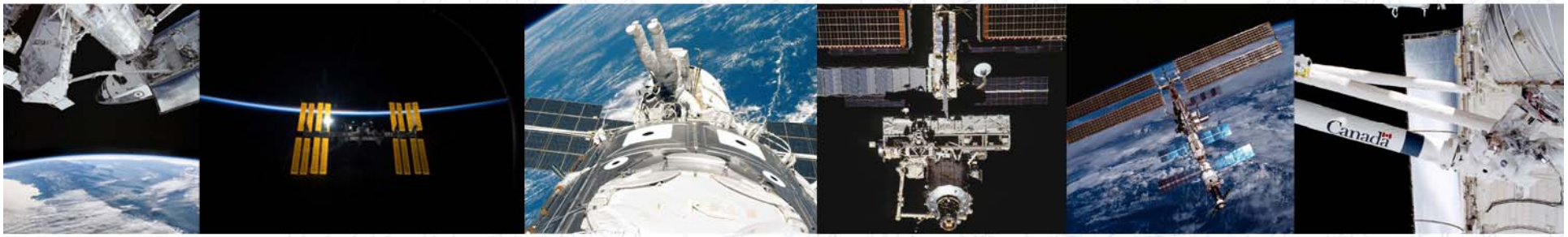
Space Exploration | International Space Station

Providing Pressurized Gasses to the International Space Station (ISS): Developing a Composite Overwrapped Pressure Vessel (COPV) for the Safe Transport of Oxygen and Nitrogen



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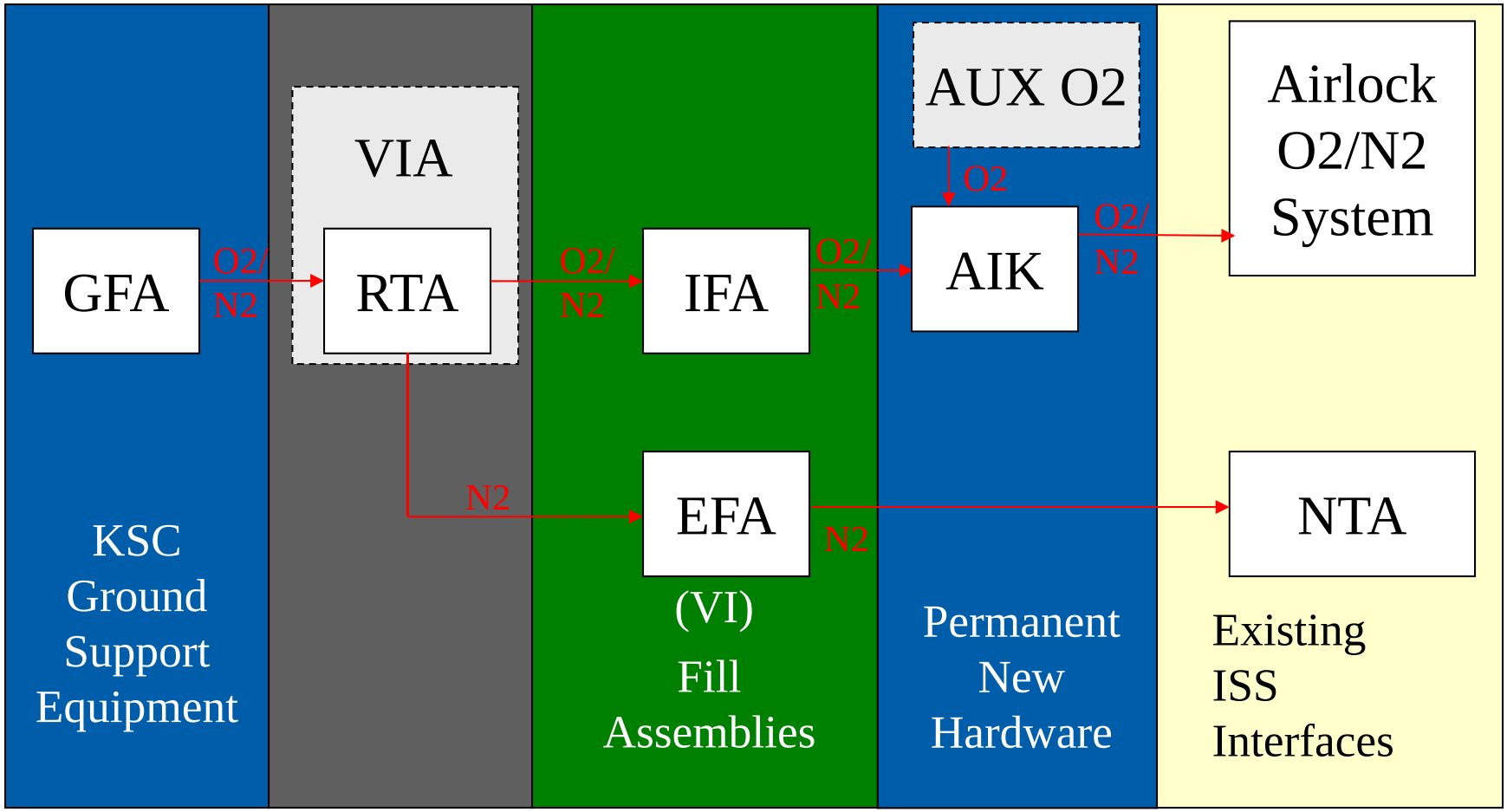
Introduction

- **Agenda**
  - NORS Background
  - NORS – COPV Overview
  - Review of COPV Standards and Various Approaches to Certification
    - SSP 30558/SSP 30559
    - MIL-STD-1522A
    - AIAA-S-081A
  - Concept of Operations (Driving Requirement Selection)
  - Current Status of NORS COPV Development

