NASA-STD-7012 Leak Test Requirements: Potential Reference for ASNT Nondestructive Testing Handbook for Leak Testing

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ABSTRACT

Developed in 2018-2019, NASA-STD-7012 Leak Test Requirements, has been drafted based mostly on the NASA technical requirement documents applicable to the International Space Station (ISS) hardware and payloads that were developed over the years taking into consideration many known references such as Leakage Testing Handbook prepared by General Electric for the Jet Propulsion Laboratory, the ASTM International standards for leak testing, and last, but not least, the ASNT Nondestructive Testing Handbook for Leak Testing. Thus, NASA-STD-7012 has a reference to the above-mentioned handbook in the leak test method/technique descriptions. However, there are some technical details that are described differently in NASA standard and ASNT Handbook. Those technical details are mostly related to the classification of the leak test methods/techniques, and also to tracer gas to working fluid (gas or liquid) leakage rate conversion methodology, and to some definitions used in the text of both NASA standard and ASNT Handbook. Those differences are going to be briefly described in this paper to let ASNT leak test experts decide if they want to refer to NASA-STD-7012 while working on the next edition of the ASNT Handbook, Volume 2 for Leak Testing.

Keywords: leak test, leakage rate, sensitivity

INTRODUCTION

NASA has many technical standards. Each NASA technical standard is assigned to a specific technical discipline, one of which is called “System and Subsystem Test, Analysis, Modeling, Evaluation”. There were several technical standards and handbooks in this group, but not for leak testing (LT). Therefore, last year Johnson Space Center (JSC) Requirements, Test and Verification Panel (RTVP) directed authors to draft a standard for LT requirements. After it was done, JSC Engineering initiated the standard through the NASA Technical Standards Office. To improve the standard, number for which was assigned as NASA-STD-7012, NASA established a Working Group (WG) that consisted of more than 20 highly qualified in aerospace hardware environmental test and verification engineers (two WG members had ASNT Level III in LT, and five WG members had a Ph.D.). In its final version, the standard was sent to all the NASA Centers for review and commenting. More than 300 comments were received, considered, and dispositioned. Later, on March 5th of 2019, NASA Chief Engineer approved it. To better inform ASNT community about specific technical details found in the new NASA standard, authors looked one more time at NDT Handbook for leak testing (by the way, for many years it always was Volume 1, but now it’s Volume 2) and the findings will be presented here.

CLASSIFICATION OF LEAK TEST METHODS

The word ‘classification’ was not mentioned in Nondestructive Testing (NDT) Handbook for Leak Testing Volume 1 (1). The only section in NDT Handbook for Leak Testing Volume 2 (2) (hereinafter called Handbook) that has word ‘classification’ in its subtitle is “Classification Relative to Test Object”, but nothing has been said regarding classification of the LT methods/techniques. It has to be mentioned that ASTM E432-91 “Standard Guide for Selection of a Leak Test Method” (3) has a guide where LT methods are divided on ‘leak location’ and ‘leak measurement’ methods that certainly required a further clarification. Therefore, in NASA-STD-7012 Leak Test Requirements (4) (hereinafter called Standard) authors proposed the following classification (see Table 1) that was previously described in (5) and (6).

Table 1: Leak Test Methods for Pressure Integrity Verification and Pinpointing Local Leaks

