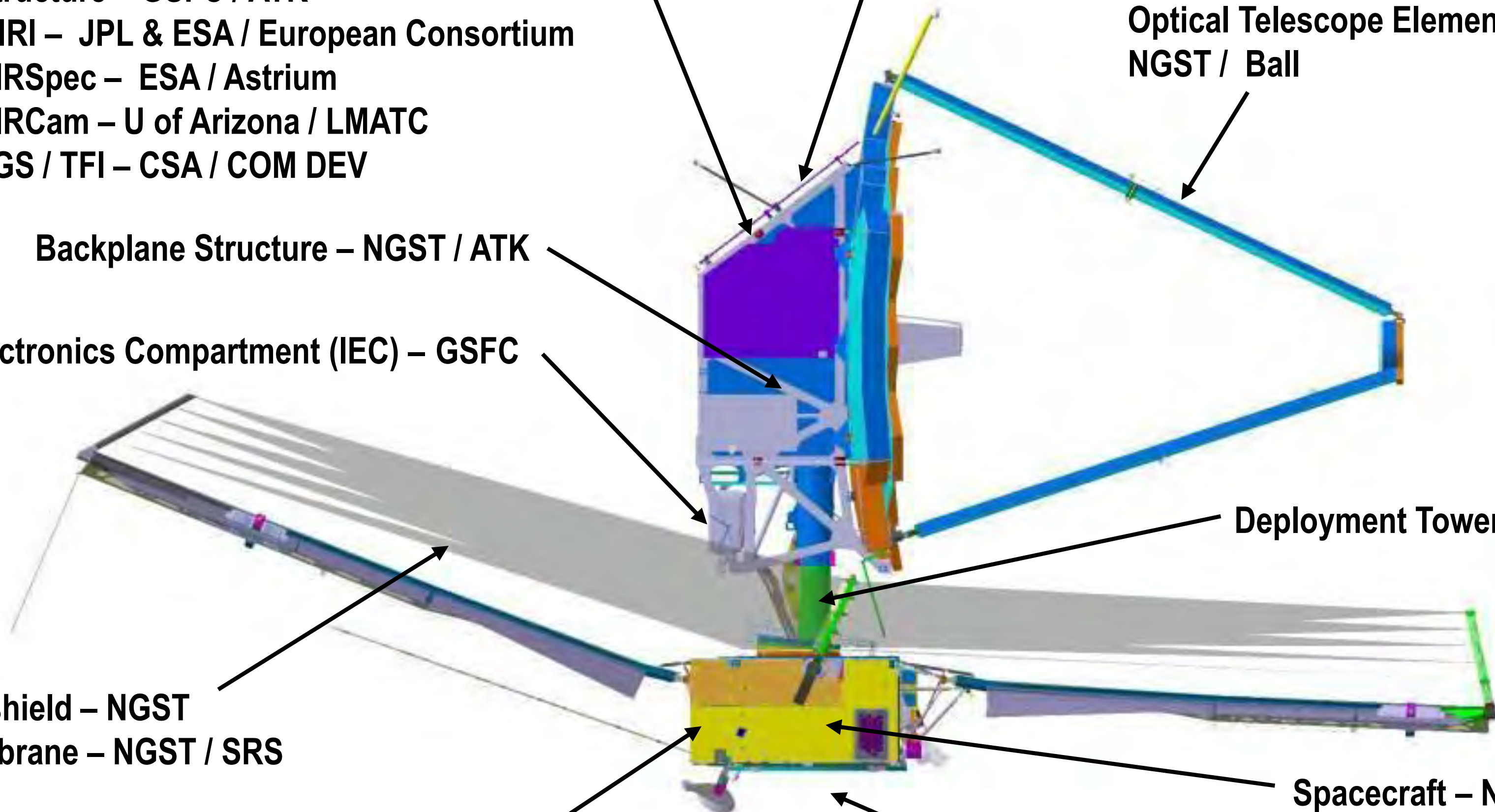


Ed Packard
NASA Goddard Space Flight Center

Presentation Outline

- CV3 Test Objectives
- CV3 Test Summary
- Test Configuration Overview
- Facility Equipment Performance
- Chamber Performance
- Lessons Learned
- Overall Test Conduct

James Webb Space Telescope



CV3 Test Objectives

Verify the ISIM System in its final configuration after environmental exposure and provide a post-environmental performance baseline, including critical ground calibrations needed for science data processing in flight.

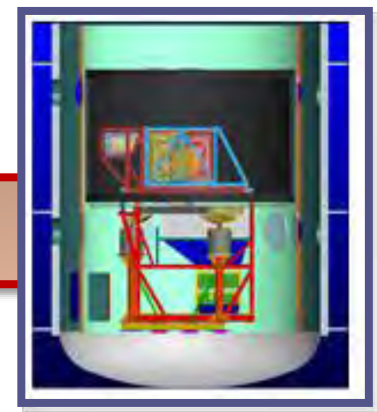
CV1 & CV2

CV1: Risk Reduction

CV2: Assess ISIM configuration & start system-level verification

Vibe, Acoustics, EMI

CV3



OTIS

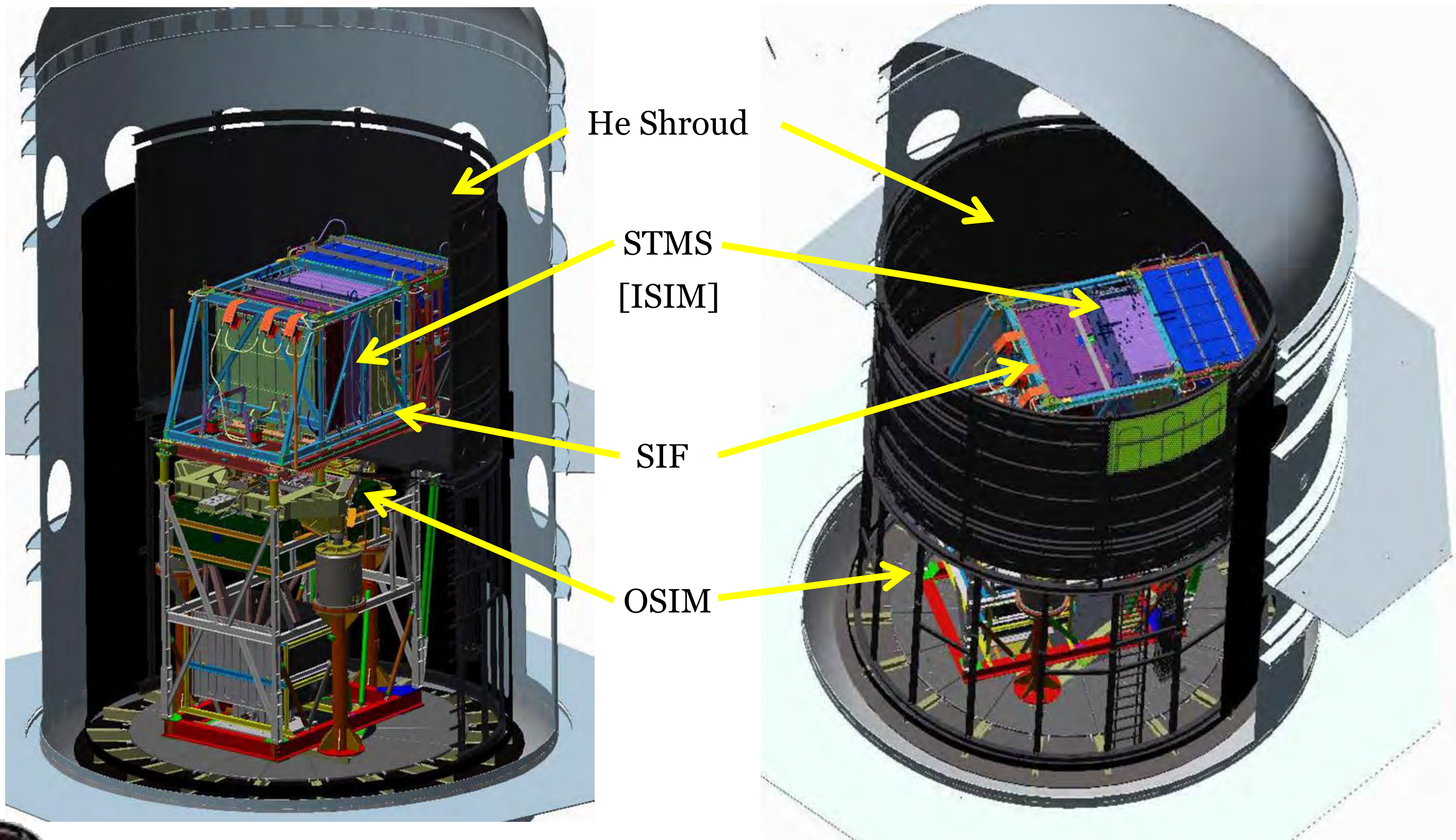
OTIS is the **O**ptical **T**elescope Element + **I**ntegrated **S**cience Instrument Module

ISIM CV3 Test Summary

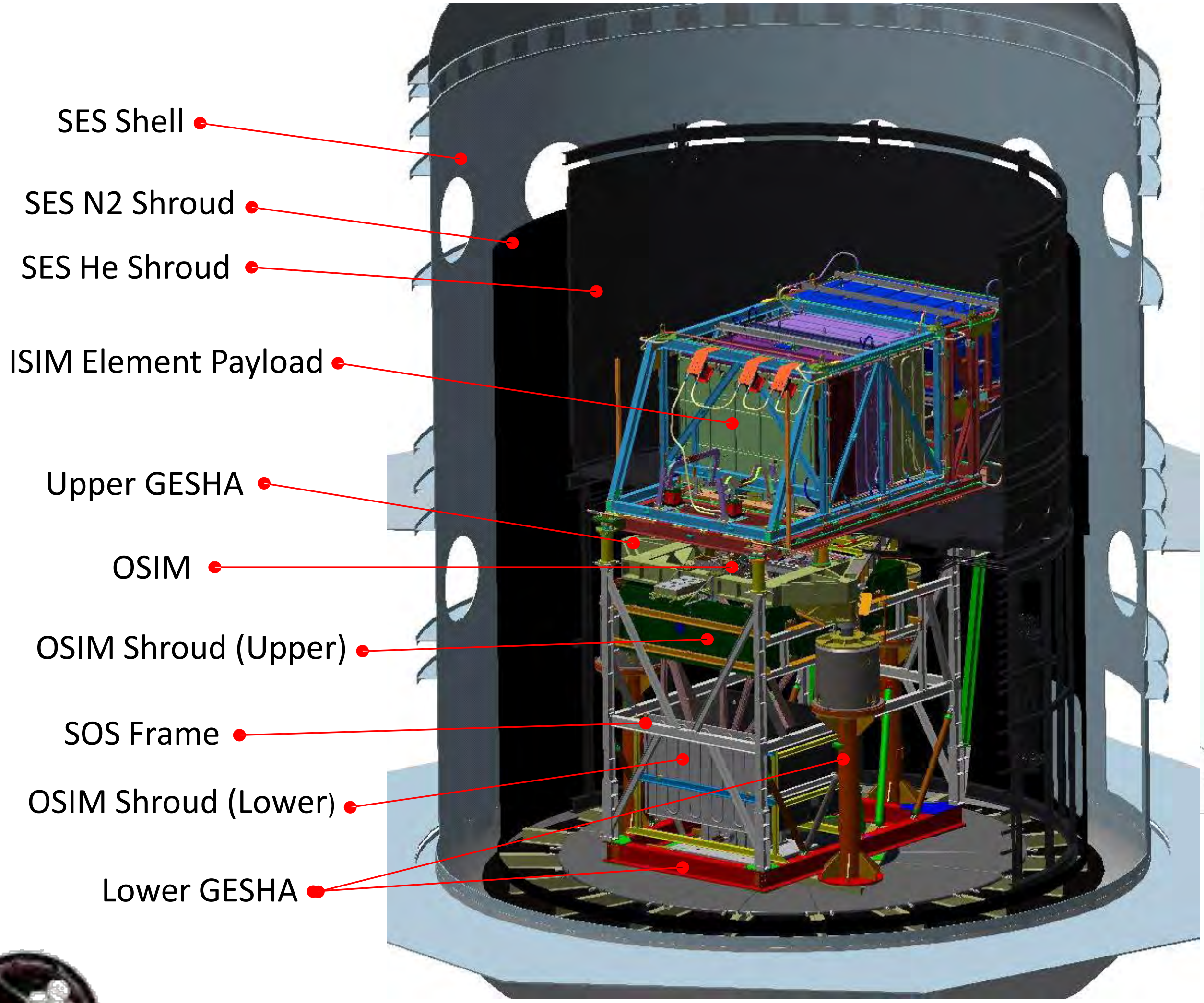
- Test dates: 10/27/2016 to 02/12/2016
- Test duration: 109 days
- He skid shut-downs: 1
- Power outages: 0
- ISIM lifted out: 02/18/2016
- Total consumables:
  - LN_2 = 935,000 gallons
  - Helium = 20 K bottles

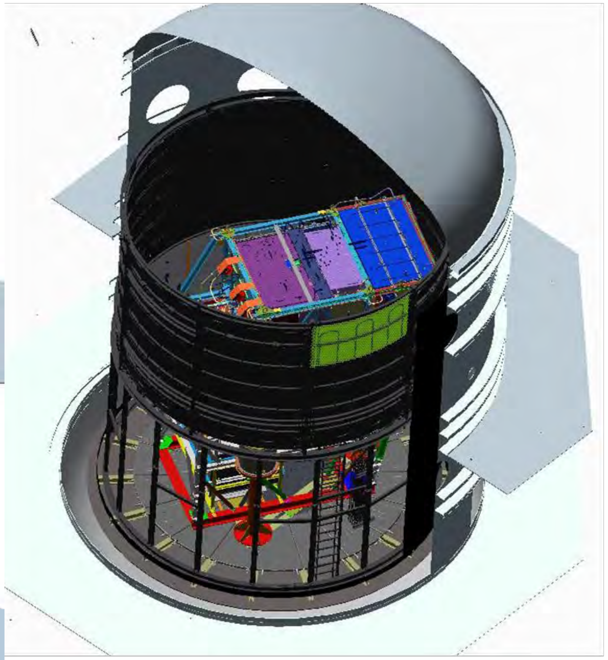
Test Set-Up for ISIM CV3

ISIM CV Testing Test Configuration



ISIM CV Testing Test Configuration





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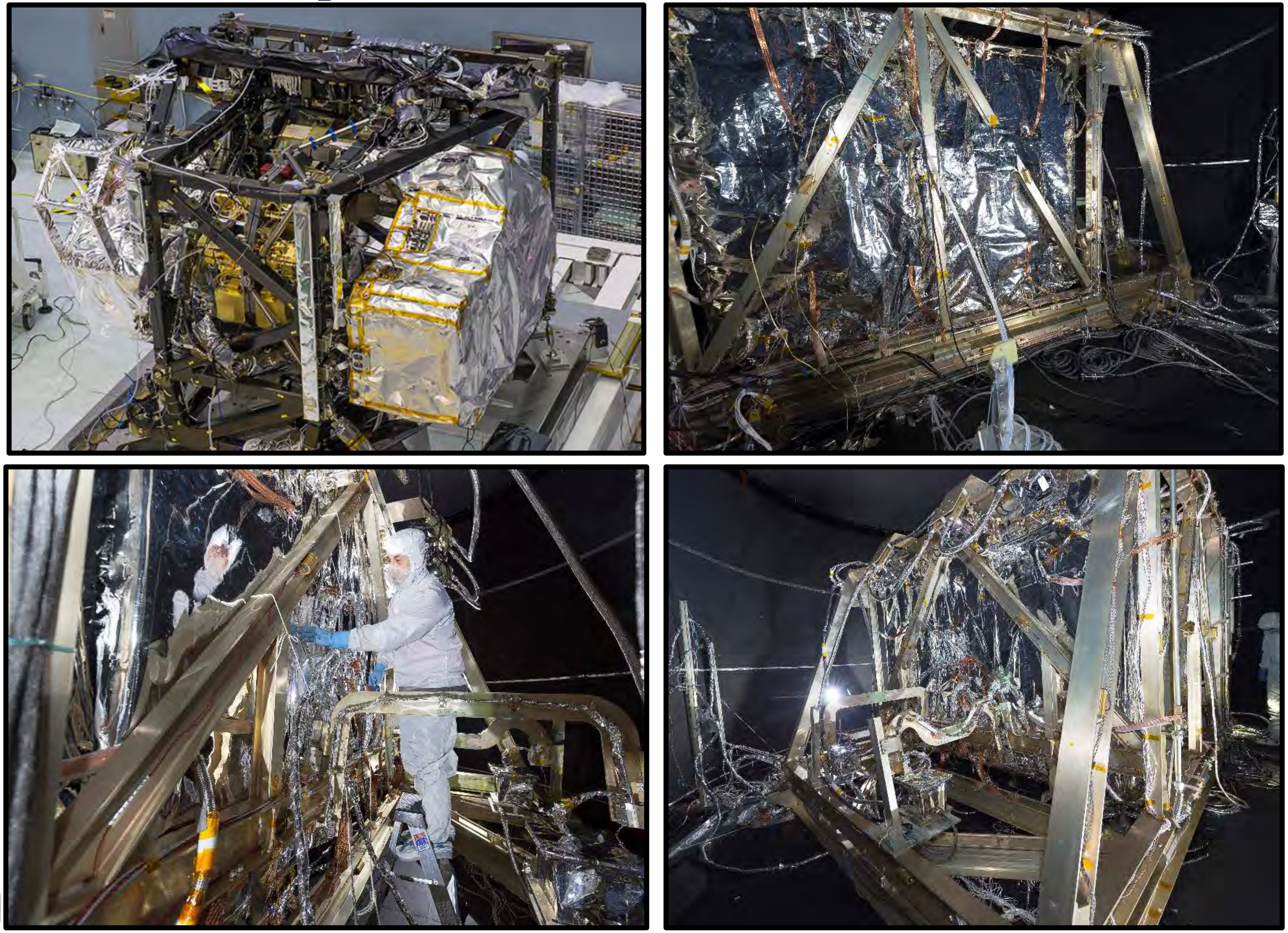