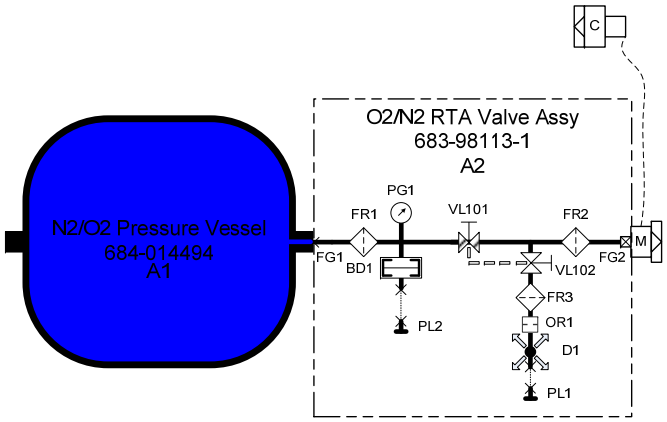
NORS Background

- **International Space Station (ISS) operation requires a continuous supply of pressurized Oxygen and Nitrogen**
  - Crew metabolic needs/emergency medical usage
  - Extravehicular Activity (EVA)
  - Maintaining normal atmospheric pressure
  - Contingency module re-pressurization
  - Payload usage
  - Thermal Control System
- **Space Shuttle retirement in 2011 removes the primary source of N2 and O2 for ISS.**
- **NASA's replacement for the Space Shuttle for O2/N2 logistics is termed the Nitrogen Oxygen Recharge System (NORS).**
- **There are 4 main elements in NORS:**
  - Recharge Tank Assembly (RTA) - A transportable tank assembly
  - Airlock Modification Kit (AMK) – provide interface and regulatory function for RTA to ISS systems.
  - External Fill Assembly (EFA) – interfaces between the RTA and the NTAs.
  - Ground Fill Assembly (GFA) – GSE used to fill the RTAs.

ISS NORS – System Overview



(B) Recharge Tank Assembly (RTA)



RECHARGE TANK ASSEMBLY, N2
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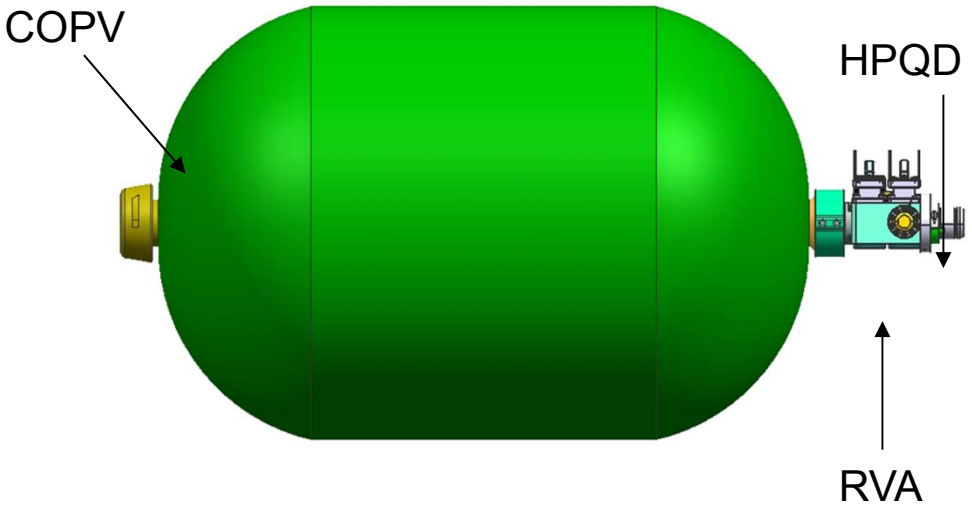
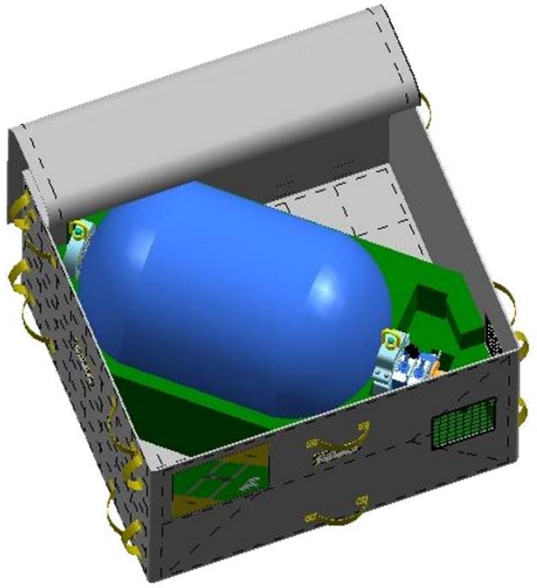
A505