Method No. and [Technique No.]	Leak Test Method[1,2]	Minimum Leakage Rate Expected to Be Verifiable (scc/sec)[3]	Maximum Allowable Leakage Rate (MALR) Setting
Methods for Total Internal-to-External Leakage Rate Verification			**A**
I [1] and [2]	**Vacuum Chamber [Chamber and Bell Jar techniques], quantitative**	**Down to 10^{-9}**	
II	**Accumulation, quantitative**	**Down to 10^{-7}**	
III	**Bombing, quantitative**	**Down to 10^{-8}**	
IV [1] and [2]	**Vacuum Exposure [Mass Loss and Pressure Loss techniques], quantitative**	**Down to 5×10^{-5}**	
V [1]	**Pressure Change [Pressure Decay technique], quantitative**	**Down to 10^{-4}**	
IX [2]	**Immersion [Total Leakage Rate technique], quantitative**	**Down to 10^{-4}**	
Methods for Total External-to-Internal Leakage Rate Verification			**A**
V [2]	**Pressure Change [Pressure Rise technique], quantitative**	**Down to 10^{-5}**	
VI	**Hood, quantitative**	**Down to 5×10^{-10}**	
Methods for Total Internal-to-Internal Leakage Rate Verification			**A**
VII	**Volumetric Displacement, quantitative**	**Down to 10^{-3}**	
VIII	**Leak Detector Direct Connection, quantitative**	**Down to 10^{-8}**	
Methods for Local Internal-to-External Leakage Rate Verification			**B**
IX [1]	**Immersion [Local Leakage Rate technique], semi-quantitative**	**Down to 10^{-4}**	
X	**Ammonia Colorimetric, semi-quantitative**	**Down to 5×10^{-6}**	
XI [1] and [2]	**Detector Probe [Joints and Flex Hoses techniques], semi-quantitative**	**Down to 10^{-5}**	
XII	**Foam/Liquid Application, semi-quantitative**	**Down to 10^{-4}**	
XIII	**Hydrostatic/Visual Inspection, semi-quantitative**	**Down to 10^{-3}**	
Method for Local External-to-Internal Leakage Rate Verification			
XIV	**Tracer Probe, semi-quantitative**	**Down to 10^{-8}**	**B**
A. Use only methods for total leakage rate verification if the MALR is set as a total leakage rate.			
B. Use only methods for local leakage rate verification if the MALR is set as a single-point leakage rate.			

***NOTES**:*
1. *The selection of a method to be chosen other than internal-to-external or external-to-internal leakage rate verification requires a special justification presented, for example, in a test article verification plan approved by the responsible safety organization;*
2. *The LT method employed should be demonstrated to have a sensitivity to detect leakage rates in accordance with this Standard;*
3. *The minimum leakage rate that could be reliably verified is dependent on many technical details specific for each method, for example, on sensitivity of the leak detector with probe attached, free volume of a particular test arrangement, and time of accumulation for the accumulation method.*

MAXIMUM ALLOWABLE LEAKAGE RATE

For the ISS hardware and payloads (hereinafter called test articles), the MALR (to be identified in the test article specifications or drawing) together with the LT method/technique (to be chosen from Table 1 to verify the MALR), shall ensure that the maximum amount of substance that could leak over the mission duration (calculated as MALR × mission duration × safety factor would prevent exceeding the allowed Toxicity Hazard Level (THL) or Spacecraft Maximum Allowable Concentration (SMAC) value, whichever is more conservative (see Table 2).

Table 2: Leak Test Methods to Be Used to Ensure Allowed THL and SMAC Values

THL or Other Limitations	Recommended MALR to Be Verified: Leak Test Method/Technique
Catastrophic	Although no greater than 10^{-9} scc/sec is a prevalent value, the specific MALR calculated in accordance with this Standard should take precedence: • Method I (to verify pressure integrity); • Method IV may be used to verify pressure integrity only if MALR for the test article filled with the gas or liquid is set to be 5×10^{-5} scc/sec or more; • Methods XI, XIV (to pinpoint local leaks).
Critical	Although no greater than 10^{-7} scc/sec is a prevalent value, the specific MALR calculated in accordance with this Standard should take precedence: • Methods I and II (to verify pressure integrity); • Method IV may be used to verify pressure integrity only if MALR for the test article filled with gas or liquid is set to be 5×10^{-5} scc/sec or more; • Methods XI, XIV (to pinpoint local leaks).
Fluid is not allowed or desired	No greater than 10^{-4} scc/sec: • Methods I, II, III, IV, and V [Technique No. 1] (to verify pressure integrity); • Methods IX, X, XI, XII, XIII, and XIV (to pinpoint local leaks).
Not safety, just general concerns about leaks	No greater than 10^{-3} scc/sec: • Methods I through XIV (selected to verify pressure integrity and/or pinpoint local leaks depending on a flow direction through leaks (out of or into the test article)).