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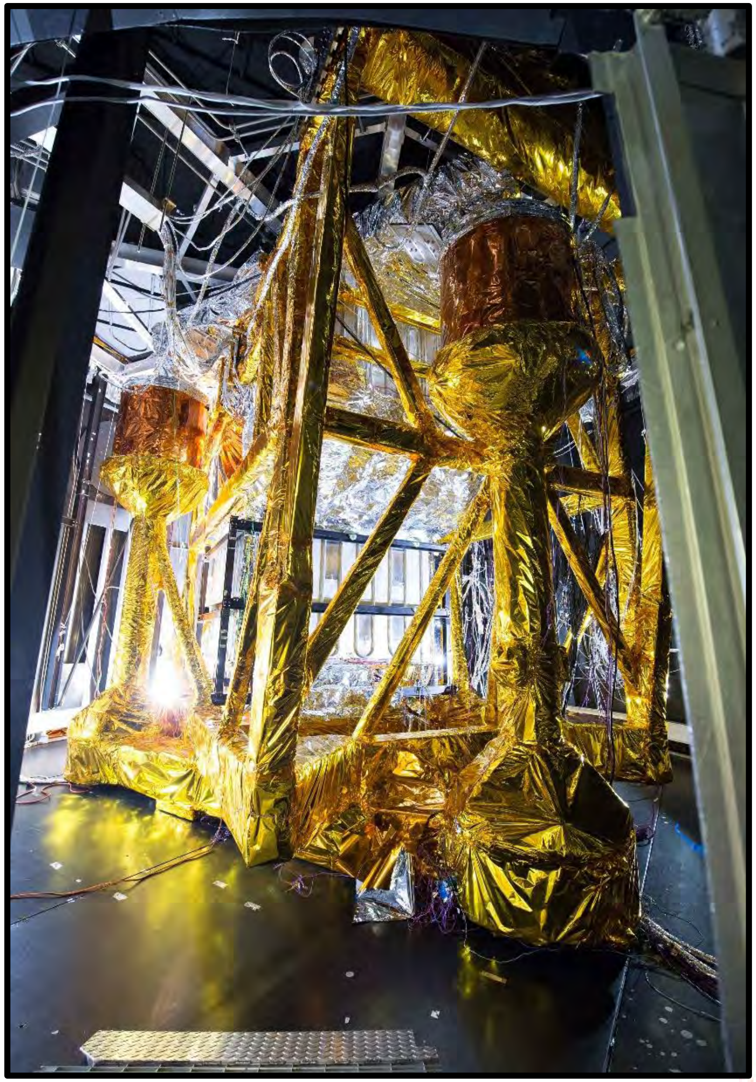


Facility Requirements for ISIM CV3

- Thermal Zones
  - SES Shroud (LN_2 → GN_2)
  - Helium Shroud (5 GHe circuits)
  - 41 Cryopanels
    - 4 TCUs
    - 6 LN_2-only lines
    - 5 GHe circuits (re-routing of some zones from CV1)
  - 171 Heater circuits
    - 9 Heater racks
    - 15 LS-336s
- Instrumentation
  - 979 monitoring sensors
    - 2 new diodes for CV3
    - 28 new Cernox sensors for CV3
    - 375 TCs (20 removed from CV2)
    - 604 other sensors
  - 193 heater control sensors

New in CV3	Description
1239-1240	HR GSE Blankets (diodes)
1357-1376	Flight Heat Straps (Cernox)
1580-1587	MIRI GSE Heat Straps (Cernox)

Instrumentation Reliability

TCs [10 of 375 = 2.7%]	4-wire sensors [9 of 604 = 1.5%]
63 – ISC NW mid	817 – He shroud
68 – ISC NW W strut	989 – MATF M-1
172 – OSIIM uppr panel	1027 – IEC shroud panel
258 – He shroud CQCM	1098 – PM-MS01
274 – UG	1131 – SIF 27
405 – PM bulkhead	1150 – PIM CCD
419 – OB upr truss –V3	1202 – ITP Bipod P2
420 – PM bulkhead	1203 – ITP Bipod P3
426 – OSIM	1204 – ITP Bipod P4
427 – OSIM bipod	

Total failure rate for CV3 monitoring sensors: **1.9%** (19 of 979 monitoring sensors failed)

CV2: 3.2%; CV1: 4.6% → improvement ~1.3% each test

Instrumentation Reliability: Power Supply Operation

- All heater racks functioned as required for the entire test duration
  - 9 heater racks
    - 141 circuits
  - 15 LS-336s
    - 30 circuits

Helium Skid Shutdowns

Total of one (1) helium skid shutdown

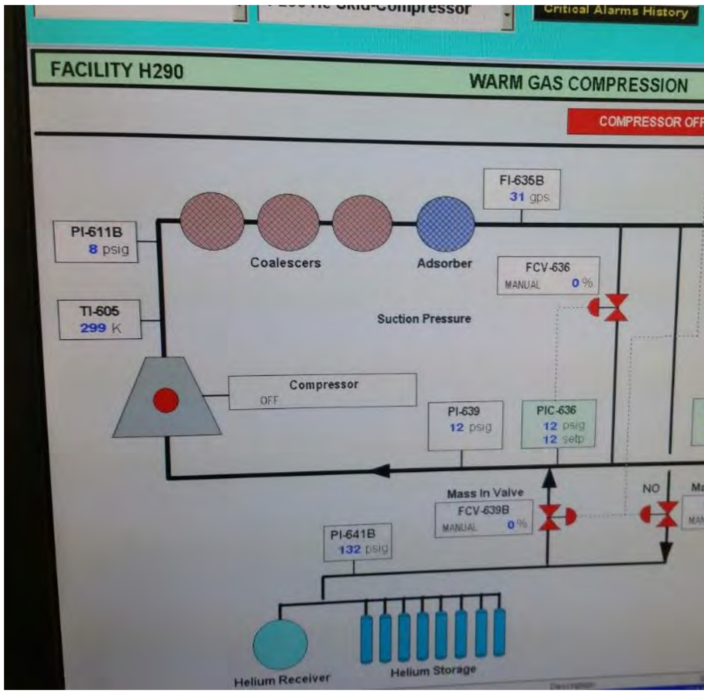
- In an attempt to expedite cool-down helium skid compressor start-up early
- Over-temp shut-down skid
- During pumpdown on 11/7/2015 0:10; minimal effect on the test

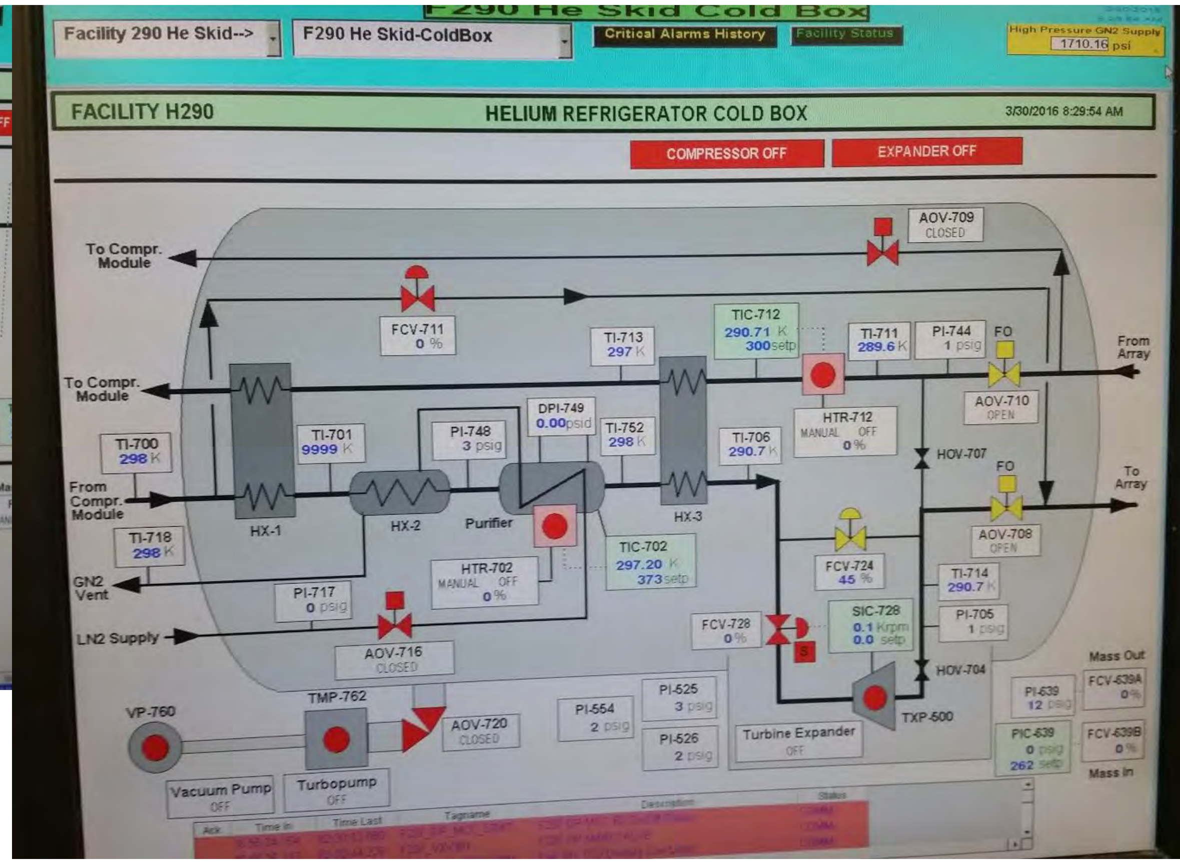
Response to a PR written about this:

Resolution: The helium skid did not lose power as stated in the PR. Instead, (only) the turbine was shut-down as a result the expander wheel hitting a inlet pressure alarm. The cross-over to turbine mode (from bypass mode) was accelerated because the differential pressure across the purifier was going up rabidly. The valve to the turbine was opened when the inlet temperature to the turbine was at 140K, instead of waiting for it to get to 100K. As a result, the higher inlet gas temperature corresponded to an inlet pressure that exceeded the limits of the expander wheel and consequently shut-down the turbine. In response, the turbine throttle valve immediately failed closed to 0%, and the bypass valve opened to almost 50%. The system (valve positioning) was restored to its configuration (prior to the turbine shutdown) well within 15 minutes. The result was a 10K spike in the expander outlet temperature (helium shroud inlet temperature), but the spike was back to its pre-shutdown temperature within 15 minutes. The effect on the helium shroud average temperatures was less than 0.5K.

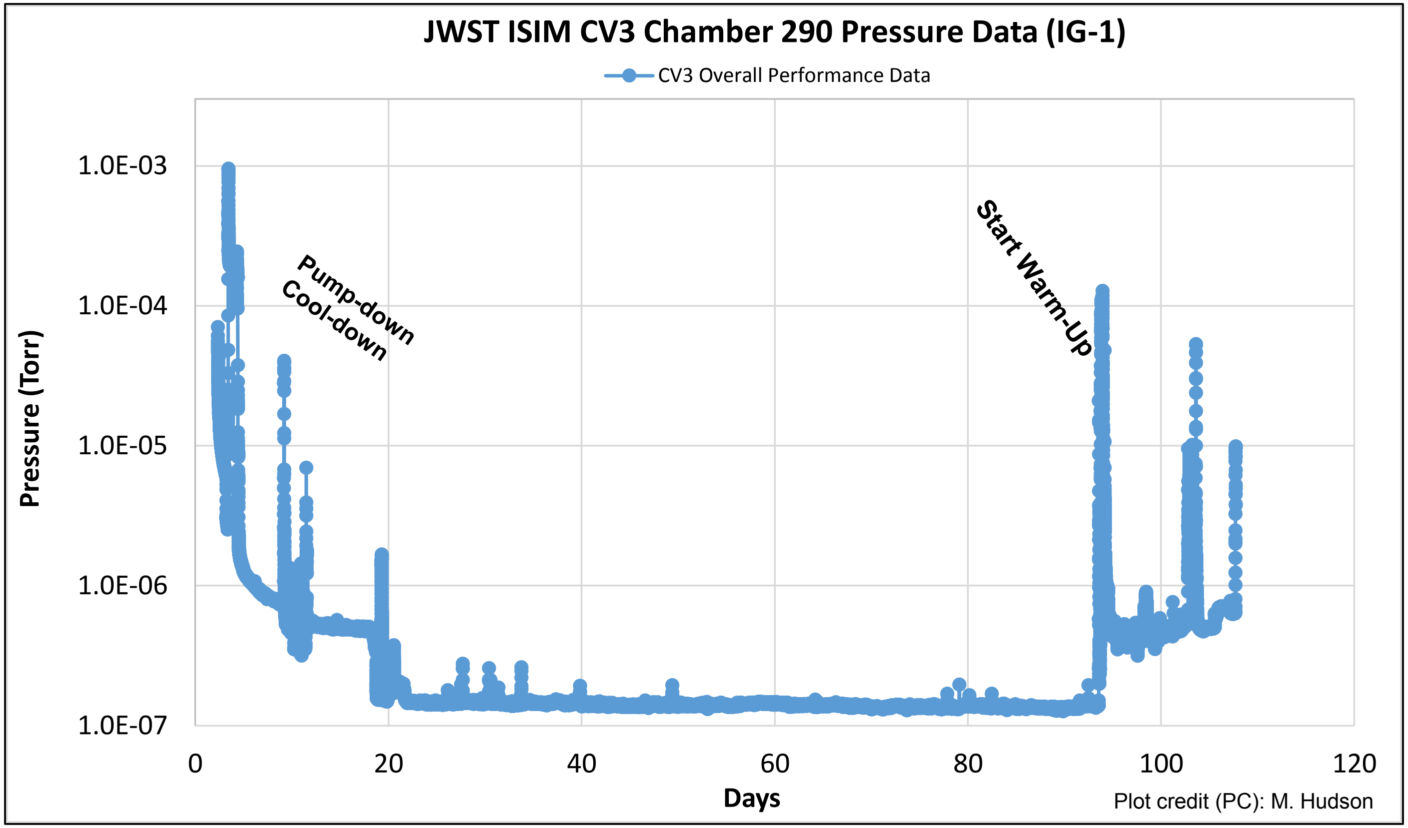
Helium Skid Shutdowns

Total of one (1) helium skid shutdown during pumpdown on 11/7/2015 0:10





Chamber Vacuum Performance



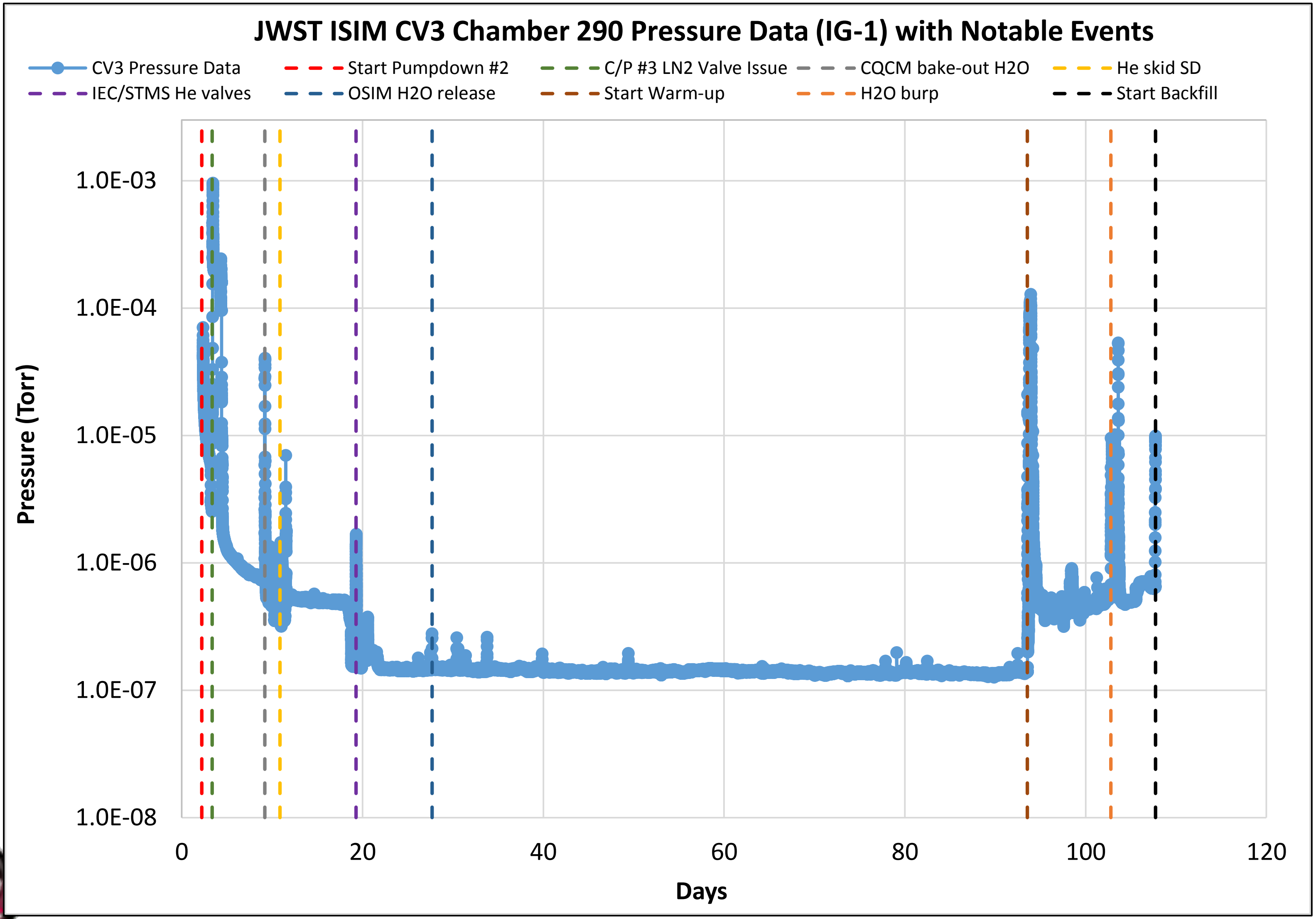
Pressure (Torr)	Time from start
5.0×10^{-5}	3.5 hrs (0.15 days)
1.0×10^{-5}	11.1 hrs (0.46 days)
5.0×10^{-6}	24.5 hrs (1.02 days)
1.0×10^{-6}	88.2 hrs (3.7 days)
5.0×10^{-7}	177.6 hrs (7.4 days)

