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Title: Failure Analysis of Compressed Natural Gas Containers for Automotive Use
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ABSTRACT

In 2009, the National Highway Traffic Safety Administration's (NHTSA's) Office of Defects Investigation made site visits to two different companies that utilized compressed natural gas (CNG) to fuel their vehicle fleets. The purpose of these site visits was to obtain information concerning two independent incidents where high pressure CNG fuel containers on fleet vehicles ruptured during or shortly after refueling. These containers were represented as conforming to industry standard ANSI/NGV2 [1], and were still within their 15 year manufacturer recommended service life (although they had experienced several years of on-road use). Further, the newer model containers were self-certified by the manufacturer as compliant with Federal Motor Vehicle Safety Standard (FMVSS) 304 [2].
After the container ruptures occurred, each of the companies, for reasons of safety, retired the sister vehicles in their fleets. The decommissioning of these fleets offered an opportunity to NHTSA to obtain some of the retired CNG containers, which experienced similar service conditions to those that ruptured during refueling, and to subject them to both nondestructive (NDE) and destructive evaluation (DE) to document in-service wear, damage and residual life.
To this end, NHTSA entered into an Interagency Agreement with the National Aeronautics and Space Administration (NASA) White Sands Test Facility (WSTF), to conduct the evaluation of the used containers and compare them to unused containers of similar design. NASA has been performing test and evaluation of composite pressure vessels, similar to those designed for automotive use, since 1978. The objective of the evaluation is to gain valuable insight into the construction and deterioration elements that could suggest potential improvements in the existing standards. Destructive and nondestructive evaluation of the aged and new containers is on-going. This paper presents the results of the evaluation to date and potential future steps in the program.

INTRODUCTION

In 2009, the National Highway Traffic Safety Administration (NHTSA's) Office of Defects Investigation made site visits to two different companies that utilized compressed natural gas (CNG) to fuel their vehicle fleets. The purpose of these site visits was to obtain information concerning two independent incidents where high pressure CNG fuel containers on-board fleet vehicles ruptured shortly after refueling. After the container ruptures occurred, each of the companies, for reasons of safety, retired the sister vehicles in their fleets. The decommissioning of these fleets offered an opportunity to NHTSA to obtain retired CNG containers which experienced similar service conditions to those that ruptured during refueling, and to subject them to both nondestructive (NDE) and destructive evaluation (DE) to document in-service wear, damage and residual life. To this end, NHTSA entered into an Interagency Agreement with the NASA/WSTF, to conduct the evaluation of the used containers and compare them to unused containers of similar design.
NHTSA had sister containers from each of the retired fleets shipped to NASA/WSTF for evaluation. The shipments included twenty-three Brunswick Type-4 CNG containers from one fleet and thirty-six Lucas Aerospace Type-2 containers from the other. The "Type" designation refers to the construction of the container. Type-1 containers are all metal – e.g., aluminum alloy or steel. Type-2 containers have a load bearing metal liner that is reinforced with composite (glass, aramid, carbon fiber or combinations thereof) hoop wrap around the parallel length of the container. Type-3 containers are fully wrapped by composite fiber and have a thin metal liner with most of the stress on the composite wrap. Type-4 containers have a non-metallic liner fully wrapped with composite fiber, which provides all of the container strength. The Brunswick containers were manufactured in 1994, and certified to ANSI/NGV2 for 15 years. The Lucas containers were manufactured in 1998 and certified for 15 years to ANSI/NGV2. They were also self-certified as compliant with FMVSS 304, which went into effect in 1995.
Federal Motor Vehicle Safety Standard 304*, Compressed Natural Gas Fuel Container Integrity*, is based on a subset of recommendations in the industry standard NGV2, and specifies performance and labeling requirements for the integrity of CNG motor vehicle fuel containers. Specifically, FMVSS 304 requires that non-welded containers (such as those evaluated in this study) do not leak or rupture in a hydrostatic burst test, when held at not less than 2.25 times the service pressure (SP) for 10 seconds. Containers must

also undergo a hydraulic pressure cycling test without leakage, and are subjected to bonfire tests per FMVSS 304. They must be labeled with information specified in the standard, and the label must remain affixed and legible for the manufacturer's recommended service life of the container. The FMVSS 304 labeling requirements are shown in Figure 1.