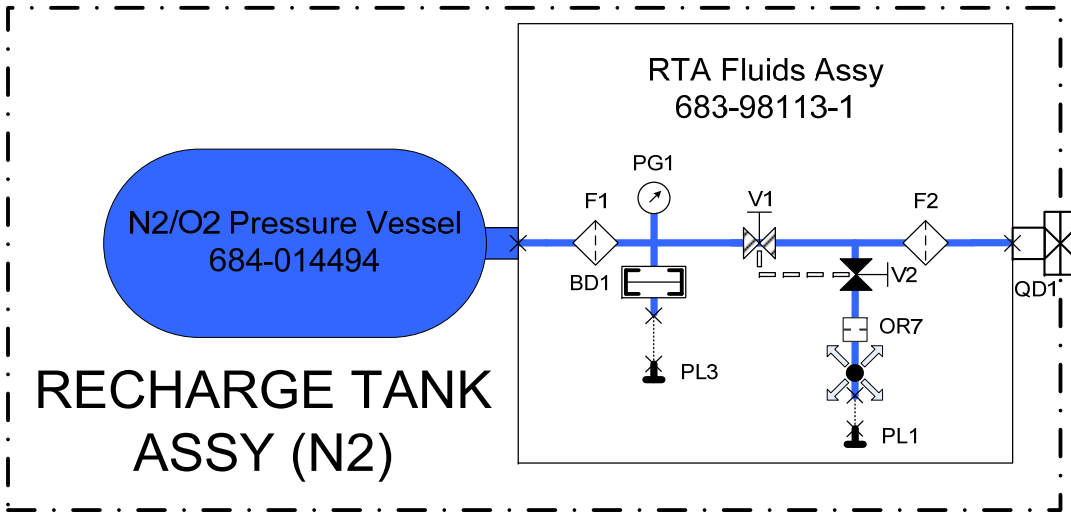


- **Used to transport 41.4 MPa (6000 psi) Oxygen and Nitrogen.**
- **Transportable while filled.**
- **Composite Overwrap Pressure Vessel (COPV)**
- **RTA Valve Assembly (RVA)**
- **High Pressure Quick Disconnect (HPQD)**



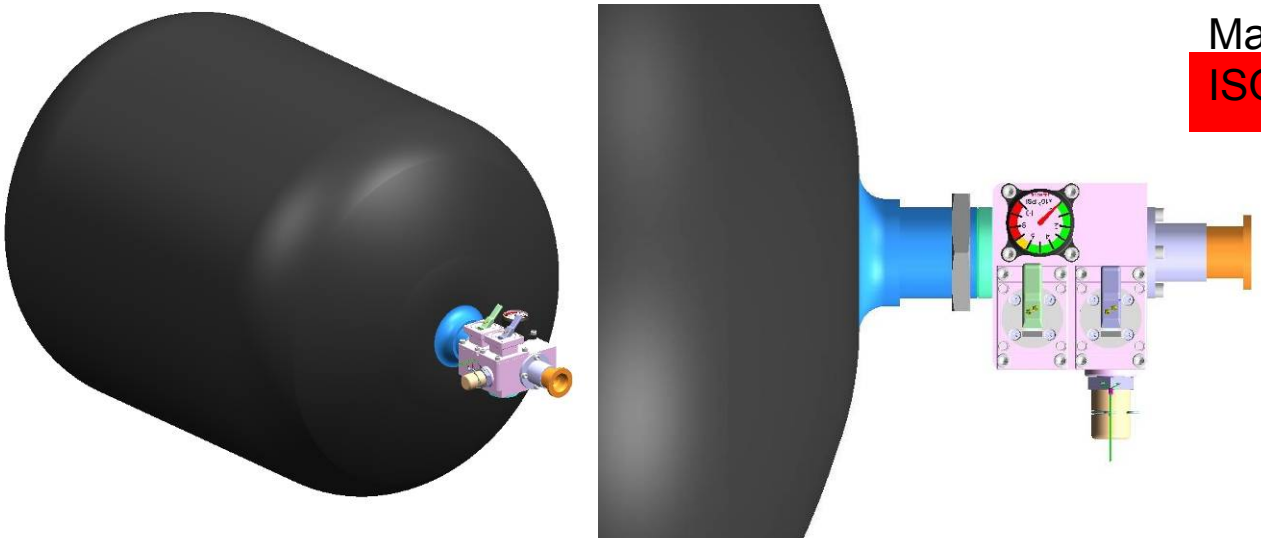
RTA Launch Configuration

COPV Pressure Vessel - RTA



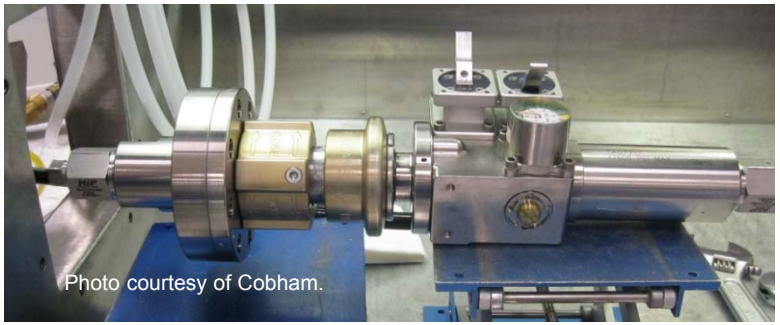
Pressure Vessel

MDP = 7000 psia
Working P (Fill P) = 6000 psia
Min Qual Cycle Spectrum =38 cycles
Min Volume = 2.43 ft^3
FOS = 3.4
Max Envelope = 31” L x 18.5” D
Max Tare Mass = 104 lbm
ISO 11119-3 Certification