Pump-down to 5×10^{-7} Torr took about 7.4 days from start of Pumpdown #2, after the initial leak was resolved

Chamber Vacuum Performance: Pumpdown CVs

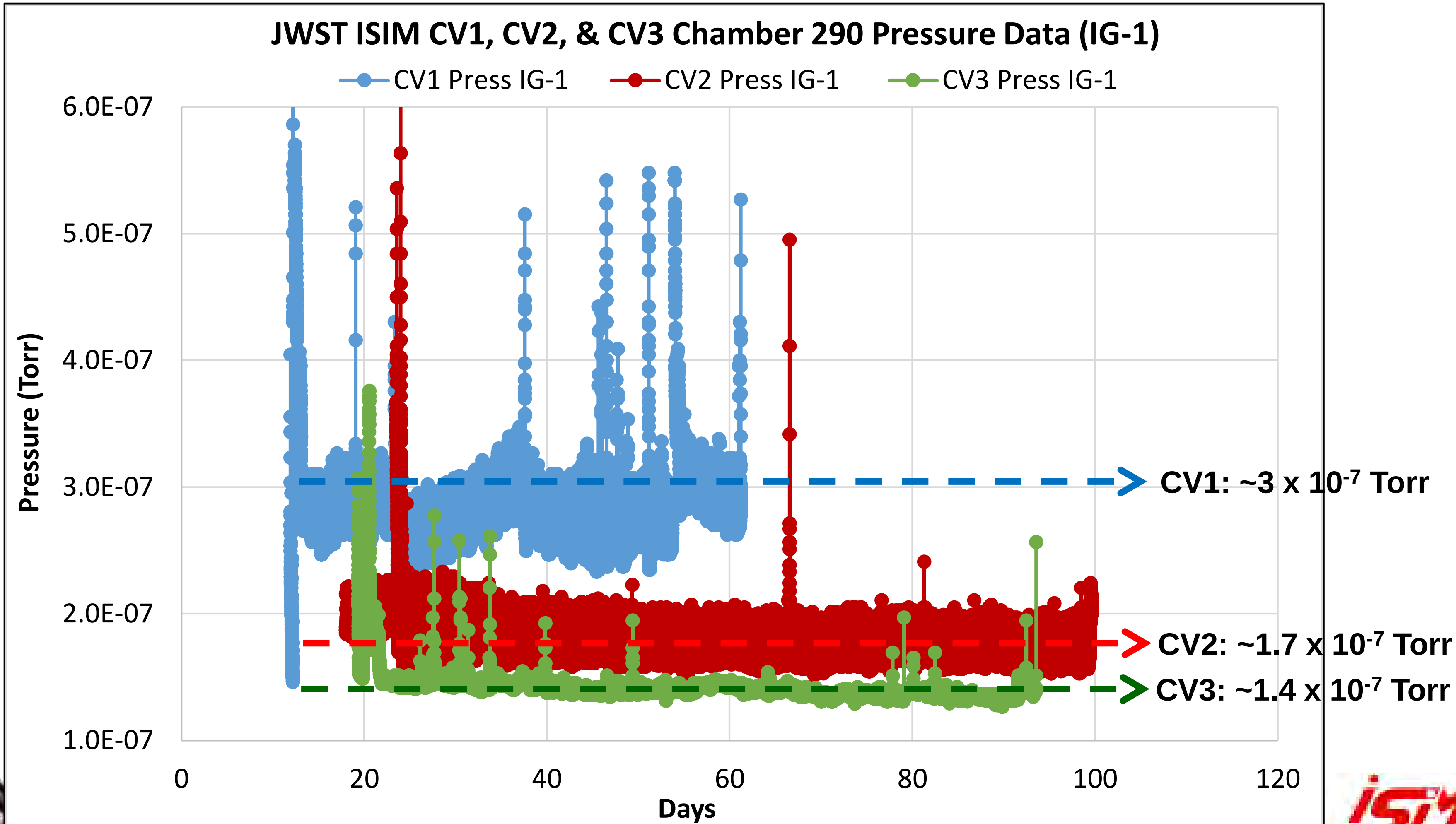
Pressure (Torr)	Time from start CV1	Time from start CV2	Time from start CV3
5.0×10^{-5}	29 hrs (1.2 days)	7.8 hrs (0.33 days)	3.5 hrs (0.15 days)
1.0×10^{-5}	35 hrs (1.5 days)	20.6 hrs (0.86 days)	11.1 hrs (0.46 days)
5.0×10^{-6}	46 hrs (1.9 days)	27 hrs (1.13 days)	24.5 hrs (1.02 days)
1.0×10^{-6}	108 hrs (4.5 days)	101 hrs (4.2 days)	88.2 hrs (3.7 days)
5.0×10^{-7}	128 hrs (5.3 days)	160 hrs (6.7 days)	177.6 hrs (7.4 days)

Chamber Vacuum Performance



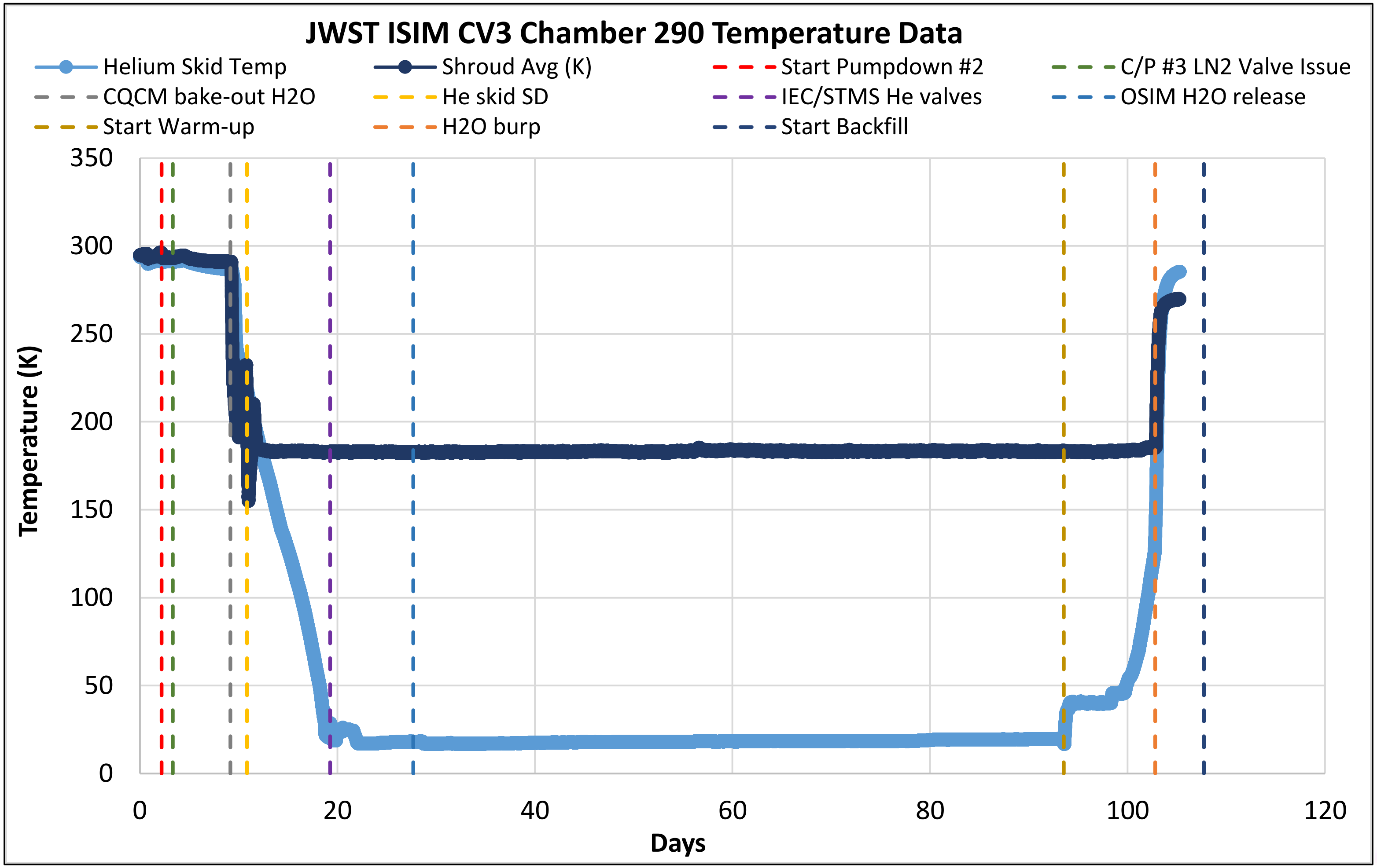
Chamber Vacuum Performance: CV1 vs. CV2 vs. CV3

During steady-state (cool-down & warm-up omitted), vacuum pressure improved with each CV test



Shrouds Temperature Performance

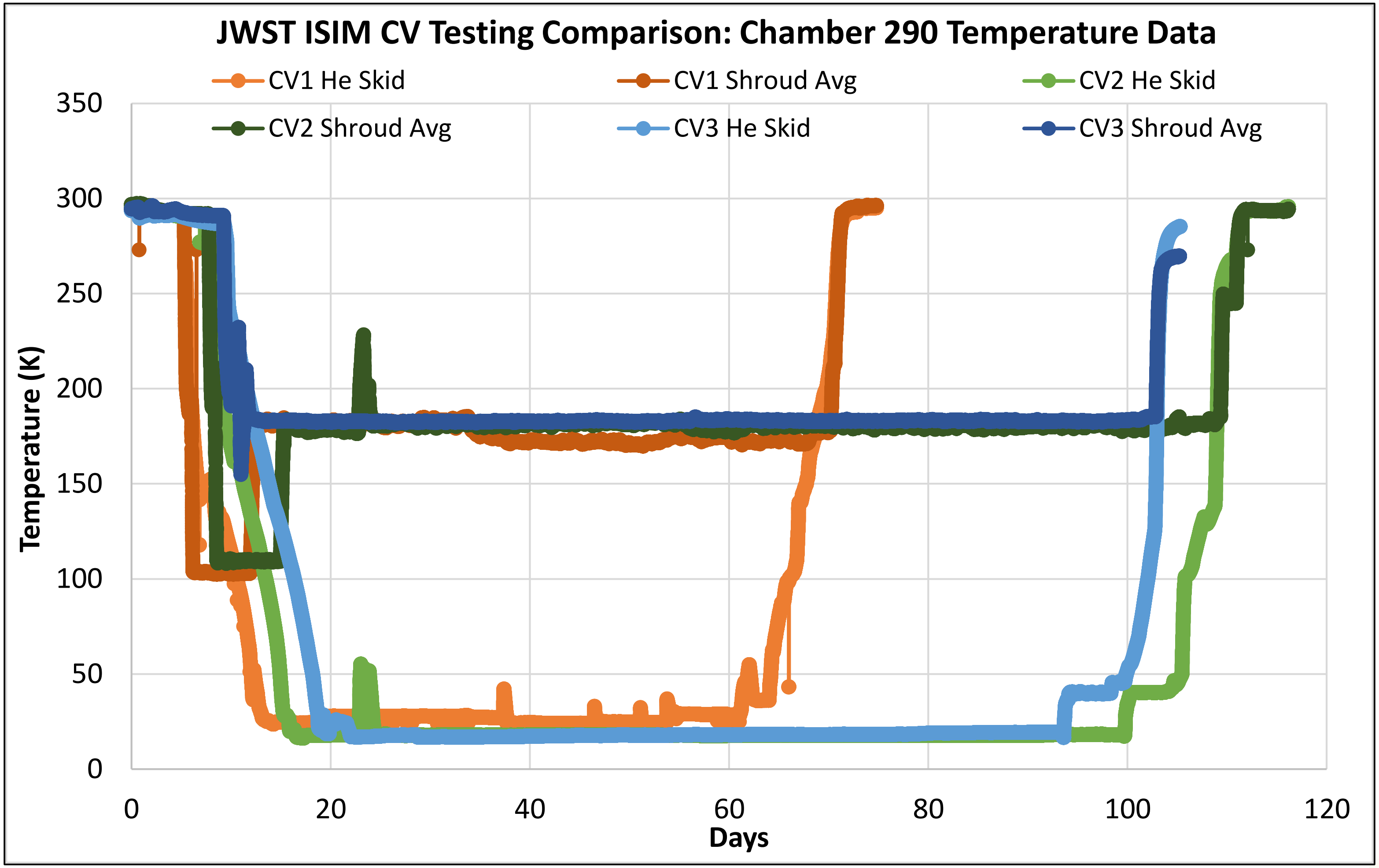
At steady state: Helium shroud average achieved: 18K ±1K || LN_2 shroud average: 180K ±3K



* = Switch $GN_2 \rightarrow LN_2$ (DAY 8 – 6/24/14 03:44)
$LN_2 \rightarrow GN_2$ (DAY 15 - 6/30/14 22:40)

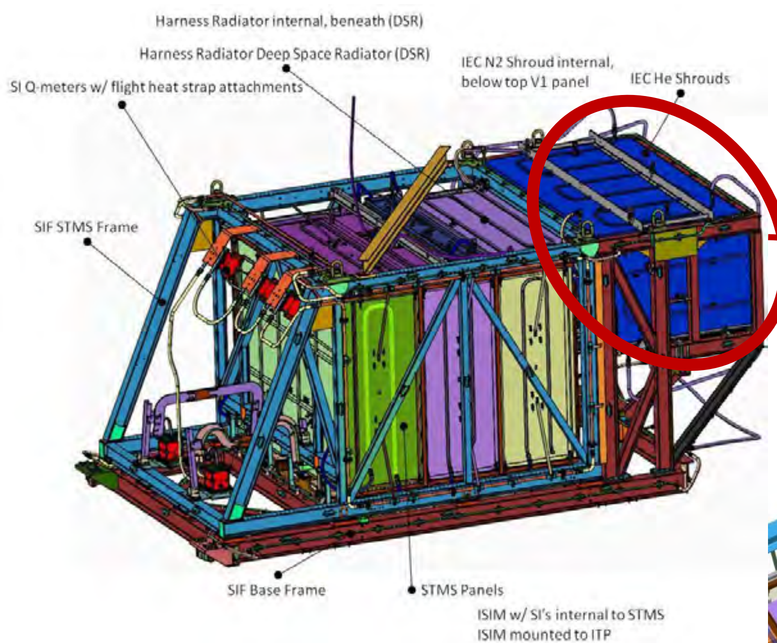
Shrouds Temp Performance CV1 vs. CV2 vs. CV3

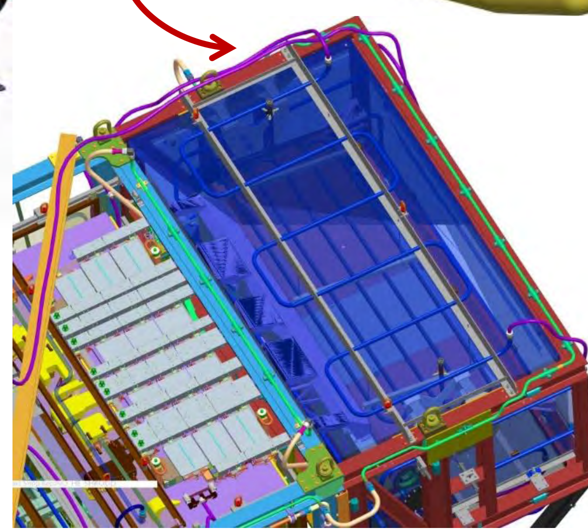
At steady state: Helium shroud average achieved: 18K ±1K || LN_2 shroud average: 180K ±3K