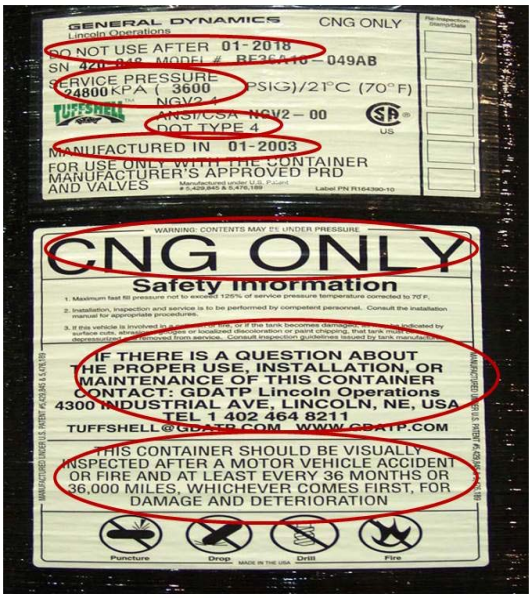

Figure 1. Labeling Requirements in FMVSS 304, CNG Fuel Container integrity

PURPOSE

The purpose of this effort is to document in-service wear, damage and residual life in CNG containers that have seen real world service, through nondestructive and destructive evaluation techniques. New containers are certified to the strength (i.e., burst) and durability (i.e., cycling) test requirements in standards and regulations such as ANSI/NGV2 and FMVSS 304, but (in this study) we seek additional data about the effects of the real world service environment on container life. While this study may not determine the root cause of the failures that occurred in the aforementioned two fleet vehicles, internal/external examination and residual strength tests may reveal weaknesses that can be addressed through improved tests, periodic inspection, and/or installation guidelines.

Synopsis of the CNG Container Failures

On June 9, 2008 a Type-2 Lucas Aerospace CNG container in a 1998 dedicated CNG Ford E350 van ruptured shorty after refueling at a Philadelphia Gas Works facility. The vehicle was equipped with three 3,000 psi rated containers that had a manufacturer recommended service life of 15 years and were manufactured in March 1998. Two 14" x 34" containers were mounted transversely in the rear of the vehicle. The third 12"x72" container, which ruptured, was mounted alongside the driveshaft inside the frame rail on the driver's side. The glass fiber overwrap failure was the result of stress corrosion cracking caused by an unidentified corrosive agent between the overwrap and the steel liner [3,4]. Over-pressurization of the steel liner during fueling also may have contributed to the failure. This may have been caused by a failure to close condition of the tank mounted solenoid valve and/or an improperly set relief valve on the fueling station [5]. Figure 2 shows the failed container.

Figure 2. Failed Type-2 Lucas Aerospace Container (portions of overwrap and steel liner missing)

On March 16, 2009 two Brunswick Type-4 containers ruptured during refueling of a laundry truck (i.e., conversion step van) in Pasadena CA. For the 3,000 psi rated containers, the manufacturer stated that the service life is 15 years and these containers were manufactured in 1994. They would have been at the end of their manufacturer recommended service life in October 2009. One of the containers was mounted vertically inside the back of the van onto a rubber padded steel ring with the shut off valve, pressure relief device (PRD), and piping exposed under the vehicle. The second ruptured container was mounted longitudinally under the vehicle, unshielded, and with its valve end dome directly beneath the vertical container [5]. The containers ruptured sequentially. The order and exact cause of rupture is unknown. Possible scenarios are that either the horizontal or vertical container failed first, due respectively to possible road damage or damage caused by the vertical mounting. The second container failed from fragmentation caused by the first rupture. Figure 3 shows some of the damage to the vehicle.

Figure3. Step Van Damaged by Type-4 Container Ruptures on Driver's side

Program Plan Overview/Status

The objective of the test program is to employ destructive and nondestructive evaluations on intact containers removed from service, and new containers. The goal is to ascertain if there are gaps in codes, standards and regulations which could be addressed to improve safety performance of future container designs.