LEAKAGE RATE UNIT CONVERSION

Conversion between leakage rate units is provided in the Leakage Testing Handbook (7), ASTM E1316 (8), and Handbook. However, for the ISS hardware and payloads, prior to conversion from a tracer gas (most frequently helium) leakage rate to a corresponding leakage rate of a working fluid (gas or liquid), the measured tracer gas leakage rate shall be recalculated per Equation 1:

$$Q_{100\%} = Q_{tg\%} \frac{100\%}{C_{tg\%}} \qquad \textbf{(Eq. 1)}$$

where

$Q_{100\%}$ = a tracer gas leakage rate recalculated to its 100% concentration.
$Q_{tg\%}$ = a measured tracer gas leakage rate at its known or estimated concentration.
$C_{tg\%}$ = a known or estimated concentration of a tracer gas inside the test article.

Tracer gas concentration shall be greater than or equal to 5% at all the points of potential leak paths during leak tests.

Conversion factors used to determine working fluid (gas or liquid) leakage rate from the measured tracer gas leakage rate may be based on the flow regime of the tracer gas and working fluid (gas or liquid) through the leak paths being tested and include the relevant pressure and thermal effects.
If the tracer gas used for leak testing is helium, conversion to a leakage rate of other fluids (most commonly used fluids (gas or liquid) are shown in the first column as an example) may be performed using the chart for conversion (see Table 3). For fluids (gas or liquid) not listed in the chart, use Equation 2 for gases or Equation 3 for liquids to find the conversion factor.

Table 3: Chart for Conversion from Helium to Other Fluids

To Convert Leakage Rate Measured with Helium as a Tracer Gas (Recalculated to its 100% Concentration)	Gas Flow Convert per Equation 2 where Viscosity Factor (VF) is:	Liquid Flow Convert per Equation 3 where VF is:
Q_{Air}	1.076	-
$Q_{Nitrogen}$	1.115	-
Q_{Oxygen}	0.971	-
$Q_{Hydrogen}$	2.226	-
Q_{Argon}	0.881	-
Q_{Neon}	0.637	-
Q_{Water}	-	0.0202
$Q_{Ammonia}$	-	0.142

NOTES:

1. *With viscous gas flow through a leak, the leakage rate is proportional to the difference in the squares of the pressures acting across the leak. The VF is calculated at 21°C (70°F) per Equation 2.*
2. *With viscous liquid flow through a leak, the leakage rate is proportional to the pressure difference. The VF is calculated at 21°C (70°F) per Equation 3.*
3. *If other than helium tracer gas was used, a new VF will be calculated as a ratio of the tracer gas and working fluid (gas or liquid) viscosities.*
4. *The conversion assumes laminar flow in the fluid leak path. Even though this is not always the physical case, making this assumption results in a conservative prediction of the leakage rate of the working fluid (gas or liquid) whether the flow of the helium (during leak testing) through the leak path and working fluid (gas or liquid while functioning on the ground or on orbit) is laminar, molecular, or in the transition region.*
5. *If the system engineers have a concern about the conservatism introduced by this approach, they may use a physics-based approach to conversion between the tracer gas and working fluid (gas or liquid) where the flow regime type (laminar, molecular, or transition) is determined for the test fluid and the working fluid and the appropriate conversions are made.*
6. *Conversion from measured helium leakage rate to water leakage rate for test articles that have hoses made of Teflon™ or similar material with high permeation rate for helium do not require a conversion factor provided that individual joints demonstrated not having any single-point leakage rate greater than 1.0×10^{-5} scc/sec (if tested via Method II (Accumulation)), and/or not having any single-point leakage above helium background in the test laboratory (if tested via Method XI (Detector Probe, Joints technique), and/or not having any single-point leakage as evidenced by one or more bubbles formed by helium in the foam or liquid (if tested via Method XII (Foam/Liquid Application)).*