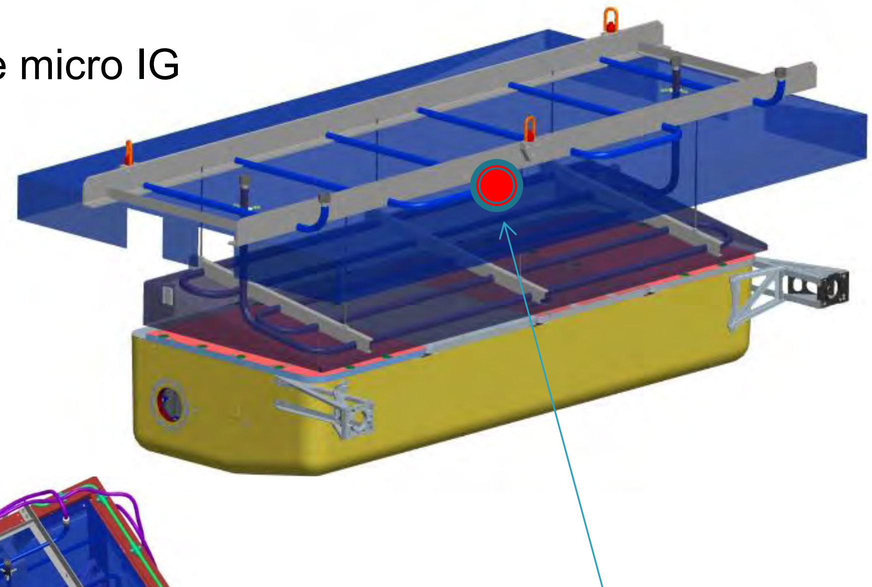


Notable Facility Changes Since CV1 → CV2 → CV3

- Micro Ion Gauges (IGs) for the ISIM Electronics Compartment (IEC)
  - CV2: moved one to IEC shroud volume
  - CV3: added redundant IEC shroud volume micro IG



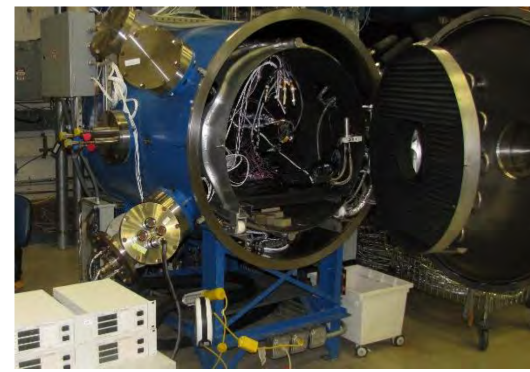


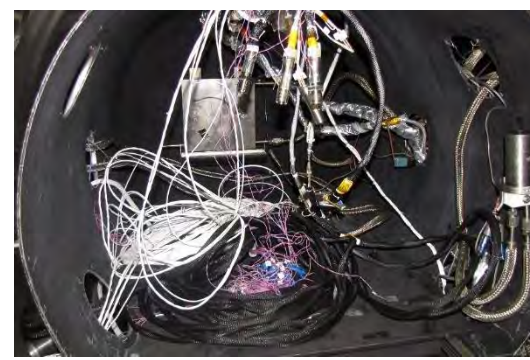


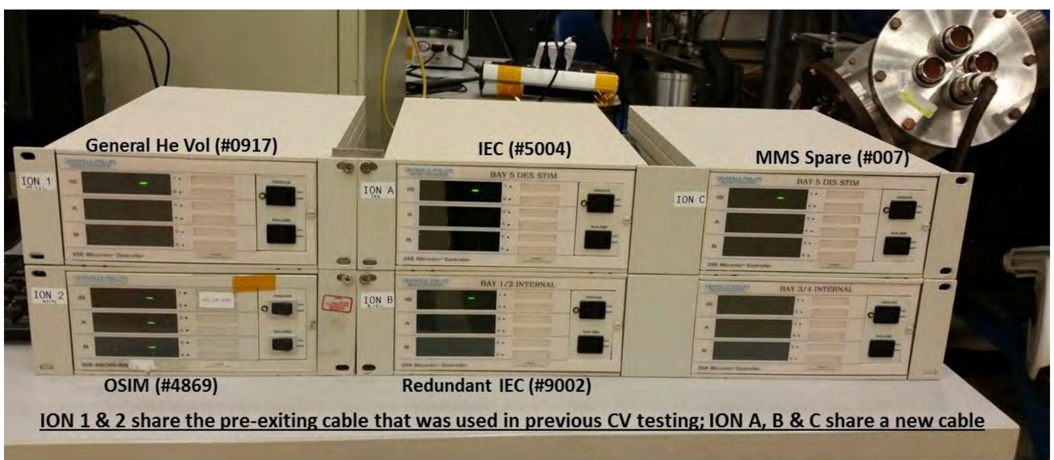
Notable Facility Changes Since CV1 → CV2 → CV3

- **Redundant micro ion gauge for IEC**

- During check-out of the CV2 IGs, it was discovered that the extension used for the IEC IG was the root cause for the erratic and unreliable readings (per the spec sheet, maximum cable length allowable is 50’)
- Cross-calibration of existing and new harnesses (+1 new redundant IEC micro IG) was performed in Facility 281







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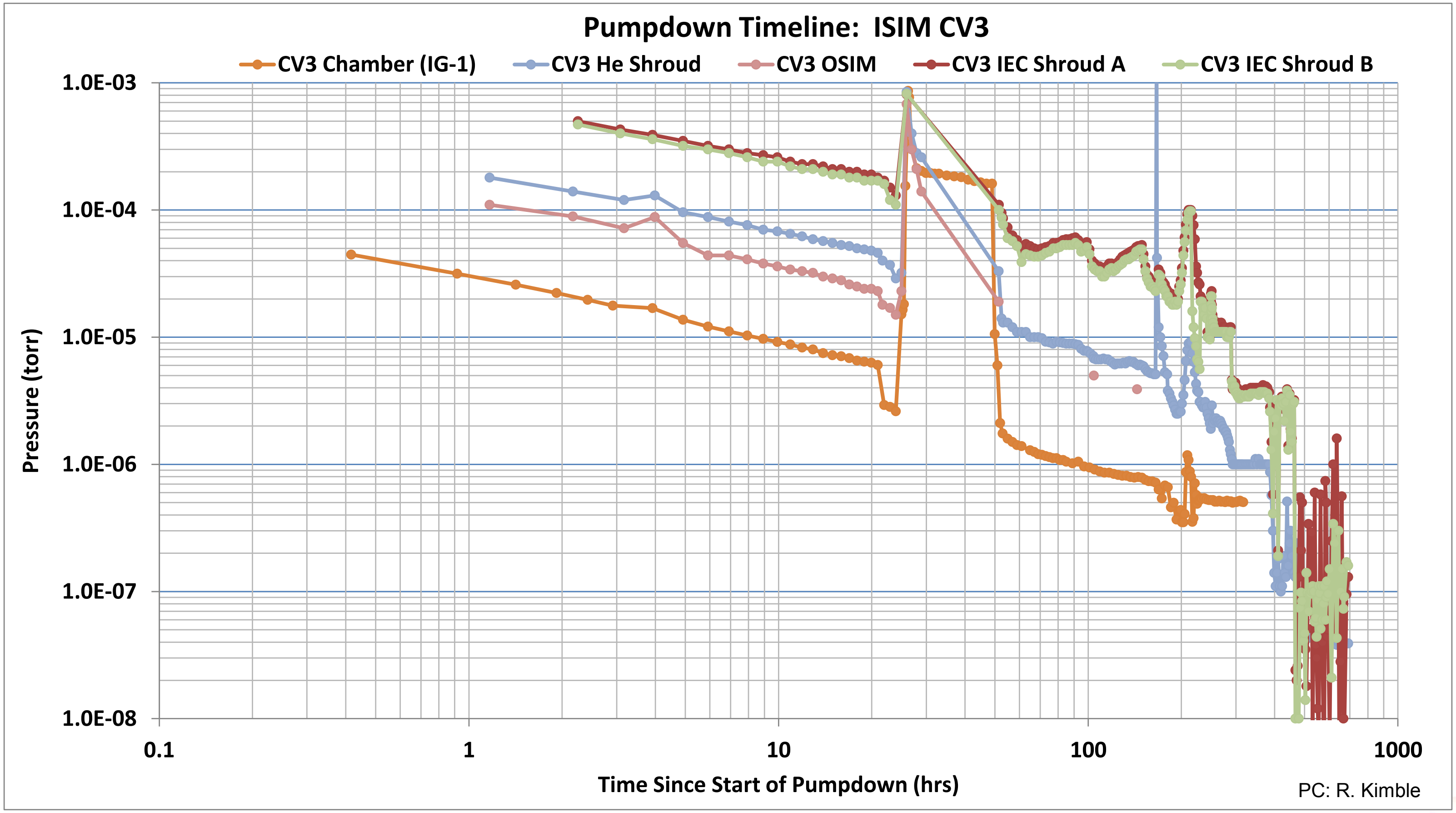

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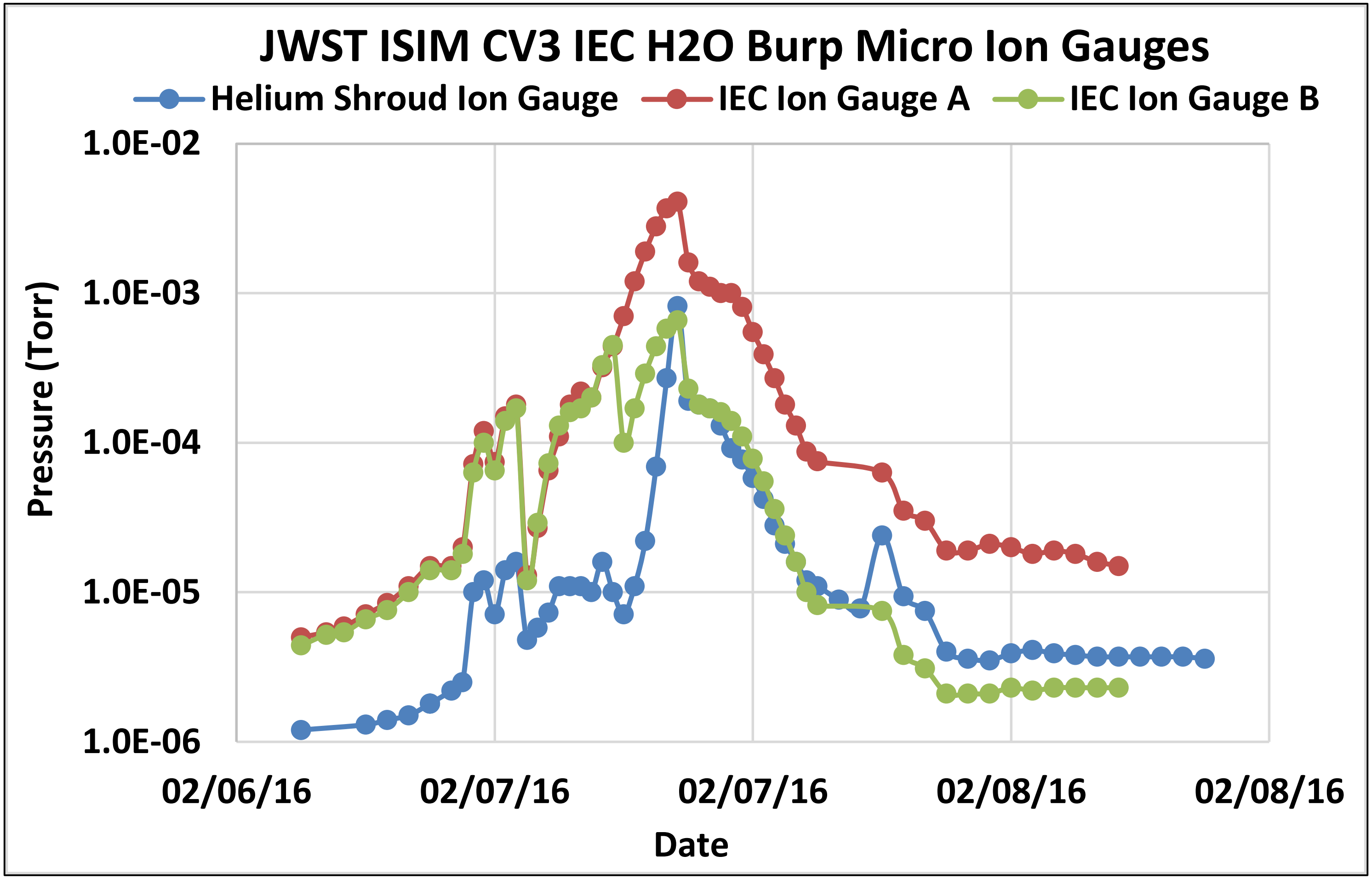
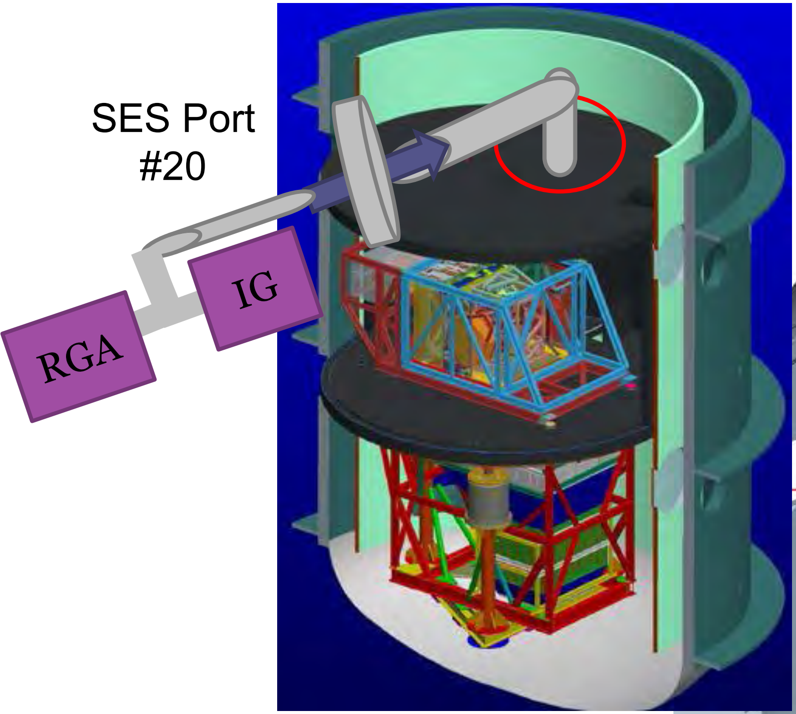
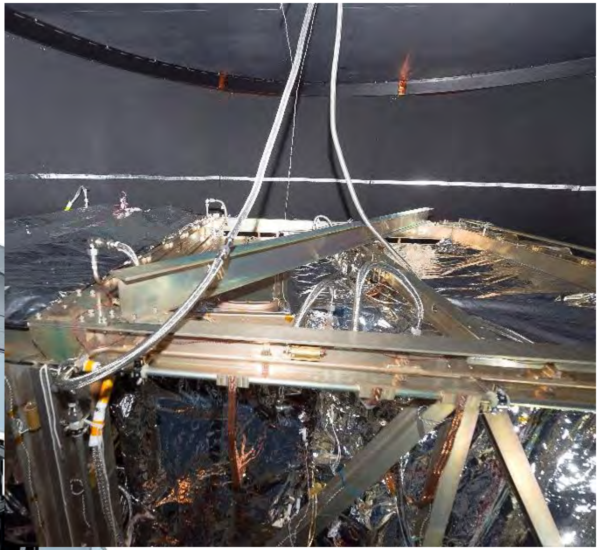


Notable Facility Changes Since CV1 → CV2 → CV3

- Residual Gas Analyzer (RGA) to monitor STMS inside helium shroud
  - CV2: Added a RGA using flex lines into helium volume
  - CV3: Bought new calibrated RGA; used SS tubing instead of flex lines





Notable Facility Changes Since CV1 → CV2 → CV3

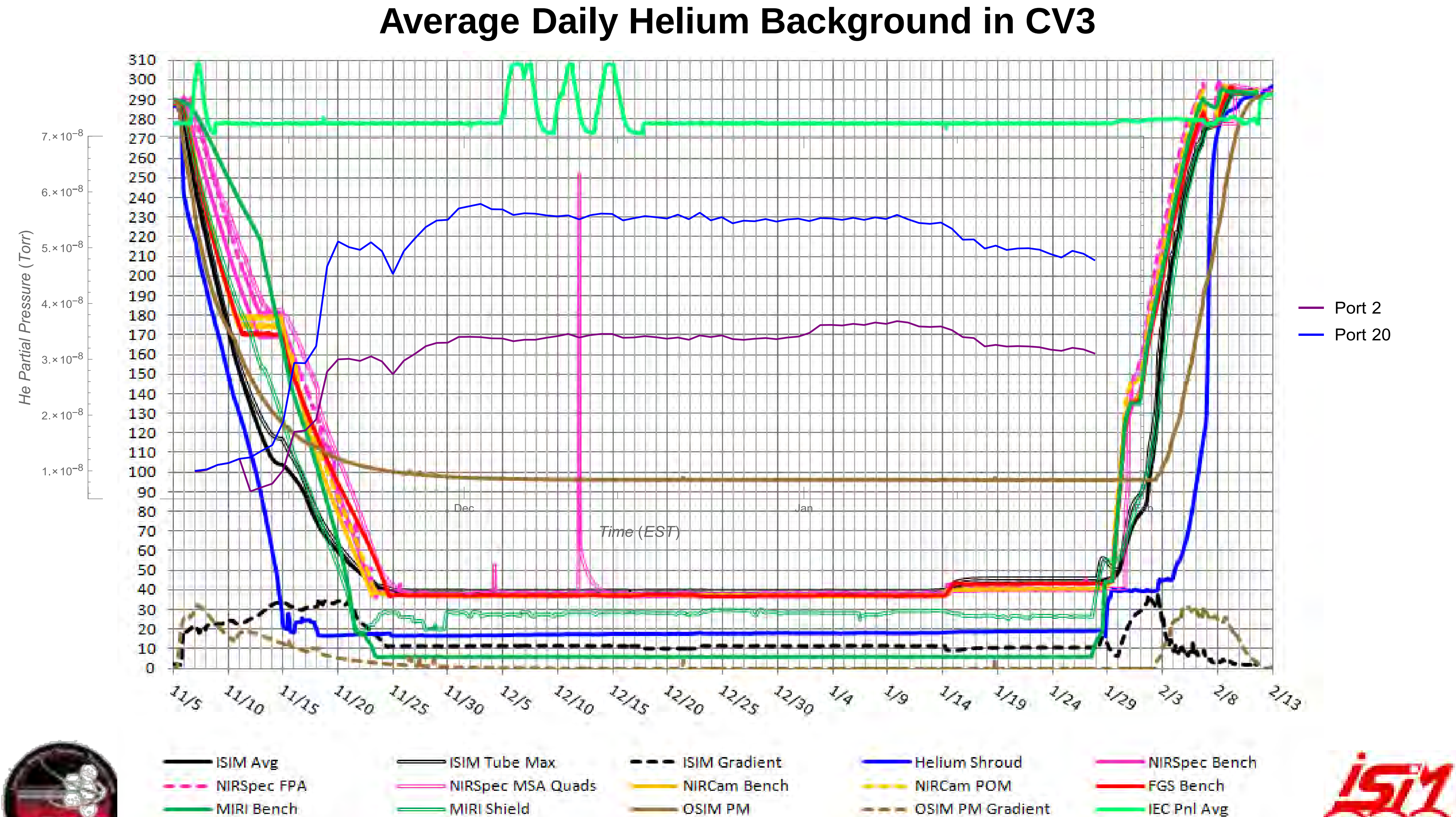
Two objectives of the RGA efforts

1. Measure helium test parasitic heat load on the MIRI Cooler
2. Verify MIRI cooler helium leak rate post-vibe to meet end-of-life (10.85) requirement not to exceed 1%