The Test Plan consists of the following major components shown in Table 1.

Table 1.
Overview of Phased Evaluation of Type-2 and Type-4 CNG Containers

	Test Plan Phase	Status
1.1	Type-4 Nondestructive Service Evaluation	Complete
1.2	Type-4 Destructive Evaluation	Complete*
1.3	Type-4 Mechanical Sectioning and Materials Analysis	Complete
1.4	Type-2 Nondestructive Service Evaluation	Underway
1.5	Type-2 Destructive Evaluation	Planned

*One additional pneumatic burst test of an aged Type-4 container will be conducted in 2015

Type-4 Test Articles
Twenty-three Type-4 containers were removed from service and shipped to WSTF for testing. The WSTF numbers assigned to the containers for testing are WSTF# 11-45269 through 11-45291. These control numbers provide traceability to historic records and to each test that is performed. The containers were individually packaged in cardboard boxes for shipment from California. Once received at NASA/WSTF the containers were locked inside controlled access facilities.

Type-4 Containers - Nondestructive Service Evaluation Methods
Each of the containers was subjected to the following nondestructive examination techniques, the results of which are documented in individual data packages.

- Shipping containers, packing materials, and all accessible exterior surfaces were inspected in the as-received condition. Digital photographs of the container, packaging arrangement, and exposed surfaces were taken.
- An as-packed coordinate system was registered to the exposed features on the test article, enabling subsequent registration with a fully-exposed-article grid coordinate system to be referenced and remain consistent throughout the examination.
- Once the CNG containers were removed from the shipping containers, visual inspections of the remaining exterior surfaces were completed and documented through a combination of near and far field photography. Visual indications were recorded and documented per the manufacturer's criteria.
- Physical dimensions such as weight, length, and circumference at several distances from the top dead center (TDC) reference boss (A-end or valve end boss), were measured and recorded.
- A detailed visual inspection damage log and high magnification photography, recorded damage indications mapped to the coordinate system on the exterior upper dome (A-end), hoop region and lower dome (B-end plug) of each container.
- Prior to internal inspection, the break-away torque of the manual valve and plugs were measured.
- Internal visual inspection and boroscopic images recorded presence of contaminants (e.g., compressor oil), bubbles, voids, staining, and other indications on the container interior.
- Radiographic images of the interior documented internal interfaces such as boss-to-liner and liner-to-overwrap.
- Flash thermography was used to reveal infrared transfer of heat into wall surface fiber layers, useful for identifying subsurface areas of delamination.
- Laser shearography was used to detect non-visible internal flaws (two containers only).
- Samples of interior and exterior contaminants and foreign debris were collected, analyzed, and archived (twenty-three samples of each collected and archived, 2 analyzed).
- Samples of residual gas in containers that arrived with valve closed were collected and analyzed (three containers only).

Type-4 Containers - Nondestructive Evaluation Results
Appendix A provides an inventory of the Type-4 containers and a summary of the NDE results. The following general observations were made.