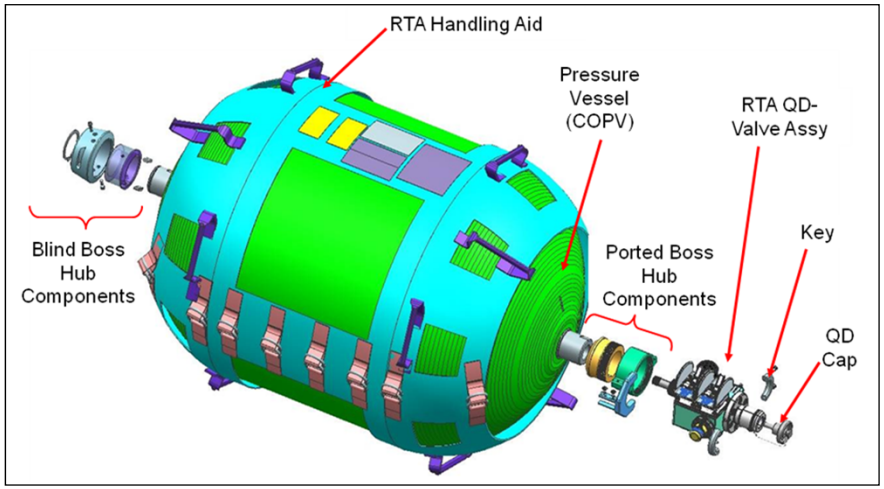


Focus on the standard selection

System Overview - RTA

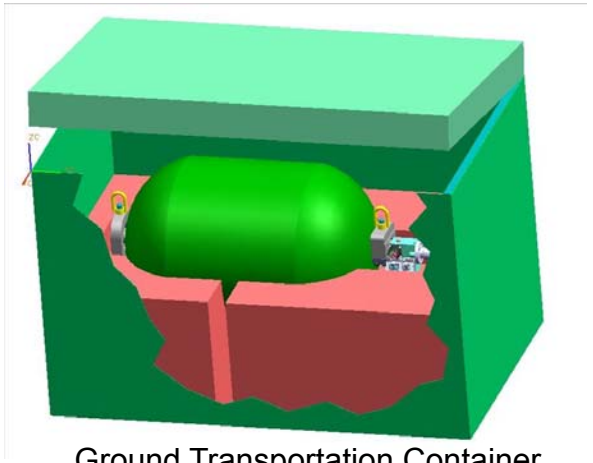


RTA Crew Trainer with human for scale

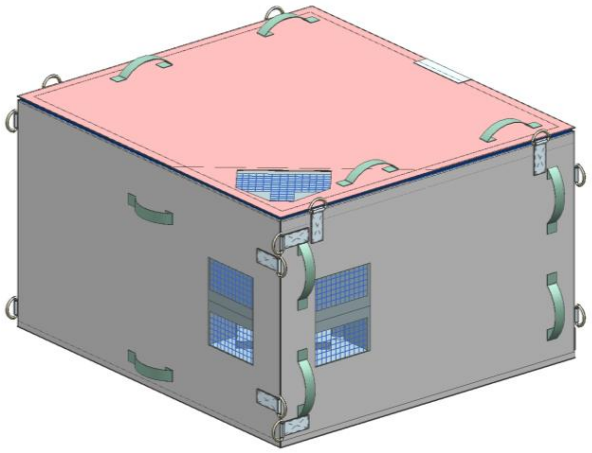


ISS NORS – Operational Overview – Ground Ops.

- **Final Assembly**
  - Occurs at Huntsville – MSFC and Houston (VIA only)
- **Ground Filling of RTAs**
  - Occurs at the Kennedy Space Center
  - RTAs will also be configured with gas specific labels and QD keys.
- **Transportation and Launch**
  - Filled RTAs are shipped in DOT compliant ATA-300 containers.
  - NORS components will be launched on commercial carriers (e.g. SpaceX, Orbital, etc) or ATV/HTV.
  - RTAs are launched in the VIA



Ground Transportation Container



Vehicle Interface Assembly

Concept of Operations (Ship Full or Ship Empty)

Ship Full

- Utilize NASA facilities and ship pressurized RTA on commercial roads
- Certify Vessel to International Standards (ISO 11119)
- Certify Vessel to NASA ISS and Launch Vehicle Standards (SSP 30558/30559)

Ship Empty

- Develop Fill Assembly at all launch facilities (Japan, French Guyana, TBD-Domestic, Commercial Crew)
- Certify Vessel to NASA ISS and Launch Vehicle Standards (SSP 30558/30559)

SSP 30558/SSP 30559 Requirements Summary

- **Documents takes specific requirements approach tailored to ISS program for fracture control, and structural design and verification of pressure vessels**
  - Defer specifically to SSP 30233 for M&P, and each other for applicable reqs
  - Much more depth/breadth of requirements regarding analysis/design vs. other standards
  - Defers to SSP 41172 for completed hardware qualification/acceptance testing requirements (no requirement for cycle test, vibe test, burst test, etc)
- **SSP 30558**
  - Requires compliance with MIL-STD-1522A (sections governing pressure vessels)
    - Approach B disallowed
  - Notable design requirements include the following:
    - **Safe Life via analysis or test (LBB not required directly [4.4.1.1 C])**
- **SSP 30559**
  - Notable design requirements include the following:
    - **Safe life via analysis using material test data**
    - Positive Margins of Safety
    - A-basis allowables
    - Use proven processes for Fabrication, Process Control, Quality Assurance
    - **Minimum FOS on burst of 2.0 and on proof of 1.5 (on MDP)**

MIL-STD-1522A Requirements Summary

- **Document takes more general requirements approach to fit all types of man rated and non-man rated space applications**
  - Limited to approach A2, LBB w/ hazardous gas, (A1 LBB w/o hazardous gas or pressure, B not acceptable for USAF/SD or ground apps, C ASME boiler and pressure code cert with minor additional reqs)
  - Requires a program to determine what type of requirements to levy on itself (structural, environmental, performance, process controls)
  - Overlaps SSP 41172 and SSP 30233 in some areas and determination would have to be made in event of potentially conflicting requirements
  - Notable design requirements include the following:
    - **LBB of liner and Safe Life via analysis or test (Safe life of overwrap 10 x safe life of liner [5.2.2.2])**
    - Positive Margins of Safety
    - A-basis allowables
    - Analysis to predict remaining life based on allowable damage limits analysis
    - **Minimum FOS on burst of 1.5 (on MEOP)**
    - Use proven processes for Fabrication, Process Control, Quality Assurance
    - **COPV w/ non-load bearing liner required to be cert-ed to ASME boiler & pressure code [5.2]**
  - Tailoring to specific program NOT allowed per scope without program approval
    - Not intended to be a “pick and choose” standard; all requirements intended to be applied