↓

- Verified the heat load on the MIRI Cooler – less than 0.7 mW: Good!
- Helium background in chamber too high to verify cooler leak rate

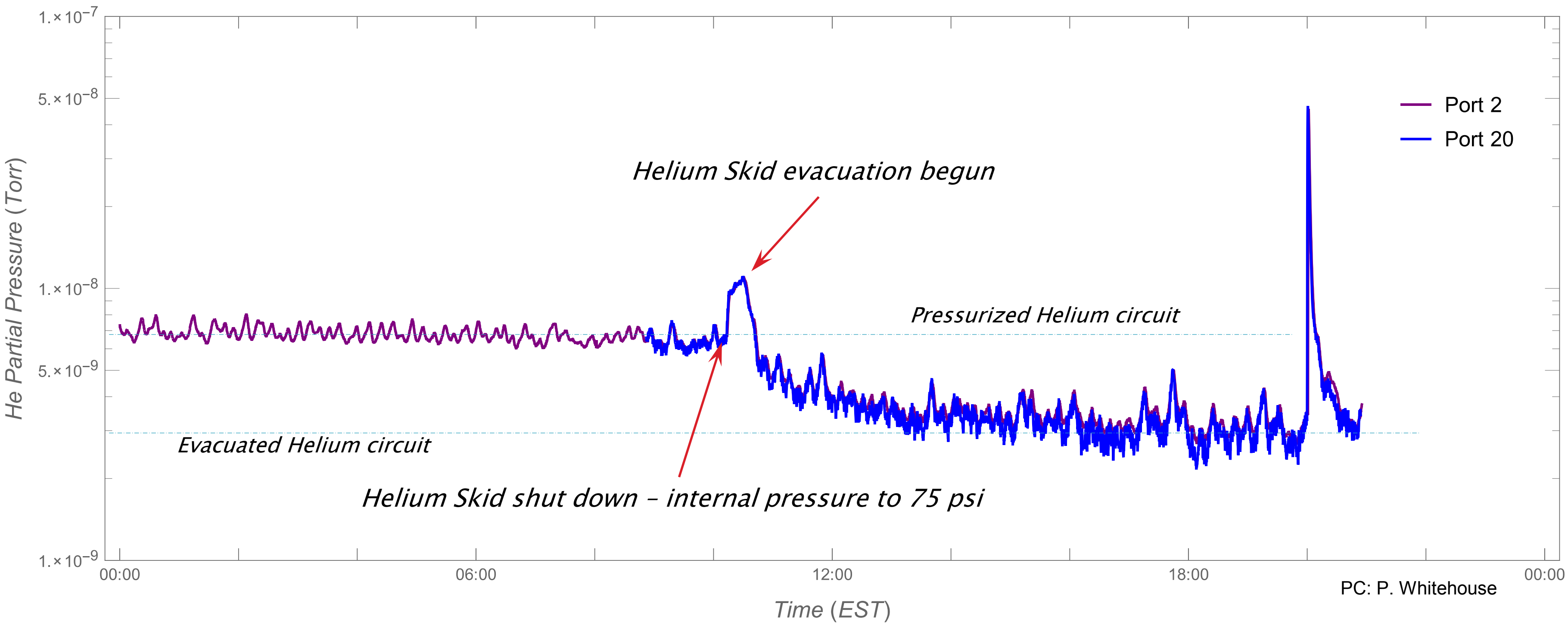
Notable Facility Changes Since CV1 → CV2 → CV3



PC: P. Whitehouse

Notable Facility Changes Since CV1 → CV2 → CV3

Average Daily Helium Readings During Warm-Up



Readings between the two RGAs are consistent at warm temperatures

Lessons Learned for CV3

#	Lesson Learned	Recommended Actions
1	Project personnel touching and/or changing facility configuration (esp. in between tests) must be verified / communicated	• Test engineer verifies with project before start of test whether the project made any facility changes • Test engineer requests that the project informs facility team when items are changed, esp. feedthrough plates and during chamber breaks
2	JWST is sensitive to vibrations caused by cryopumps knocking	• Purged and cleaned during test • Contact cryopump manufacturer
3	Stringent leak checking is possible and effective	• Continue adopting the more stringent leak checking techniques to meet high leak-tight requirements
4	Helium leak rate detection is a difficult endeavor for high sensitivity measurement requirements	• Determine the helium background requirement beforehand to gauge whether or not it would be achieveable in test
5	Do not assume reliability of the SES LN_2 skid from one test after another	• Check PLC before JWST Core 2 in SES • Consider adopting standard operations to include a check-out of skid before test
6	Understand the effects of accelerating standard procedure	• Ensure facility operators evaluate potential consequences of changes made in order to accelerate a test

Actions/Issues after CV3 (before Core 2)

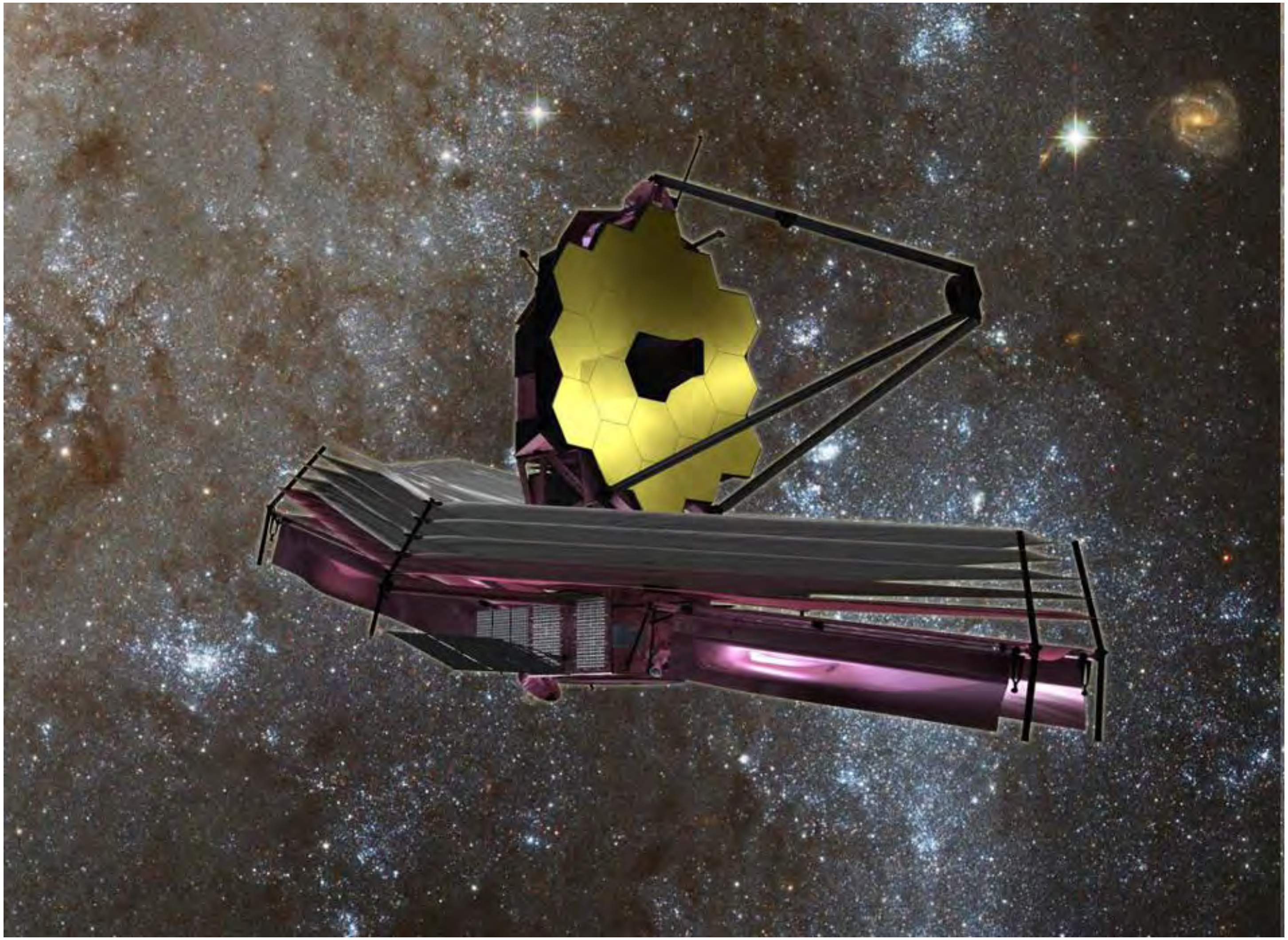
Description	Status/Notes	Target completion
Cryopump #4 needs replacement actuator with a manual override, limit switches	Actuator received.	2/26/2016
Cryopump #1 will not pump down it is believed because the rebuilt seals on the main valve actuator are leaking through to the cryo cavity.	Spare parts received.	3/9/2016
Cryopump #6 main valve will not close because main valve actuator is leaking. Actuator will need to be fixed.	Spare parts received.	3/23/2016
Coldheads on cryopump #7 is banging Intermittently.	Coldheads received.	3/18/2016
Cryopump #2 is still banging intermittently: send back to PHPK for evaluation of the drive head & displacers		3/21/2016
The LN2 thermal system could not flood the bottom shroud during the test. At the conclusion of the test the LN2 skid will need to be checked out to determine why the LN2 pump pressure on both pumps is low. Cavitation do to PLC logic. Pump vent valves do not appear to open to prime the pump during start up	PLC changes	4/11/2016
High Pressure GN2 TESCOM REGULATOR Fabrication and INSTALLATION		3/4/2016
RV replacement for GN2 backfill system		3/11/2016
Cryopump #7: Oil inside cold-heads	PO placed 02/10/16	3/18/2016

Overall Test Conduct

Outstanding support provided

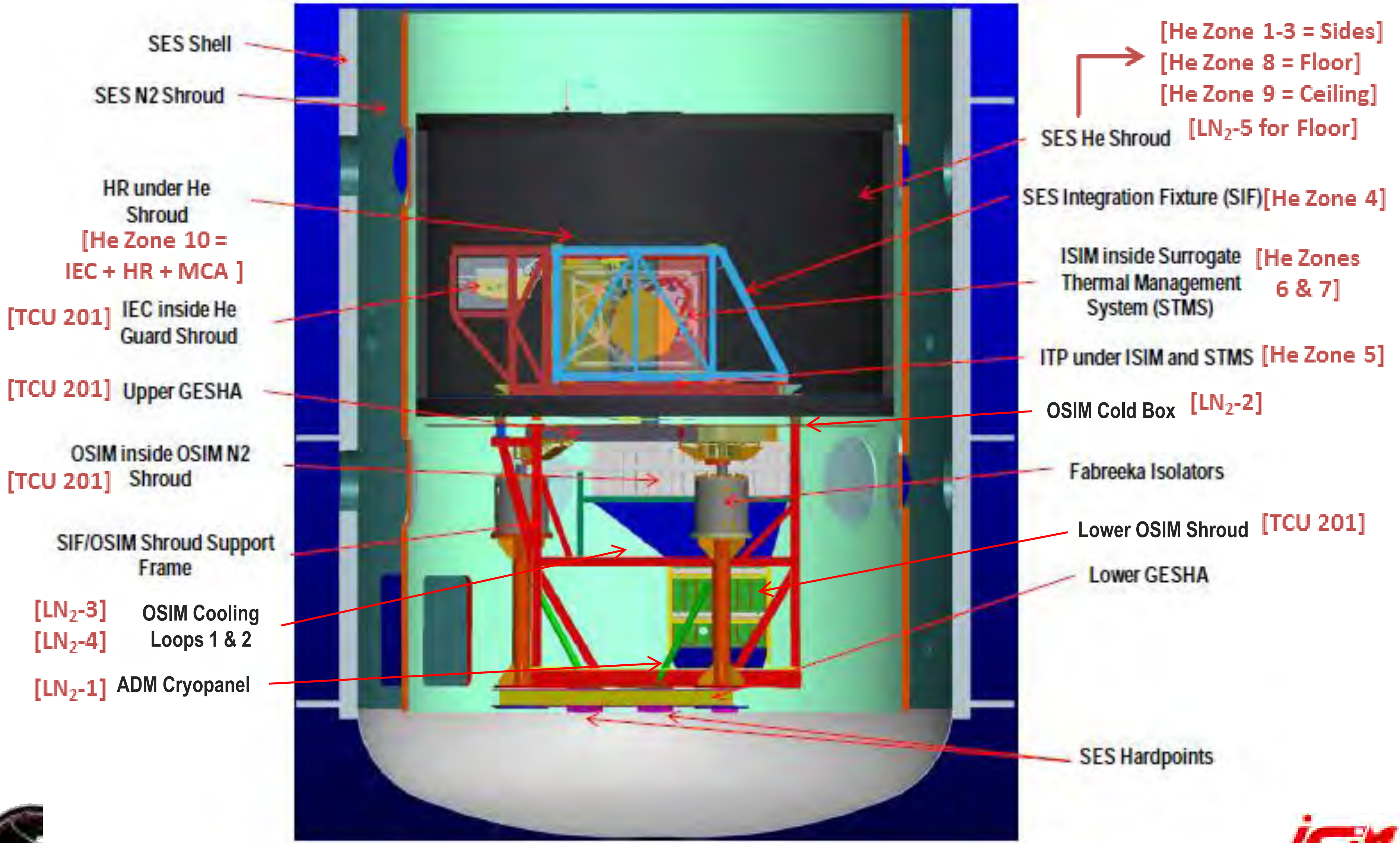
- High praise and commendation for support during snowstorm that enabled ISIM to successfully maintain hardware and personnel safety
  - "I would to pass along my sincere thanks to the ISIM Team for their scarifies and dedication during the snow storm. Hopefully, this is the last challenge mother nature throws at us as the test winds down and we warm up." –Bill Ochs (JWST Manager)
  - "I would like to take this opportunity to commend the SES Operations team for their extraordinary actions during the blizzard our area experienced over the last week…Thanks to their efforts, testing of ISIM was able to continue as planned and on schedule. Their personal sacrifice during this declared state of emergency goes far above and beyond the call of regular duty here at GSFC, and is most deserving of special recognition." –Jamie Dunn (ISIM Manager)
- Messages of appreciation from ISIM Team Members throughout the test
  - "I'm sure you know it already -- but in the spirit of not only sending bad news -- both IEC shroud pressure gauges have been working throughout the test and are giving pretty closely consistent and sensible readings throughout -- so your new shorter harnesses appear to have done the trick. All four gauges have worked well." –Randy Kimble (JWST I&T Project Scientist)
  - "Chamber leak corrected - excellent job chamber people, finding the leak and correcting it." –Steve Mann (JWST ISIM Test Operations Lead)
  - "Congrats to the entire team! Outstanding job and I couldn't be more proud of the ISIM Team." –Bill Ochs (JWST Manager)

Questions?