- Some damage was observed on several shipping containers, including mechanical damage and oil contamination.
- Inconsistent and/or variable debris buildup was observed on test article exteriors.
- Some labels were missing, illegible, or obscured by container mounting straps in service.
- Some labels were wrinkled in such a way to imply containers were shifting within vehicle mounts during service.
- Paint transfer was observed on numerous test articles. Primers, paints, or other "incidental contact" chemicals not addressed in testing may not be compatible with container overwrap materials.
- Break-away torque of the pressure fittings on containers varied from below 5 ft-lb to 170 ft-lb, with oil on the outside of some containers which was chemically similar to oil found on the inside, possibly indicating a chemical/flammability hazard.
- The largest average container circumference was near the dome regions. The smallest circumference was near the center of the container length.
- No provisions for proper torque of the pressure fittings (wrench flats) are available. Over torque may cause damage to boss-to-liner or boss-to-overwrap interface.
- Mechanical damage was present up to Level 2 per CGA Pamphlet C-6.4-2007 and Level 2b per OEM technical inspection manual. Level 1 damage does not require repair. Level 2 damage requires the manufacturer's recommendation in writing for disposition or repair of the container. Level 3 damage requires the container to be condemned.
- Rubber hose mounting ring and adhesive material was observed on containers that were mounted vertically in vehicles which may not be compatible with overwrap.
- Vertical dome mounting configuration was not addressed by the container manufacturer, which recommends horizontal strap mounting with guidance on strap locations. There may be potential for direct dome mounting to damage the structural composite.
- Circumferential witness marks were unevenly spaced from boss to boss with a variation in witness mark width. This provides evidence of shifting during service. Torque and pre-load specifications on container straps should preclude structural damage and limit lateral translation.
- Oil was observed on the interior and exterior of the test articles, internally as much as half a gallon of compressor oil was measured in a container used in the horizontal mounting configuration.
- Liner visual indications such as blistering were observed in the dome regions of almost all test articles. Significance of blistering, whether from manufacture or use, is unknown.
- Evidence of severe liner separation from overwrap and boss was observed in one container via computed radiography.
- Laser shearography data was of little value and excessively noisy due to as-received surface condition of containers. The "Tuffshell" sacrificial glass layer distorts data in the hoop transition and dome regions. Application of a dulling developer solution improved readings slightly.
- Thermography data was of little value. The overall composite wall thickness and sacrificial glass layer distorts heat transfer characteristics. The addition of impact protection in hoop transition and dome regions confounded useful data from the load bearing surface underneath.
- Three containers with closed valves had 1 – 5 psi residual gaseous contents composed of approximately 94% air, 3.5% ethane, 1.5% propane, 0.6% butane and a trace amount of methane.
- Exterior contaminants consisted of kaolin (clay), aliphatic hydrocarbon (oil), and silicon dioxide (sand) – all expected road contaminants.
- Interior contaminants were a two phase oil residue/paste consisting of aliphatic hydrocarbon and polypropylene glycol, white crystalline carboxylic acid and cellulose acetate butyrate.

Type-4 Containers - Destructive Evaluation Methods
Seven of the twenty-three containers that were examined nondestructively were selected for destructive evaluation under this test plan. The NDE served as the basis for selection of six test vessels to undergo

hydraulic cycling and burst, based on the test methods in certification standards. One container was selected for pneumatic burst testing, as pneumatic burst was the failure mode in the delivery vehicles. For comparison, two new vessels of similar design were also selected for hydraulic burst testing. Unfortunately the new containers are not the exact configuration of the service containers, but they do share many of the same features of construction and materials, giving them some limited value as reference test articles. A comparison of the containers is provided in Table 2.

Table 2.
Typical Dimensions of Type-4 Service and New Containers

Description	Service Containers	New Containers
Manufacturer	Brunswick Composites (now Lincoln)	Lincoln Composites
Mfgr Part Number	RA30A16-055AB	240172-030
Service Pressure (SP)	3000 psig	3600 psig
Standard	NGV2-4	ANSI/CSA NGV2
Volume	124 L	54 L
Length (typical)	55 in.	35 in.
Weight	114 lb	65 lb
Diameter (typical)	16 in.	13.8 in.
Shell Construction	Glass/C/epoxy hybrid with TuffShell®[a] protective shoulder	Glass/C/epoxy hybrid with TuffShell protective shoulder
Liner Material	HDPE	HDPE
Resin	Epoxy	Epoxy
Fiber Reinforcement	Carbon and glass fiber hybrid	Carbon and glass fiber hybrid

[a] TuffShell® is a registered trademark of General Dynamics Armament and Technical Products, Inc., Charlotte, North Carolina.

Selection of the containers for cycling and burst testing sought to provide data representative from as broad a sample of container use-conditions as possible. Therefore, containers selected were as follows in Table 3.