Equations for use in Table 3:

$$Q_F = Q_{He} [(P^2_{INT} - P^2_{EXT})_F]/P^2_{INT,\ He}\ VF \qquad \textbf{(Eq. 2)}$$

$$Q_F = Q_{He}\, 2P_0\, [(P_{INT} - P_{EXT})_F]/P^2_{INT,\ He}\ VF \qquad \textbf{(Eq. 3)}$$

where

Q_F = *a fluid leakage rate in scc/sec (if fluid is a gas) and cubic centimeter (cc)/sec (if fluid is a liquid).*
Q_{He} = *a helium leakage rate in scc/sec.*
P_{INT} = *an internal pressure for fluid (shown with* $_F$*) and helium (shown with* $_{He}$*).*
P_{EXT} = *an external pressure for fluid (shown with* $_F$*) and helium (shown with* $_{He}$*).*
VF = the ratio of the dynamic viscosities (μ) of the tracer gas and the working fluid.
P_0 = *atmospheric pressure in consistent units.*

DEFINITIONS

There is a lot of definitions commonly used in the leak testing process, however, some of the definitions used in the Standard are not found in the Handbook (see Table 4).

Table 4. Definitions used in the Standard but missing in the Handbook

Definitions in the Standard	Definitions in the Handbook
Calibration of Leak Test Setup: The comparison or the adjustment of a leak test setup to a known reference called a calibrated or standard leak often traceable to the National Institute of Standards and Technology (NIST). For other leak test standard tools such as graduated flasks, columns, and pipettes purchased at standard scientific suppliers, the calibration of the graduations should be accepted. Tracer gas leak standards should bear a calibration certification sticker from metrology or the vendor and should be within the prescribed dates and, if equipped with a pressure gauge, within the appropriate pressure range.	None
External-to-Internal Total Leakage: The combined leakage rate of a fluid (most frequently tracer gas) through all the existing leaks from outside to inside of a test article being tested.	None
Internal-to-External Total Leakage: The combined leakage rate of a fluid (most frequently tracer gas) through all the existing leaks from inside of a test article being tested to outside.	None
Internal-to-Internal Total Leakage: The combined leakage rate of a fluid (most frequently tracer gas) through all the existing leaks across an internal barrier (static or moveable) within a test article.	None
Leak Detector Output Stabilization: Four consecutive readings taken no less than 5 minutes apart after three time constants have been exceeded with no more than a 10 percent (%) variation in the leak detector output from one measurement to the next, including the first and last measurements.	None
Leak Test Setup: The total end-to-end configuration of the ground support equipment (GSE) specific for each leak test method. For example, the test setup for tracer gas methods can include a leak detector connected to a vacuum chamber, bell jar, detector probe, hood, or enclosure.	None
Quantitative Leak Test Method/Technique: A test method/technique that, after proper calibration, provides the total leakage rate measurement for the test article or its part, but not intended to pinpoint an exact location of any specific leak.	None
Relative Sensitivity: A ratio calculated as a standard leak in leakage rate units (e.g., standard cubic centimeters per second) per a leak detector output in either scale divisions or the same leakage rate units (called "bag factor" for accumulation method). To be used for determining the test article leakage rate.	None
Semi-quantitative Leak Test Method/Technique: A test method/technique that, after proper calibration, provides the estimated local leakage rate measurement for a part of the test article, but not a total leakage rate measurement for the test article as a whole.	None
Test Article: A system, its subsystem or component that will be pressurized with any operational fluid (gas or liquid) or sealed with positive or negative operational fluid pressure inside it for operation.	None

CONCLUSIONS

1. The Standard and the Handbook have specific technical details such as classification of LT methods/techniques, conversion from a tracer gas (most frequently helium) leakage rate to a corresponding leakage rate of a working fluid (gas or liquid), and definitions that are described differently.
2. ASNT may consider the Standard as a reference when working on fifth edition of the Handbook.

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