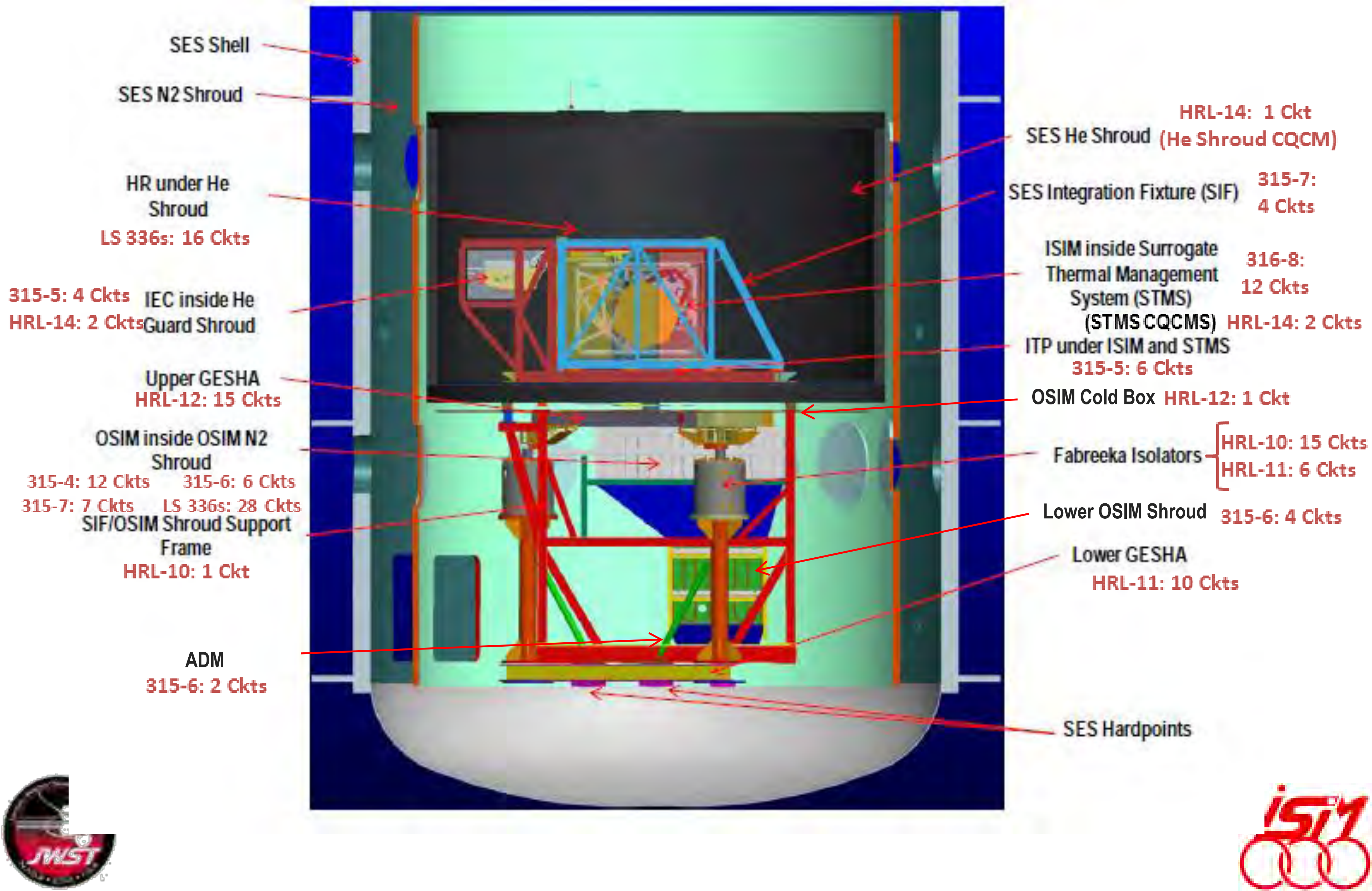


Backup Charts

LN2 & GHe Cryo Zones [TCUs, LN2–only Lines, & He Lines]



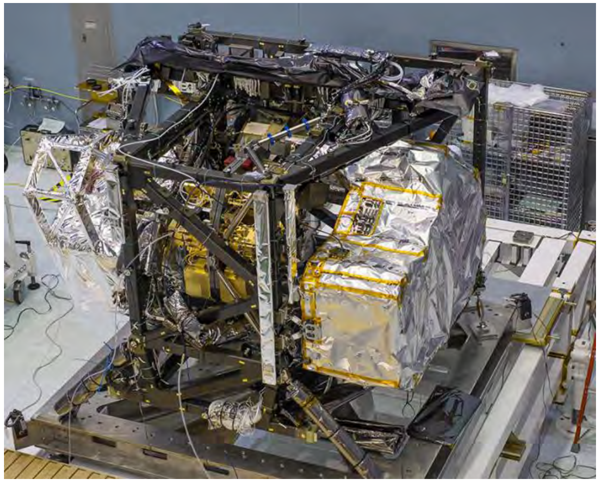
Heater Zones [Heater Racks]

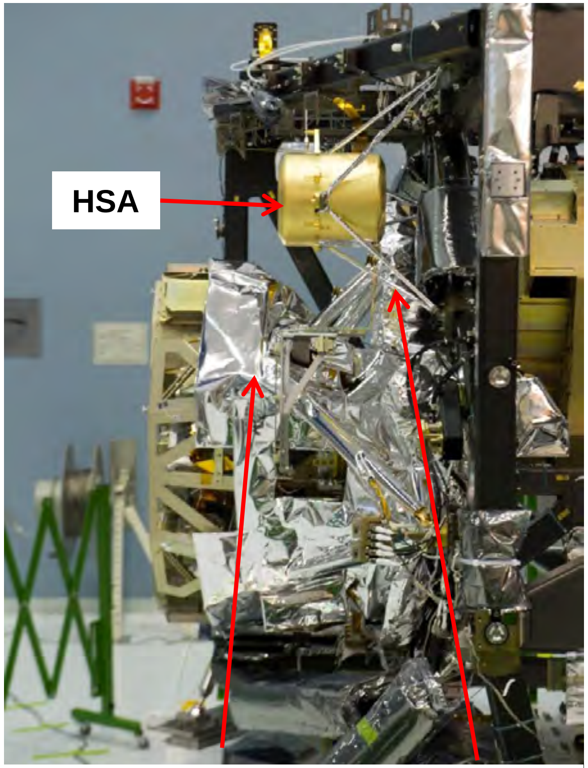


Test Configuration for ISIM CV Testing

Notable hardware changes since CV2:

- NIRCam new detectors arrays
- MIRI cooler flight unit (CV2 had flight-like assemblies: cooler lines and heat exchanger stage assembly, HSA)
- NIRSpec kinematic mounts change
- FGS guider detector assemblies
- New focal plane electronics





Refrigerant Lines and Line Support

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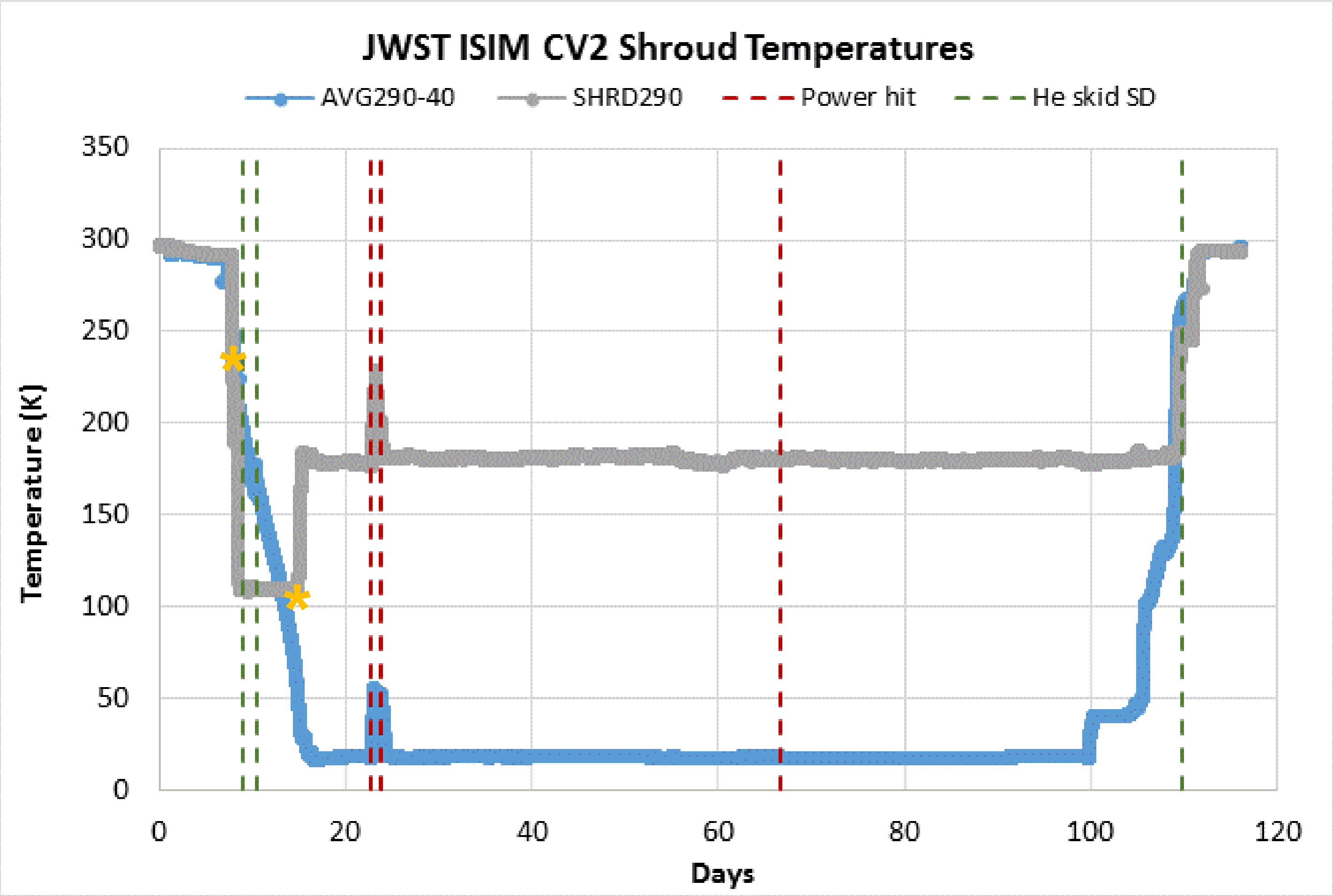


* = Switch GN_2 → LN_2 (DAY 8 – 6/24/14 03:44)
LN_2 → GN_2 (DAY 15 - 6/30/14 22:40)

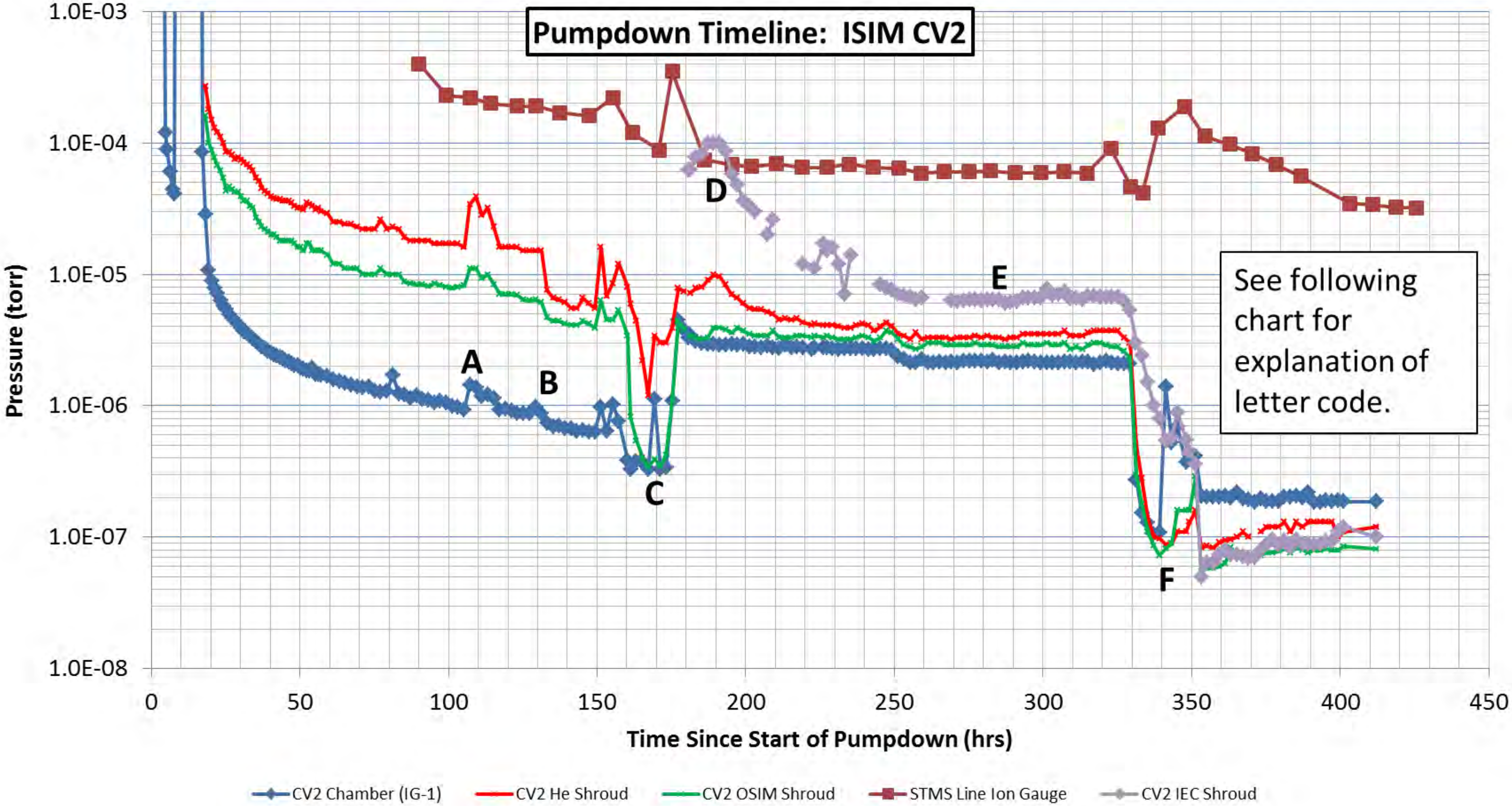
Notable Facility Changes Since CV2

1) Redundant micro ion gauge for IEC
2) New, calibrated RGA for helium shroud volume
3) New cryopumps

PR-	Issue	Updated Status
0391	Micro Ion Gauge #1 (IEC shroud) does not power on and stay on	• Ion gauge was removed and checked-out • A new, redundant micro IG is being provided for CV3 • Delivered two IEC micro IGs to ISIM for installation on 9/14/15

Notable Facility Changes Since CV2

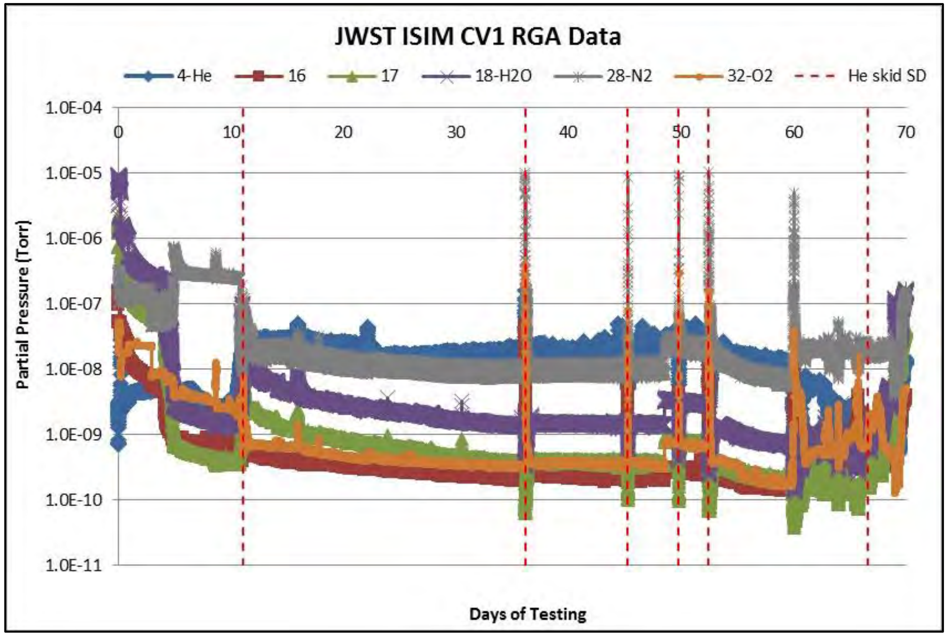
1) Redundant micro ion gauge for IEC



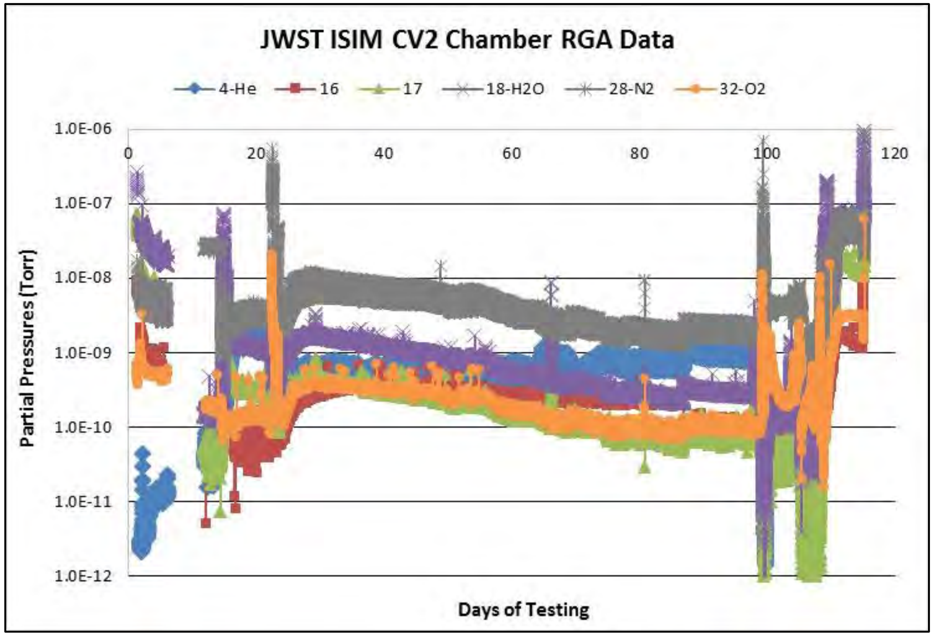
- **A:** Response to raising IEC N2 panel temp
- **B:** Response to cooling of CQCM lines
- **C:** Adjustments to facility N2 shroud
- **D:** IEC temperature cycle from 273-308 K and back, after which pressure continues to drop as IEC He panels get cold enough to sink water
- **E:** Pressure in IEC shroud stabilizes, though panels are 130K →100K, with much lower water vapor pressure than P observed: **suggests an N_2 leak inside IEC shroud; need to check/fix before CV3**
- **F:** He panels reach temperature for sinking N_2/O_2; pressures everywhere plummet