Table 3.
Type-4 Container Cycling and Burst Tests

Hydraulic Cycling and Burst
New Test Articles: WSTF ID #12-45898 WSTF ID #12-45894 - Previously pressure cycled : (15,000 cycles to 1.25*SP) Service Test Articles (Unconstrained during Testing) Vertically-Mounted: WSTF ID#11-45272 Horizontally-Mounted: WSTF ID# 11-45276 Service Test Articles (Constrained in OEM Mounting Straps): Vertically-Mounted: WSTF ID#11-45278 Horizontally-Mounted: WSTF ID# 11-45273 Service Test Articles (Unconstrained, Tuffshell Removed from Dome): Vertically-Mounted: WSTF ID#11-45281

Horizontally-Mounted: WSTF ID#11-45282
Pneumatic Burst (Nitrogen Fill Gas)
Service Test Article (Unconstrained during Testing) Vertically-Mounted WSTF ID#11-45269

Pressure data, volumetric response, dome response, strain response (sixteen strain gauges) and high speed video was collected for each of the tests and archived in data packages.

Hydraulic testing on eight containers consisted of seven pressure cycles, each with a dwell time of sixty seconds, and then ramp at <50 psi/sec to burst. These pressurization rates are in family with existing limits. Cycle 1 had a dwell pressure of 1000 psi and was performed as an instrumentation check-out cycle. Cycles 2, 4 and 6 were to service pressure, and cycles 3, 5, and 7 were to 1.25 times service pressure.

Type-4 Containers - Destructive Evaluation Results

Observations and results of hydraulic cycling and burst tests are as follows:

- All Type-4 service test containers demonstrated repeatable response during cycling.
- Strain response was consistent in each respective gage location across the population of containers tested.
- Compressive/negative strain was observed in the transition regions.
- Volumetric change (mass of water put into the container) remained consistent.
- Containers grew axially (0.5 – 0.75 inches) between ambient and full fill pressure.
- Radial growth was minimal to 1.25 SP
- No significant difference in response was observed between unconstrained vs. constrained pressurization test conditions (OEM-supplied mounts were installed on constrained containers per OEM guidelines and in locations consistent with "witness marks" on service containers.)
- All containers exceeded minimum allowable burst pressure of 2.25 SP.
- No significant difference in response was observed between the new test container and the sister new container that had been previously cycled 15,000 times to 1.25 SP.
- All containers demonstrated the same failure mode. Split/rupture in the cylindrical section of the container. This was a different failure mode from that observed in the field.

Table 4 shows the burst pressures for each container.

Table 4.
Hydraulic Burst Test Results

WSTF ID	Burst Pressure (psi)	Service Pressure (psi)	Ratio Burst to Service Pressure
11-45898	12015	3600	3.34
11-45894	12521	3600	3.48
11-45272	8511	3000	2.84
11-45276	8166	3000	2.72
11-45278	8553	3000	2.85
11-45273	8246	3000	2.75
11-45281	8395	3000	2.80
11-45282	8358	3000	2.79

Observations and results of the pneumatic burst test are as follows:

- The final burst pressure was 7904 psi. Ratio of burst to service pressure (3000 psi) was 2.63.
- Rupture pressure was approximately 500 psi lower than the average hydraulic burst pressure of other test articles. This may be a temperature effect (adiabatic compression). One or more additional pneumatic burst tests for comparison are desirable.

- The failure mode resulted in total destruction of the container.
- Apparent rupture initiation location was in the mid-hoop region, similar to the hydraulic burst tests. Again, this was a different failure mode from that observed in the field.
- Rupture spiraled axially simultaneously toward both A and B-Ends.
- B-End remnants were found 220 feet from "ground zero".

Type-4 Containers - Mechanical Sectioning and Materials Analysis Methods
NASA/WSTF entered into an agreement with the Materials Science and Engineering Laboratory of the National Institute of Standards and Technology (NIST) to conduct complementary evaluation of mechanical and physical properties of coupon samples that were sectioned from the composite overwrap layer of two of the service containers (WSTF #11-45284 and 11-45290). Sections were examined microscopically for voids, porosity, matrix and ply cracking, and delamination. Specimens were tested for tensile and fatigue strength.

Type-4 Containers – Mechanical Sectioning and Materials Analysis Results
- There was significant void percentage throughout the dome/body transition region and body region of the container.
- Multiple cracks and ply delamination were found throughout the transition region.
- Ultimate tensile strength of straight-sided specimens had little data scatter.
- Fatigue of specimens at normal operating strains for 20,000 cycles had no effect on specimen residual strength.
- The Glass Transition Temperature (Tg) of samples compared to historical reference data increased with container use and age. This result may indicate an increase in brittleness.