MIL-STD-1522A Requirements Summary

- **Qualification Test Requirements**
  - Cycle test to 4 x specified cycle life min. 50 cycles, at critical use temp
  - Vibration test per MIL-STD-1540 (plan test in advance and envelope worst case conditions)
  - Burst test to FOS, then to actual burst
  - Leak test not expressly required
- **Acceptance Test Requirements**
  - NDI per program specification
  - Proof to 1.5 x MEOP at critical use temp for burst ≥ 2 for min. of 5 mins
  - Leak test not expressly required
- **Total tanks required for destructive testing**
  - 2 for Qualification (cycle and burst)

TABLE II. Qualification Test Requirements

Test Item	No yield after	No Burst at(1)
Vessel #1(2)	-	Burst Factor x MEOP
Vessel #2	Cycle at 1.5 x MEOP for 2 x predicted number of operating cycles. (50 cycles minimum) or Cycle at 1.0 x MEOP for 4 x predicted number of operating cycles. (50 cycles minimum)	Burst Factor x MEOP

(1) After demonstrating no burst at the defined test level, increase pressure to actual burst of vessel. Record actual burst pressure.

(2) Test may be deleted at discretion of procuring agency.

AIAA-S-081A Requirements Summary

- **Document takes more general requirements approach to fit all types of man rated and non-man rated space applications**
  - Requires a program to determine what type of requirements to levy on itself (structural, environmental, performance, process controls)
  - Overlaps SSP 41172 and SSP 30233 in some areas and determination would have to be made in event of potentially conflicting requirements
  - Notable design requirements include the following:

    LBB of liner and Safe Life via analysis or test

    Positive Margins of Safety

    Minimum FOS on burst of 1.5 (on MEOP)

    Stress Rupture Reliability of 0.999 probability for survival for one year

    Damage Control Plan; controls verified by test

    Analysis to predict remaining life based on DCP test verified damage

    A-basis allowable determined by sub-scale COPV or full-scale COPV burst test [5.3.2]

    Use proven processes for Fabrication, Process Control, Quality Assurance
  - Tailoring to specific program allowed per paragraph 2

    Would need to go through to pick and choose requirements (make determination for verification of design requirements if required; potentially exclude DCP test, A-basis allowable test, and stress rupture reliability; resolve any potential SSP 30233 conflicts).

AIAA-S-081A Requirements Summary

- **Design Requirements Verification table**
- **Qualification Test Requirements**
  - Acceptance tests
  - Cycle test to 4 x specified cycle life min. 50 cycles, at critical use temp
  - Vibration test per MIL-STD-1540 (plan test in advance and envelope worst case conditions)
  - Burst test to FOS, then to actual burst
  - Leak test (no parameters given) after Cycling
- **Acceptance Test Requirements**
  - NDI per program specification
  - Leak test (no parameters given)
  - Proof to 1.5 x MEOP at critical use temp for burst ≥ 2 for min. of 5 mins
- **Total tanks required for destructive testing**
  - 2 for Qualification (cycle and burst)
  - Several for DCP controls (based on type of protection)
  - 1 for A-basis allowables determination

Table 1 — Design Requirements Verification Matrix

Requirement Section	Section Title	Verification Method	Verification Section (s)
5.2.2	Strength	Analysis & Test	6.1.1, 6.3.2, 6.4.3
5.2.3	Stiffness	Analysis & Test	6.1.1, 6.4.2,6.4.3
5.2.5	Margin of Safety	Analysis or Test	6.1.1, 6.2.5
5.2.6	Fatigue Life	Analysis or Test	6.1.2, 6.2.1, 6.4.1
5.2.7	Damage Tolerance Life (Safe-Life)	Analysis or Test	6.1.3, 6.2.2
5.2.8	Leak-Before-Burst	Analysis or Test	6.1.4, 6.2.3
5.2.10	Mechanical Damage Control	Test	6.2.4

Table 2 — Qualification Pressure Testing Requirements

Test Item	Life Cycle Testing, Demonstrate No Detrimental Effects[a]	Burst Testing, Demonstrate No Burst at[b]
Vessel #1[c]		Burst Factor x MEOP
Vessel # 2	Cycle for 4 times service life, including proof tests[d,e]	Burst Factor x MEOP

[a] Detrimental effects causing unacceptable, unusual, unplanned, or out of specification damage and/or rejectable indications.

[b] Unless otherwise specified by the procurement agency and launch-site/range safety office having jurisdiction, after demonstrating no failures at the design burst pressure test level, increase pressure to actual burst of vessel. Record actual burst pressure.

[c] Test vessel may be deleted with the agreement of the procurement agency and launch-site/range safety office.

[d] All pressure cycles in excess of 0.25 MEOP will be considered in the life cycle test.

[e] If the total number of pressure cycles at MEOP or above times four (4) is less than 50 cycles, the differences required to meet the 50 cycles minimum, must be demonstrated by continuing to cycle from zero pressure to MEOP and back to zero pressure until the 50 cycles minimum is met. "Zero pressure" may be as high as 5% of the test pressure.