CV1 vs. CV2 Chamber RGA Detection Levels

ISIM CV1: Chamber RGA detected helium levels around 1.5×10^{-7} Torr



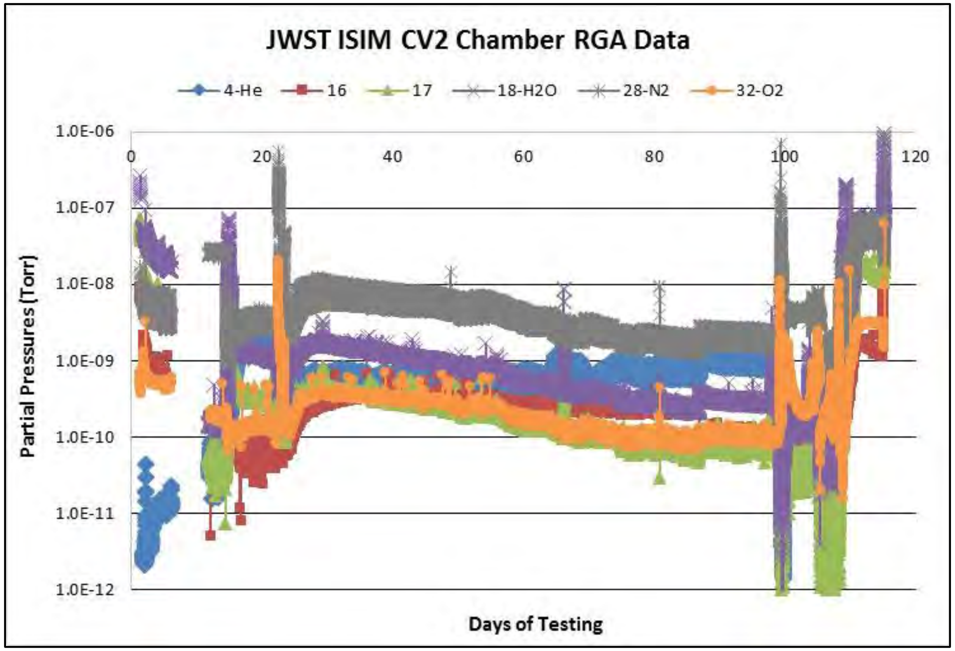
ISIM CV2: Chamber RGA detected helium levels around 1.0×10^{-9} Torr



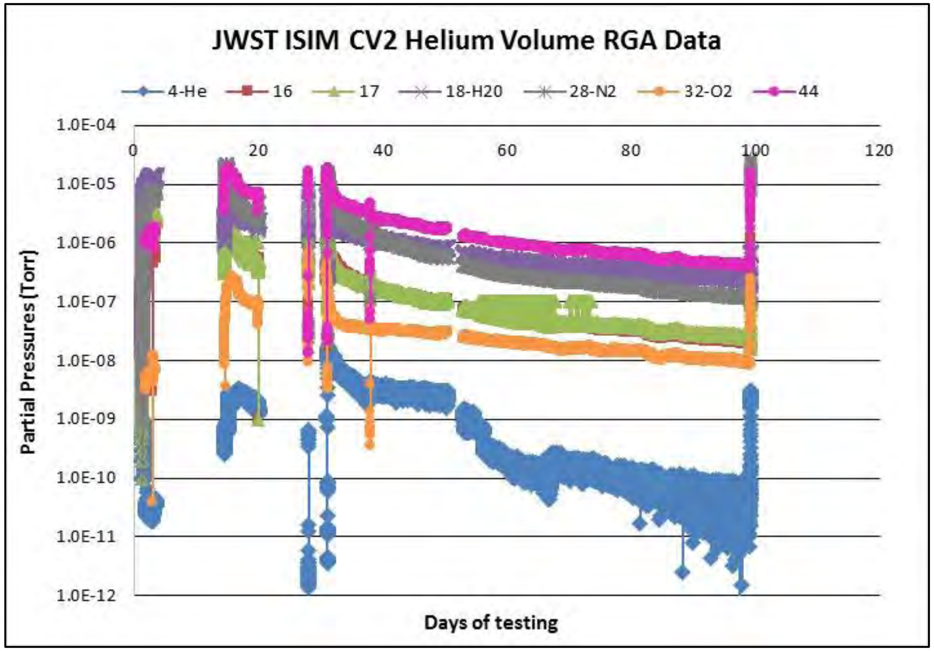
Levels of detected helium using chamber RGA decreased by almost two orders of magnitude from CV1 to CV2

CV2 Chamber RGA vs. Helium Volume RGA Detection

ISIM CV2 Chamber RGA detected helium levels around 1.0 x 10^{-9} Torr



ISIM CV2 ISIM/STMS volume RGA detected helium levels consistently <1.0 x 10^{-8} Torr



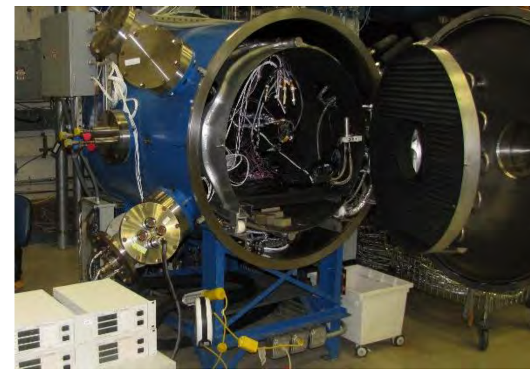
ISIM CV2 Chamber RGA detected helium levels were more consistent throughout the test, whereas the detectable helium levels using the ISIM/STMS RGA slowly decreased throughout the test

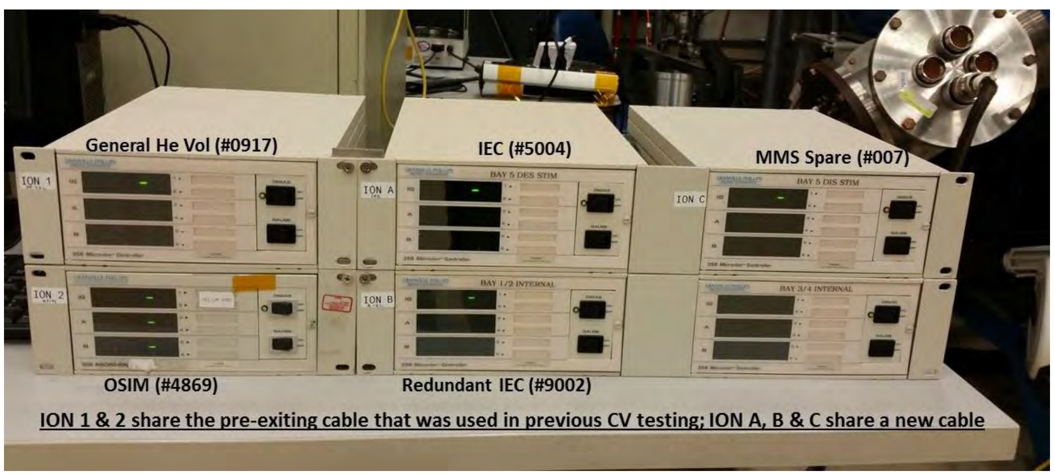
Both in CV1 & CV2, the difference between the total chamber RGA partial pressure readings & the chamber IG pressure readings was ~2.0 x 10^{-7} Torr higher pressure (lower vacuum) on the IG

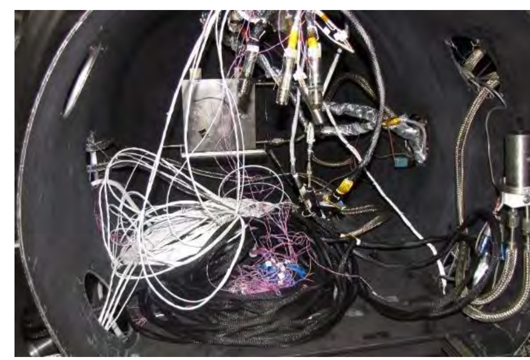
Notable Facility Changes Since CV2

1) Redundant micro ion gauge for IEC

- During check-out of the CV2 IGs, it was discovered that the extension used for the IEC IG was the root cause for the erratic and unreliable readings (per the spec sheet, maximum cable length allowable is 50’)
- Cross-calibration of existing and new harnesses (+1 new redundant IEC micro IG) was performed in Facility 281

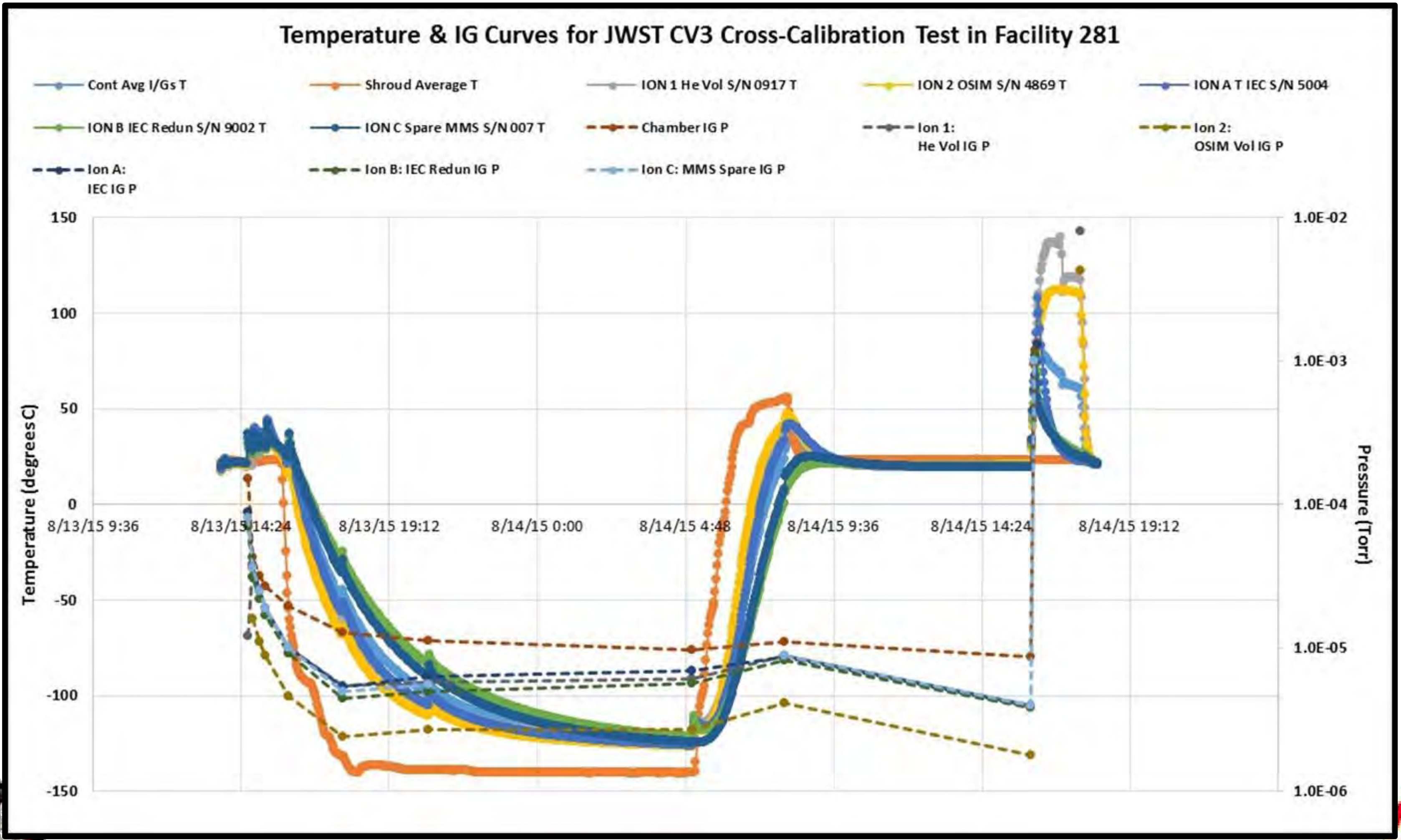






Notable Facility Changes Since CV2

1) **Redundant micro ion gauge for IEC**



Notable Facility Changes Since CV2

1) Redundant micro ion gauge for IEC
2) New, calibrated RGA for helium shroud volume
3) New cryopumps

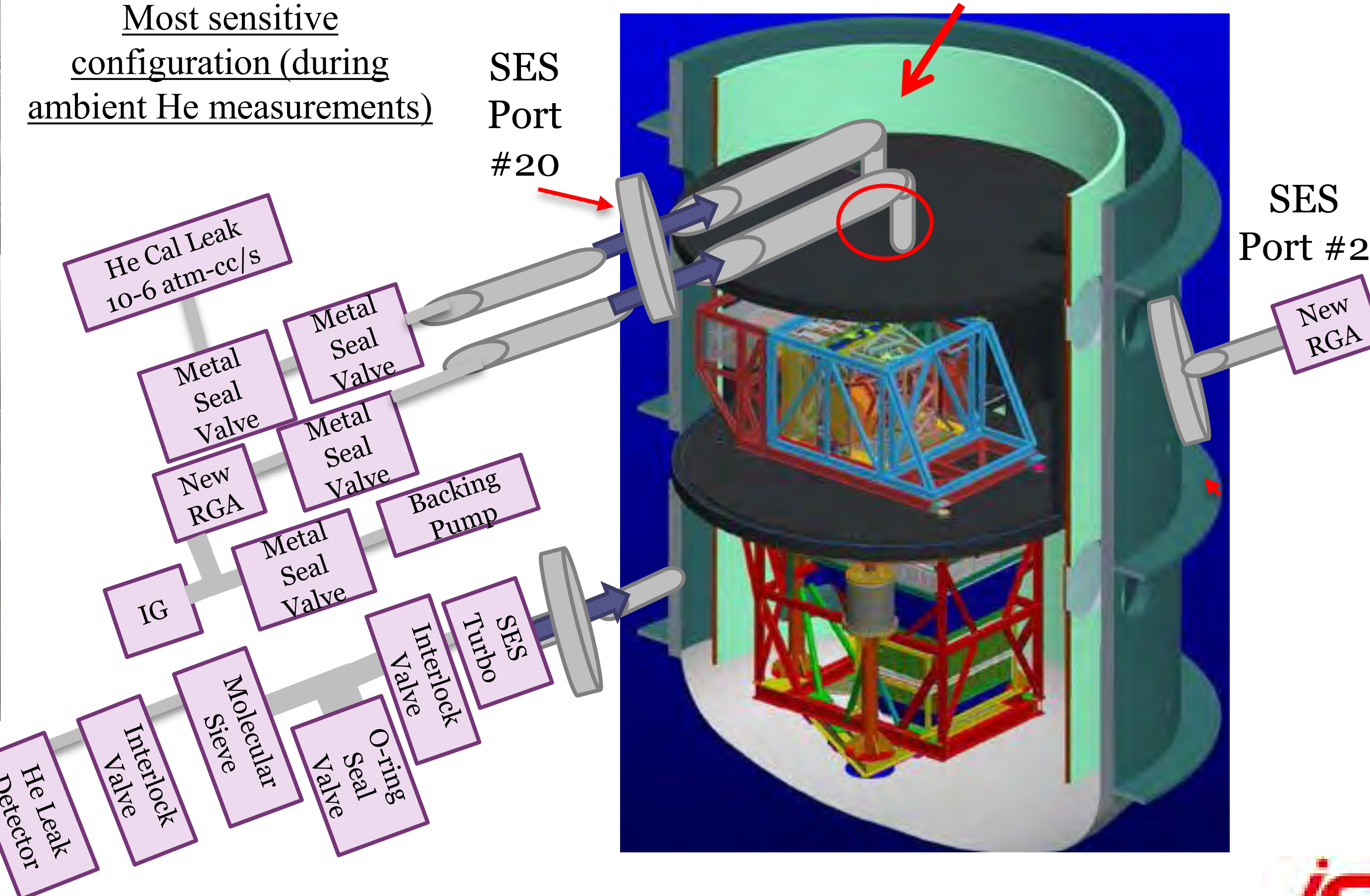
- MIRI requirement: 6.2 K (-266.8°C) at the instrument
  - 2-stage cooler system
  - Accurate heat map required during environmental testing
- Issues during CV1 & CV2
  - Measured heat loads to cooler from MIRI higher than expected
  - Presumed cause is higher levels of helium in chamber

Notable Facility Changes Since CV2

2) **New, calibrated RGA for helium shroud volume**

Entrance of two (1/2" SS line) tubing from chamber port thru the hole on the roof of He Shroud

Most sensitive configuration (during ambient He measurements)