Type-2 Test Articles
Thirty-six Type-2 containers were removed from service at Philadelphia Gas Works and shipped to WSTF for testing. In addition to these containers, WSTF maintains an inventory of thirty-one Pressed Steel Type-2 containers, which have seen real world service, and are available for comparative testing in this program. All containers are locked inside controlled access storage in the original shipping configuration. These containers are banded to pallets.

Type-2 Containers – Nondestructive Evaluation Methods
The nondestructive evaluation of the Lucas Aerospace and Pressed Steel containers employs the same techniques as those used for the Type-4 containers. Including the Pressed Steel containers in the evaluation provides a good representation from an additional vendor. These evaluations are scheduled to be completed in July 2015.

Type-2 Containers - Destructive Evaluation
In general, the destructive evaluation will follow the test plan developed for the Type-4 containers. However, since there are major differences in construction and failure modes between the two container designs, some modifications are planned, and others may develop over the course of the nondestructive evaluation.
For example, unlike the plastic liner of the Type-4 container, we believe the steel liner of the Type-2 container would be capable of withstanding at least 50% of the design burst pressure. Therefore, it is planned to conduct burst tests on containers, as received, and with the composite overwrap removed, to determine residual strength in the liner alone. These evaluations are scheduled to be completed in July 2015.

CONCLUSIONS AND RECOMMENDATIONS

NDE revealed mechanical damage and chemical exposure, which could be reduced through improved installation considerations. This damage was evidenced by missing and wrinkled labels, debris buildup, and "witness marks" left by container straps that indicated shifting during service, which may induce surface damage or stress on container valves and fittings. A large amount of compressor oil and other contaminants were drained from the interior of some containers. The effects of these contaminants on the container interior are unknown and could be assessed in further research. CGA Pamphlet C6.4 Level 2+ damage was observed on the exterior of two of the containers. It is not known whether this damage could have been detected in a periodic inspection with the container in situ, but CGA inspection requires the manufacturer's recommendation in writing for repair or disposal for Level 2 damage. No inspection records for the Type-4 containers were available. Labeling should remain on

the containers for life, in order to provide safety and tracking information like manufacturer contact information, service pressure rating, and end of life date for the containers.

The new and used Type-4 containers all exceeded the minimum hydrostatic burst strength requirement in FMVSS 304 of 2.25*SP. The container that was pneumatically burst exceeded the minimum burst strength as well, although at a lower margin. Running additional pneumatic burst tests of a Type-4 container would help to determine whether this result is consistent.

Microscopic inspection of composite coupon sections revealed voids, cracks, and ply delamination. Additional evaluation of new and used construction materials could provide insight into the relationship between physical and mechanical properties of samples and container performance and to provide comparison of what typical void and micro-cracking of unused containers looks like.

REFERENCES

[1] ANSI NGV2 (1992) Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers

[2] 49 CFR Part 571, FMVSS 304, Compressed Natural Gas Container Integrity, Effective Date March 27, 1995

[3] Brown, C., (2008) Metallurgical Evaluation of a Compressed Natural Gas Tank Cylinder Liner From PGW #3436, Report No. 0809-25278, Stork Technimet, Inc.

[4] Stenmark, N., (2008) Failure Analysis of a Composite Wrap on a Compressed Natural Gas Tank from PGW #3436, Report No. 0810-25584, Stork Technimet, Inc.