Safety Design & Testing – Different Approaches

	Failure Mode	ISO 11119-3 (Consumer)	AIAA S-081 A
1	Composite Stress Rupture	Fiber Stress Ratio (2.4C, 3K, 3.4Glass) Test to 3.0 for all	Burst Factor 1.5
2 3	Liner Cycle Fatigue (parent material) Liner Weld Cycle Fatigue	Ambient & Environmental Cycle Tests	Leak-Before-Burst & Safe-Life
4	Pressure Buildup (gas heating after fill)	Increase Pressure in Ambient Cycle Test	MOP Controlled
5	Collateral Damage	Flaw Test & Drop Test	Damage Control Plan
6	Liner Buckling (critical with very thin liner)	Vacuum-Cycle Test	Thicken Liner

ISO 11119-3 Assumes 10 year operational life and corresponding number of cycles.
AIAA S-081 uses ‘one size fits all’ approach; ISOL Verification by test not Analysis.
Consumer Vs. Space: Materials Space v. Cost

Current Program Requirement/Verification Approach

- **Program baseline for NORS RTA to ship full within CONUS and to ATV, HTV launch sites in French Guiana and Japan, respectively**
  - Need to meet DOT/ISO standards to be able to ship pressurized tank assemblies (for pressure vessel, ISO 11119-3)
  - NORS RTA Pressure Vessel envelope drawing consolidates ISS and ISO/DOT requirements in order to satisfy ISO for ship full, and still meet or exceed ISS requirements

2012 Update to Certification Test Plan

- **NASA Directed Boeing to Alleviate Full ISO certification, and reduce required ISO qualification testing to obtain DOT Special Permit**
  - Verification of structural/fracture control requirements via test program
- **Requirements Changes**
  - Retain current requirements/testing approach
  - Modify ISO/DOT certification requirements appropriately
  - ISO testing still meets verification intent for SSP 30559/30558 section 3 requirements

Summary

- **To supply oxygen and nitrogen to the International Space Station, a COPV tank is being developed to meet requirements beyond that which have been flown.**
- **In order to 'Ship Full' and support compatibility with a range of launch site operations, the vessel was designed for certification to International Standards (ISO) that have a different approach than current NASA certification approaches.**
- **These requirements were in addition to existing NASA certification standards had to be met.**
- **Initial risk-reduction development tests have been successful. Qualification is in progress.**

Back up

Current Baseline Requirement/Verification Approach

ISO 11119-3 Certification Test Summary

ISO 11119-3 Qualification Testing			
Paragraph	**Title**	**Test Summary/Description**	**Required**
8.5.1	Hydraulic Pressure (Proof)	Hydraulically press to Ph for 30 sec min w/o failure or leakage	X
8.5.2	Hydraulic Expansion	Hydraulically press to Ph for 30 sec min, measuring elastic expansion, w/o failure, leakage, or expansion > 110% of batch	X
8.5.3	Cylinder Burst	Hydraulically press 3 tanks to failure, Pb must be >= 2 x Ph	X
8.5.4	Ambient Cycle	Hydraulically press 2 tanks ambient to Pmax for 5000 cycles (10 yr life) or 12000 cycles (unlimited life), w/o failure or leakage, and then additional 5000 cycles (10 yrs life) or 12000 cycles (unlimited life), ambient to Pmax, w/o failure (leakage allowed)	X
8.5.5	Vacuum	N/A (only required for tank internally exposed to vacuum	
8.5.6	Environmental Cycle	Hydraullically press ambient to Pw for 5000 cycles w/ skin maintained at 140-158 degF & >=95% RH, 5000 cycles ambient to Pw w/ skin at -58 to -76 degF, 30 cycles at ambient environment, ambient to Ph, then subject to burst test where burst >=1.4 x Ph (12.6 ksi)	X
8.5.7	High Temperature Creep	Hydraullically press 2 tanks to Ph for 1000 hours (20 yr life) or 2000 hours (unlimited life) w/ external T >158 deg F, RH<50%, then must pass leak test and burst test w/ Pb >= 2 x Ph (18 ksi)	X
8.5.8	Flaw	Test 2 tanks, 2 cuts 1mm thick, 40% overwrap thickness deep, 5 x overwrap thickness long; one transverse, one longitudinal. 1 Tank must then pass burst test Pb >= 4/3 x Ph (12 ksi), 1 Tank must pass Ambient cycle test at Pw for first 1000 cycles w/o leakage (no burst allowed), and up to 4000 more cycles until leaks (no burst allowed)	X
8.5.9	Drop	Drop tank 1.8 meters onto cement, once on each top, bottom, side and 45 deg angle (ported end down); must then pass 3000 cycles ambient to Pw w/o leakage or burst, plus additional 9000 cycles w/o burst or until failure by leakage	X
8.5.10	High Velocity Impact (Gunfire)	Impact tank pneumatically press-ed at Pw with 0.3 caliber armour-piercing projectile (37-51 mm) nominal speed 850 m/s at 45 deg impact angle to cyclindrical section; must remain in one piece	X
8.5.11	Fire Resistance	Fit burst disc to tank set between Ph & 1.15 x Ph, press pneumatically to Pw, create fire around tank such that >=590 deg C 25 mm below tank in 2 min; must not burst tank in 2 min (venting or leaking is acceptable)	X
8.5.12	Permeability	N/A (only required of w/ non-metalic or no liners)	
8.5.13	Torque	Valve fitted to tank 2 times and torqued to 150%. Bubble leat test for 10 min after being held at Pw for 2 hours; must leak less than 1 bubble/2 min and show no visible damage or deformation	X
8.5.14	Salt Water	N/A (only required for underwater applications)	
8.5.15	Leak	Leak test at Pw via bubble testing or trace gas and mass spectrometer method	X
8.5.16	Pneumatic Cycle	Pneumatically press to Pw for 72 hours, pneumatic cycle to Pw for 100 cycles (each cycle 55 - 65 min), again pressure to Pw for 72 hours, then subject to Ambient Cycle Test; cylinder must not blister or collapse and pass Ambient Cycle Test.	X
8.5.17	Water Boil	N/A (only required for tanks w/o liners)	