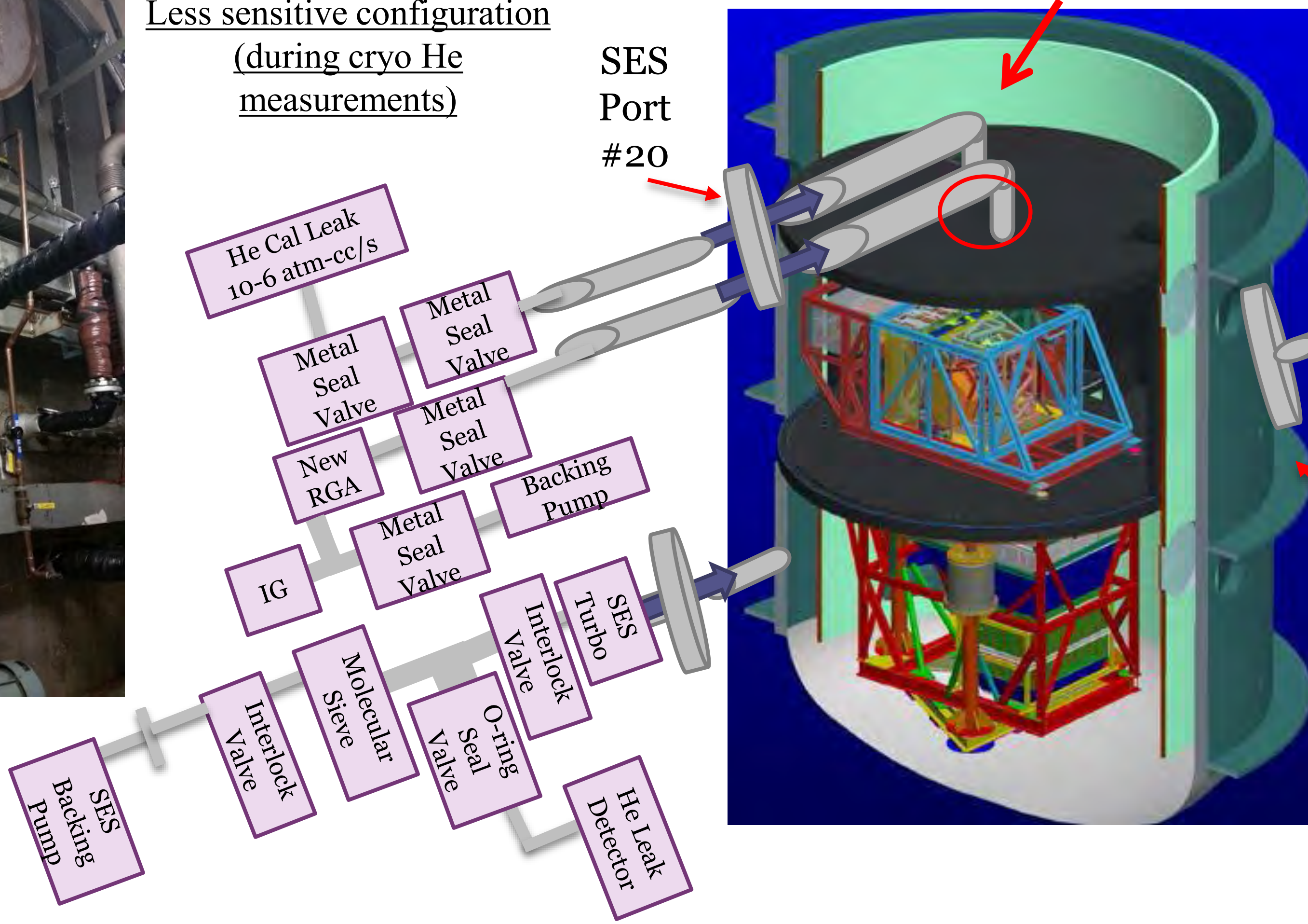


Notable Facility Changes Since CV2

2) **New, calibrated RGA for helium shroud volume**

Less sensitive configuration (during cryo He measurements)

Entrance of two (1/2" SS line) tubing from chamber port thru the hole on the roof of He Shroud

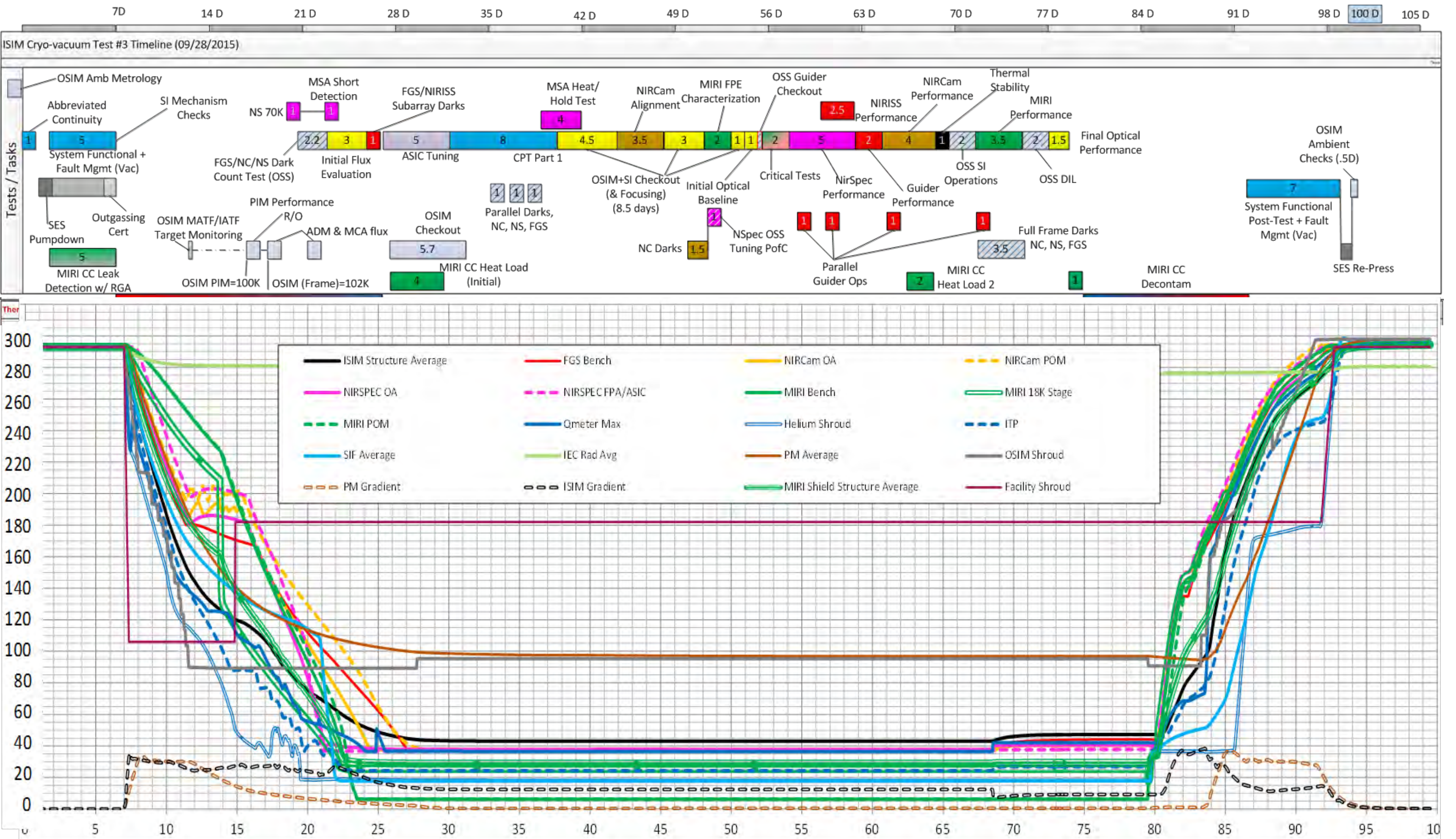


Notable Facility Changes Since CV2

1) Redundant micro ion gauge for IEC
2) New, calibrated RGA for helium shroud volume
3) New cryopumps

- Cryopump #2 made intermittent banging noises during CV2
  - Oil found on coldheads
  - Contaminated coldheads shipped to PHPK
  - PHPK investigated and replaced coldheads
- Cryopump #4 & #6 were replaced
- Cryopump #3 was rebuilt
- Cryopumps started testing/check-out October 1, 2015: test for 13 days at cold pumping on itself

CV3 Test Profile

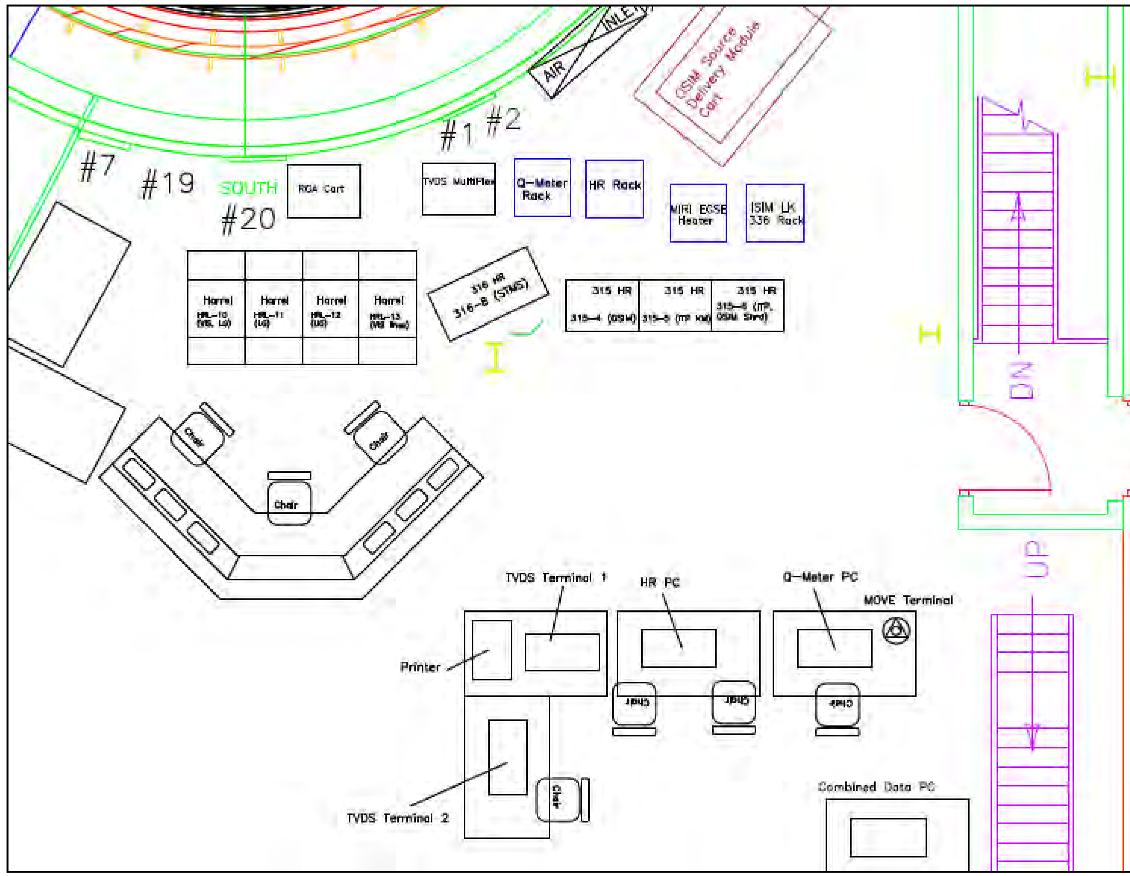


SES Facility LN2 Valve Failure

- **An LN2 valve was discovered in a failed open position. This was flowing LN2 to the GN2 compressor. The excess LN2 needs to be dumped from the system, which requires securing the LN2 supply. This takes the chamber cryopumps off-line.**
- Resolution: the excess LN2 was vented from the system while the chamber pressure was maintained, using only the chamber turbopump, at ~2x10E-4 Torr. After the GN2 heat exchanger and LN2 lines were sufficiently drained on Saturday 10/31/15, the cryopump LN2 valve was made operational again. The facility is back to normal operation. The root cause of the GN2 heat exchanger flooding event was determined. The GN2 skid was shut-down and locked-out to allow a Proconex technician to troubleshoot and recalibrate a faulty positioner that indicated it had failed. In doing so, all the GN2 skid valves assumed their failed (open/close) safety position, and all pressure control loops were disabled. As a result, the heat exchanger GN2 inventory control loop which maintains a pressure of 60 to 70 PSIG was disabled allowing for the GN2 pressure in the heat exchanger to drop to 0 PSIG. Without there being pressure in the exchanger, the LN2 from the vent line filled up the exchanger. Once power was restored to the GN2 skid the pressure in the exchanger was reestablished without further incident.

Facility Preparation Status

- Data Acquisition
  - 3 TVDS stations set-up
    - 2 at SES
    - 1 in ICC for JWST (B29/R156)
  - Q-meter
  - Harness Radiator
  - TCR forms completed
  - Stand-alone systems in progress
    - CQCMs (x2)
    - RGAs (x2)
- Facility PMs have been completed, and none are scheduled for the duration of the CV3 test



Facility Preparation Status

- Documentation
  - Safety Evaluation Form
    - No changes from CV2
    - Request has been made to JWST to sign CV3 form, which will be added to the folder of safety evaluations for all the hardware in previous JWST tests
  - 549 procedure
    - Send out for review Tuesday, 10/13/15
    - Will collect signatures by Tuesday, 10/20/15
- Helium skid
  - Clean-up will start with pumping and purging when all hook-ups are completed
  - 20 He gas bottles being ordered for the SES
  - Rental generator contract for CV3 duration: arrive & install 10/13/15, electrically check-out and power transfer check on 10/15/15

Top Facility-Related Risks for JWST

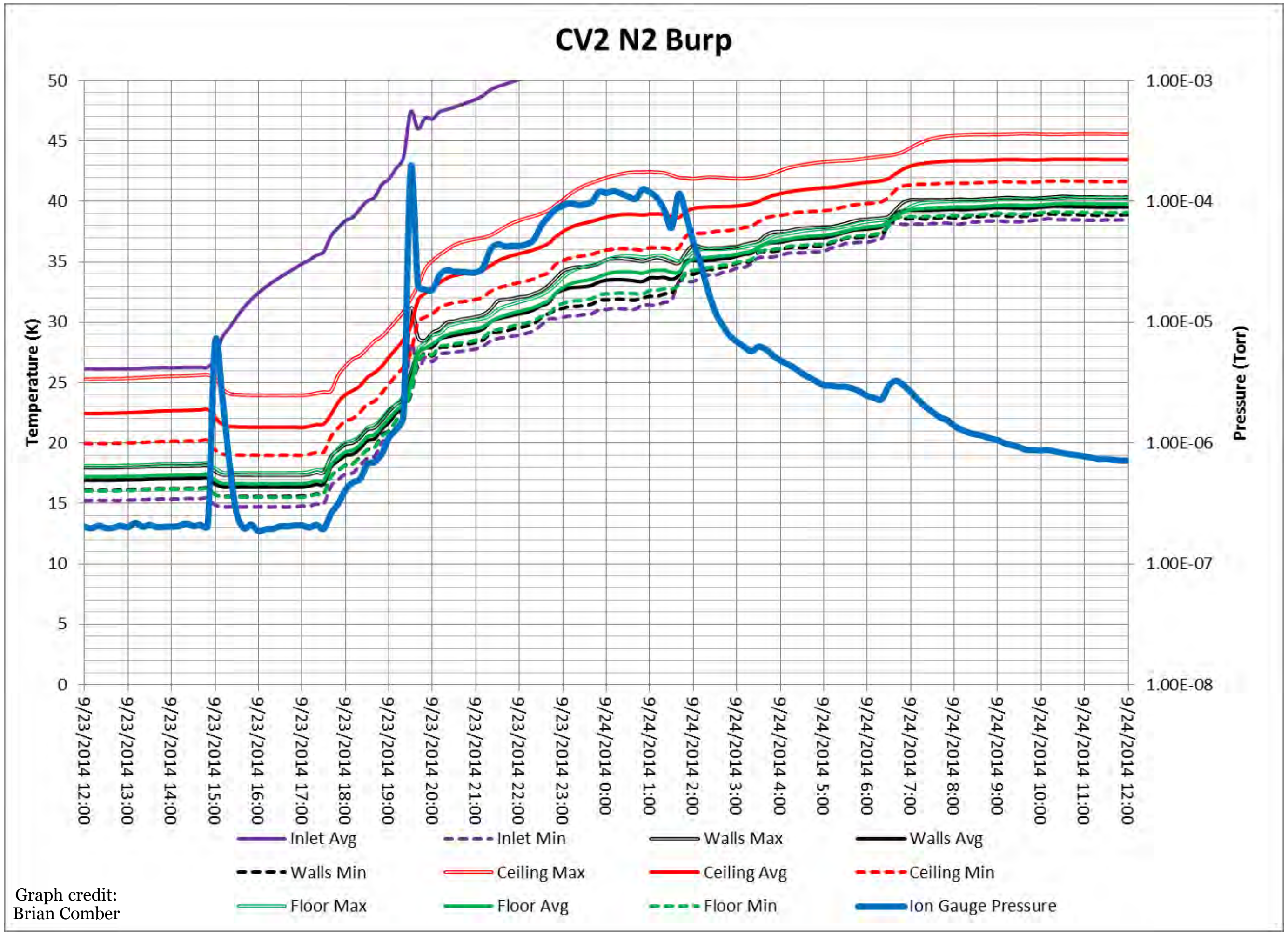
Description	Mitigations

Helium Leaks: MIRI Cooler heat load from CV1 was high & He measurements not sensitive enough in CV2	• Standard leak check levels were made more stringent for CV2
	  • Measured leaks to 10^{-9} Torr range
	  • Will use sniffer capable of measuring 10^{-11} Torr range to measure region that cannot pull vacuum to leak check
	• Developed extensive calibrated RGA plan with MIRI team

Nitrogen leaks	• Purge lines to SIs in He volume
	  • Leak check purge lines
	  • Disconnect, evacuate and cap after pumpdown
	• Nitrogen shroud will operate in GN2 mode at steady state

Power outage	• Will verify He skid UPS performance • All JWST critical equipment on UPS
Chilled water outage	• FMD 24/7 support • Developed chilled water outage response plan & will communicate plan with JWST
New cryopumps	• Test for 13 days

The Nitrogen (and Oxygen) Burp



Graph credit:
Brian Comber

Estimate of gas released: up to 700 g, or 0.65 torr, if released suddenly into the chamber → thermal effects would be significant

Compared to OSIM Nitrogen (& Oxygen) Burp