[5] Horne, D., (2010) CNG Cylinder Safety Issues & Opportunities, Natural Gas Vehicle Technologies Forum, October 12, 2010, Clean Vehicle Education Foundation

Appendix A

Table A1: NDE Summary of Service Containers (Horizontally Mounted

WSTF ID	S/N	Breakaway Torque Manual Valve (ft/lb)	Breakaway Torque Plug (ft/lb)	Weight [2] (lb)	Visual Inspection Internal Oil Present	Visual Inspection Internal Blister/wrinkle Indications	Visual Inspection External (# of indications) General [4]	Visual Inspection External (# of indications) CGA Level 1	Visual Inspection External (# of indications) CGA Level 2	Chemical Sampling External	Chemical Sampling Internal	Gas Sampling	Radiography A-End	Radiography Hoop	Radiography B-End
11-45271	43-3	105	< 5	118.7	Pooling	YES	6	3	1	Archived	Archived	N/A	Boss fitting delamination	Deformed Liner	Boss fitting delamination
11-45273	35-191	105	< 5	118.2	Trace	YES	4	5	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45274	35-190	110	< 5	119.2	Trace	YES	7	4	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45276	35-106	90	< 5	118.9	Pooling	YES	2	3	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45277	35-107	105	< 5	120	Pooling	YES	5	6	0	Archived	Archived	N/A	No anomalies observed	No anomalies observed	No anomalies observed
11-45279	35-079	105	< 5	119.5	Pooling	YES	1	8	1	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45280	35-078	105	< 5	119.7	Pooling	YES	3	4	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45282	35-109	110	< 5	119.5	Trace	NO	2	6	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45283	35-111 [1]	N/A	N/A	120.0	Pooling	YES	6	5	0	LWO# 726585	LWO# 726475	N/A	No anomalies observed	No anomalies observed	No anomalies observed
11-45285	35-042	40	< 5	118.7	Trace	YES	3	6	3	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45286	35-039	100	< 5	117.7	Trace	YES	2	3	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45289	35-123	130	< 5	121.2 [3]	Pooling	YES	3	1	1	Archived	Archived	Archived (~5 psig)	Boss fitting delamination	No anomalies observed	No anomalies observed
11-45290	35-121	115	< 5	121.4 [3]	Pooling	YES	3	0	0	Archived	Archived	Archived (~5 psig)	Boss fitting delamination	No anomalies observed	No anomalies observed

Notes:

1 Label detached and found loose within shipping container
2 Weight obtained after removal of boss fittings, includes residual oil
3 Weight includes closed boss fittings and residual gas contents
4 General indications, not assigned a classification level per CGA inspection criteria

Table A2: NDE Summary of Service Containers (Vertically Mounted)

WSTF ID	S/N	Breakaway Torque		Weight [2]	Visual Inspection					Chemical Sampling			Radiography		
		Manual Valve	Plug		Internal		External (# of indications)			External	Internal	Gas Sampling	A-End	Hoop	B-End
		(ft/lb)	(ft/lb)	(lb)	Oil Present	Blister/wrinkle Indications	General [4]	CGA Level 1	CGA Level 2						
11-45269	35-119	20	< 5	119.0	NO	YES	4	7	1	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45270	43-2	110	< 5	117.8	NO	YES	4	6	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45272	35-189	120	170	117.1	Trace	YES	2	7	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45275	35-041	110	< 5	117.8	NO	YES	7	8	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45278	35-074	100	< 5	120.1 [3]	NO	YES	2	7	0	Archived	Archived	Archived (~1 psig)	No anomalies observed	No anomalies observed	No anomalies observed
11-45281	35-108	105	170	117.6	Trace	YES	2	6	0	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45284	35-040	120	160	117.8	Trace	YES	2	7	1	Archived	Archived	N/A	Boss fitting delamination	No anomalies observed	Boss fitting delamination
11-45287	35-122	105	< 5	118.1	Trace	YES	3	6	1	Archived	Archived	N/A	No anomalies observed	No anomalies observed	No anomalies observed
11-45288	35-120	115	< 5	118.9	Trace	YES	3	8	2	Archived	Archived	N/A	No anomalies observed	No anomalies observed	No anomalies observed
11-45291	35-038	N/A	N/A	117.4	Trace	YES	2	11	1	LWO# 726585	LWO# 726475	N/A	Boss fitting delamination	No anomalies observed	No anomalies observed

Notes:

1 Label detached and found loose within shipping container
2 Weight obtained after removal of boss fittings, includes residual oil
3 Weight includes closed boss fittings and residual gas contents
4 General indications, not assigned a classification level per CGA inspection criteria