NOTE: Pw = working pressure (6 ksi), Pmax = dedicated gas test pressure (8 ksi), Ph = test pressure (9 ksi [Proof]), Pb = burst pressure (>18 ksi)

Current Baseline Requirement/Verification Approach

- **The below testing is performed in addition to ISO 11119-3 required testing**
- **Qualification**
  - Random Vibration
    Test per SSP 41172 for CIRD* Random Vibe spectrum along with mass simulator for RTA Valve Assembly
  - Sinusoidal Vibration
    Test per SSP 41172 for CIRD Flight Shock spectrum
  - Infrared Emission
    Test per ASTM E 408 or equivalent
  - Pressure
    No additional testing required; meet ISS Proof (1.5 x MDP) during autofrettage process (expected pressurization to ~11.5 ksia)
  - Leak
    No additional testing required; meet ISS Leak at MDP per Methods II, III, or VIII via ISO leak testing
  - Life
    Minimal additional testing required; DFRM of specified cycles enveloped by ISO cycle testing, except for 6 cold cycles at 6 ksia and -80 deg F
- **Acceptance**
  - Pressure
    No additional testing required; meet ISS Proof (1.5 x MDP) during autofrettage process (expected pressurization to ~11.5 ksia)
  - Leak
    No additional testing required; meet ISS Leak at MDP per Methods II, III, or VIII via ISO leak testing

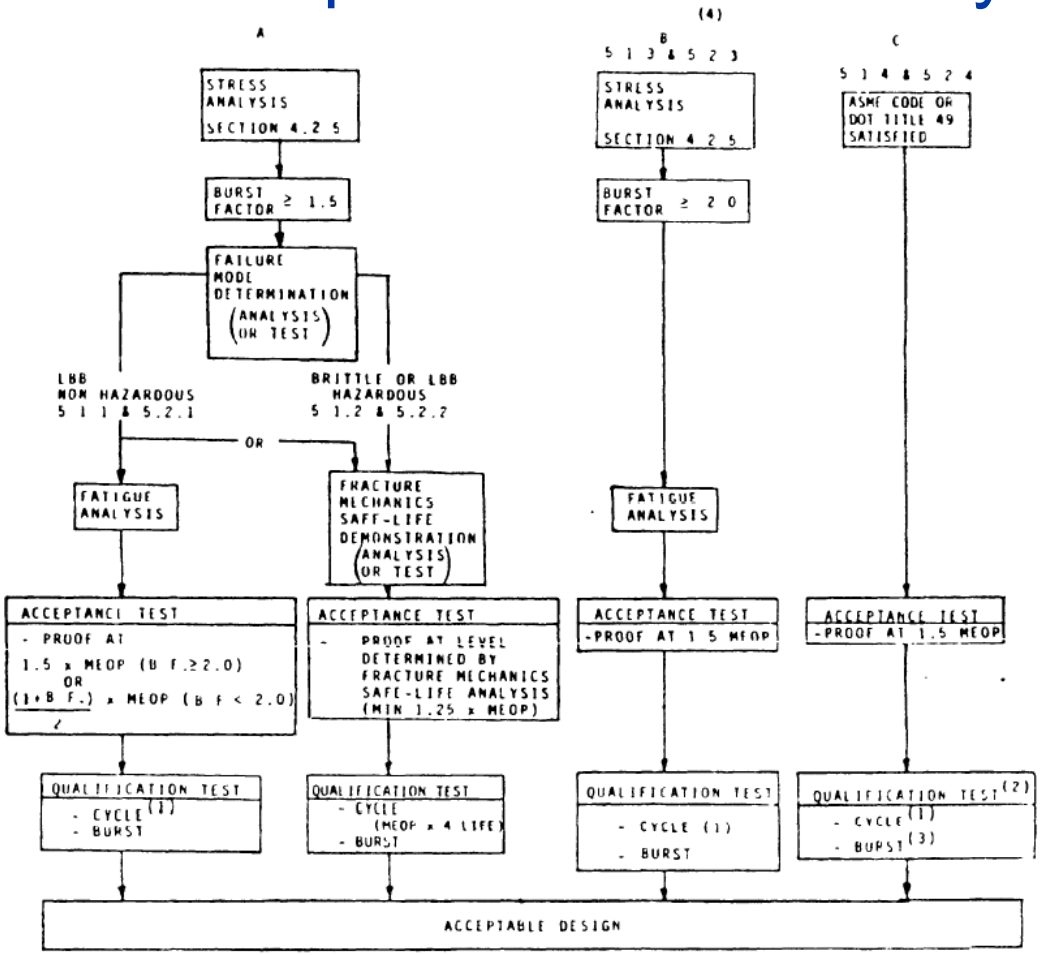
Current Baseline Requirement/Verification Approach

ISO 11119-3 Batch Acceptance Test Summary

ISO 11119-3 Batch Testing			
Paragraph	**Title**	**Test Summary/Description**	**Required**
9.4.4	Hydraulic Pressure (Proof)	Hydraulically press to Ph for 30 sec min w/o failure or leakage (All tanks in batch)	X
9.4.5	Ambient Cycle	Hydraulically press 1 tank ambient to Ph for 5000 cycles (10 yr life) or 24000 cycles (unlimited life), w/o failure or leakage (1 tank in batch)	X
9.4.6	Cylinder Burst	Hydraulically press 1 tank to failure, Pb must be >= 2 x Ph (1 tank in batch)	X
9.4.7	Leak	Leak test at Pw via bubble testing or trace gas and mass spectrometer method (All tanks in batch)	X

NOTE: Pw = working pressure (6 ksi), Pmax = dedicated gas test pressure (8 ksi), Ph = test pressure (9 ksi [Proof]), Pb = burst pressure (>18 ksi)

MIL-STD-1522A Requirements Summary



NOTES (1) CYCLE TEST AT EITHER MEOP x 4 LIFE OR 1.5 MEOP x 2 LIFE

(2) GROUND SUPPORT EQUIPMENT REQUIRE FUNCTIONAL TEST ONLY

(3) BURST OR DISPOSITION VESSEL WITH APPROVAL OF THE PROCURING AGENCY

(4) [illegible] NOT ACCEPTABLE FOR USAF/SD USE

SSP 41172 Requirements Summary

TABLE 4−1 COMPONENT QUALIFICATION TESTS

Test	Electronic or Electrical Equipment	Antennas	Moving Mechanical Assembly/ Mechanisms	Solar Panel	Batteries	Fluid or Propulsion Equipment	Pressure Vessels	Thermal Equipment	Optical Equipment
Functional (1)	R	R	R	R	R	R	R	R	R
Thermal Vacuum (4)	R	R	R	R	R	R	–	R	R
Thermal Cycling	R	R	ER	R	–	R	–	R(8)	R
Depress/Repress (5)	R	–	R	–	–	R	R	R(9)	R
Sinusoidal Vibration	–	–	–	–	–	–	–	–	–
Random (3) Vibration	R	R	R	–	R	R	R	R	R
Acoustic Vibration	R(3)	R(3)	–	R	–	–	–	–	–
Pyro Shock (10)	R	–	R	–	R	R	–	R	R
Acceleration	–	–	–	–	–	–	–	–	–
Humidity	–	–	–	–	–	–	–	–	–
Pressure	–	–	–	–	R(2)	R	R	–	–
Leak	R(2)	–	–	–	R(2)	R	R	R	R
EMI/EMC (11)	R	–	–	–	–	–	–	–	–
Life	–	–	R	–	–	–	–	–	–
Corona (6) (7)	R	–	–	–	–	–	–	–	–

LEGEND: R = REQUIRED − The ISS requires as a minimum that the article be tested if the subject environment is experienced during the article's life cycle. ER = EVALUATION REQUIRED − Test requires an evaluation from the cognizant technical team and Test and Verification (T&V) representative.

Notes:

(1) Functional tests shall be conducted prior to and following environmental test.
(2) Required only on sealed or pressurized equipment.
(3) Either random vibration or acoustic vibration test required with the other optional.
(4) External components only.
(5) Internal components only.
(6) Corona testing is not required for components with a sealed chassis or components which are powered on and operating under space vacuum conditions only.
(7) See Table 4−1a for component voltage criteria dictating corona testing.
(8) Thermal Cycling shall not be required for passive thermal equipment.
(9) A depress/repress test is not required if ultimate pressure testing provides a more severe differential pressure across the unit.
(10) Applicable if the hardware is exposed to a Pyro Shock environment.
(11) When multiple test articles exists, only one is required for the qualification of design.

TABLE 5−1 COMPONENT ACCEPTANCE TESTS

Test	Electronic or Electrical Equipment	Antennas	Moving Mechanical Assembly/ Mechanism	Solar Panel	Batteries	Fluid or Propulsion Equipment	Pressure Vessels	Thermal Equipment	Optical Equipment
Functional (1)	R	R	R	R	R	R	R	R	R
Thermal Vacuum (8)	R(4)	–	R	–	R	R	–	R	–
Thermal Cycling	R(4)	–	ER	–	–	R	–	–	R
Random Vibration	R	R	R	–	–	R(5)	–	R(5)	R
Acoustic Vibration	–	R(3)	R(3)	R	–	–	–	–	–
Pressure	–	–	–	–	R(2)	R	R	–	–
Leak	R(2)	–	–	–	R(2)	R	R	R	R(2)
Burn−In	R	–	–	–	–	–	–	–	–
Oxygen Compatibility	–	–	–	–	–	R(10)	–	–	–
Corona (11) (12)	R	–	–	–	–	–	–	–	–

LEGEND: R = REQUIRED − The ISS requires as a minimum that the article be tested to detect material and workmanship defects. ER = EVALUATION REQUIRED − Test requires an evaluation from the cognizant technical team and T&V representative.

Notes:

(1) Functional tests shall be conducted prior to and following environmental test.
(2) Required only on sealed or pressurized equipment.
(3) Either random vibration or acoustic vibration test required with the other optional.
(4) Minimum 100 degrees F (55.6 degrees C) sweep required.
(5) Only maximum predicted flight spectrum and level minus 6 dB required.
(6) Deleted.
(7) Deleted.
(8) For components which operate in pressurized environment only, thermal vacuum testing is optional.
(9) When a proven technique of acceptance by inspection without vibration testing has been demonstrated on previous space programs, items are not required to undergo random vibration or acoustic vibration acceptance tests.
(10) Only required for components wetted with pure oxygen.
(11) Corona testing is not required for components with a sealed chassis or components which are powered on and operating under space vacuum conditions only.
(12) See Table 5−a1 for component voltage criteria dictating corona testing.