

USCAR Inflator Technical Requirements and Validation

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USCAR INFLATOR TECHNICAL REQUIREMENTS AND VALIDATION

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1. INTRODUCTION

1.1 Scope

This specification establishes the performance and validation requirements for the inflator assembly used in airbag modules.

1.2 Preface Definitions

Inflator: For the purposes of this specification, an Inflator is a device that delivers a defined quantity or volume of gas with a defined rate of mass flow to a cushion or chamber, to directly provide occupant restraints as defined by the intended customer engineering group(s). Specific design elements are not limited except by the performance and reliability requirements contained herein.

Degradation (*following environmental conditioning*): Refers to a change in ballistic performance that falls outside of the reference window established by a virgin control group per [3.2.9, Inflator Performance and Variability Limits](#) (i.e., DV/PV baseline group). In addition, a failure of the Inflator to meet any other requirement as stated in this document after environmental conditioning shall also be defined as degradation.

Tailorability: The ability to tune slope, onset, output (peak pressure), and output ratio (dual stage Inflators) independently to meet the various program requirements.

Variability: Refers to performance variation within a group of Inflators that falls outside of the reference window established by a virgin control group (i.e., DV/PV baseline group) per [3.2.9, Inflator Performance and Variability Limits](#).

Shall Requirements: The Inflator is required to meet all shall requirements. The use of “shall” in this document denotes a binding provision that must be met unless a deviation is granted by the Responsible Vehicle Engineering Organization. Deviations to “shall” requirements will only be considered and, if approved, granted by the Responsible Vehicle Engineering Organization after evaluating appropriate available technologies and balancing all Module and restraint system performance considerations.

Should Requirements: Should requirements are to provide preferred requirements where absolute compliance is not required. “Should” denotes a preference or desired conformance which, if not met, require acceptance by the Responsible Vehicle Engineering Organization. The final determination of the subject performance requirement shall be made by the Responsible Vehicle Engineering Organization.

Responsible Vehicle Engineering Organization (RVEO): Intended vehicle manufacturer; OEM responsible for approving Inflator technology for use in their vehicles.

QFS: Refers to ‘Qualified for Sourcing’ and is synonymous with ‘Bookshelving.’ The procedure for attaining QFS status for an Inflator is detailed in [Appendix A, Pre-Source Qualification \(QFS\) Requirements](#).

For additional definitions see [Appendix E, Glossary](#).

1.3 Changes to this Document

This document is to be considered a living document. Revisions are to be based on relevant experience and changes to the application environments of the participating OEMs. All changes to the document are to be decided upon by a joint USCAR committee as appointed by the participating OEMs and ratified by their respective organizations.

2. APPLICABLE DOCUMENTS

SAE J211-2	Instrumentation for Impact Test - Part 2: Photographic Instrumentation
SAE J1794	SAE Restraint Systems Effluent Test Procedure
SAE J2238	Airbag Inflator Ballistic Tank Test Procedure, Gas Generating Devices Used in Inflatable Restraint Systems
SAE/USCAR-28	Initiator Technical Requirements and Validation
ISO 9001:2015	Quality management systems - Requirements
ISO 17025	General Requirements for the competence of testing and calibration laboratories
MIL-STD-810G	Environmental Engineering Considerations and Laboratory Tests
IATF 16949:2016	Automotive Quality Management System Standard
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus

[999-U-002-1-Z02 USCAR Standard Connector Pocket Chart Drawing](#)

In the case of new releases of the listed reference documents, the latest version shall be applicable except where direct conflicts with this document take place. In the case of a direct conflict, this document shall supersede, and the previous version of the referenced document(s) shall be applicable.

3. REQUIREMENTS

3.1 General Requirements

3.1.1 General

The Inflator supplied under this specification shall meet all functional requirements outlined in this specification. The Inflator shall meet these requirements both before and after the environmental conditioning specified and over the deployment temperature range. This specification represents a minimum set of requirements. Any technology that presents functional, quality and/or durability issues that are not addressed in this specification shall be required to complete additional testing. Test requirements of such systems shall be proposed by the inflator supplier and agreed to by the RVEO. All testing shall be based on supporting a 15-year vehicle life.

3.1.2 Quality

All structural and performance related features shall be manufactured and/or processed in accordance with automotive industry accepted quality requirements (PPAP per AIAG or IATF 16949 process) for purchased materials and shall be done with the concurrence of the RVEO Supplier Quality Assurance group(s).

3.1.3 Production Requirements

As a general assumption, Inflators qualified to this specification will meet this specification on an ongoing production basis unless specifically excepted by the RVEO. All prototype parts must be representative of production intent. Any differences must be identified with rationale for equivalence.

3.1.4 Reliability

The Inflator shall demonstrate, through successful completion of the PV test matrices, a reliability of 99% at 99.9999% confidence without any failures during deployment, degradation as defined in this specification, or failure to meet any shall requirements of this specification.

3.1.5 Heavy Metal Compounds Reporting and Recyclability Requirements

The Inflator Supplier shall provide timely information verifying product compliance with current OEM requirements regarding the use of Heavy Metals or Heavy Metal Compounds in the manufacture of the Inflator. The Inflator supplier shall provide, at the request of the RVEO, a breakdown of the materials in the Inflator for recycling purposes.

3.1.6 Informational Requirements

The Inflator Supplier shall provide the information as defined in the following subsections prior to, or in conjunction with, the DV report. Use of the 'QFS Checklist' is highly recommended for organization and completeness of the information. The Inflator DV shall not be considered complete without prior or joint submission of the informational requirements.

3.1.6.1 Inflator Pre-Source Qualification (QFS)

The Inflator Supplier shall provide the information outlined in [Appendix A, Inflator Pre-source Qualification \(QFS\) Requirements](#).

3.1.6.2 Inflator Soak Back Heat

In addition to the information supplied in the QFS, and for the specific Inflator output in consideration, a temperature trace of the external surface of the Inflator after deployment shall be provided after hot deployment per [5.2.2.7, Open Air Test Procedure](#). The measurements shall be taken from the highest temperature area of the Inflator, showing the peak temperature reached immediately and throughout the full cool down cycle of the Inflator. The data shall be provided as part of the DV and PV reports. Placement of the temperature measuring probe(s) shall be based on temperature mapping for the worst-case location and approved by the RVEO.

3.1.6.3 Inflator Performance Envelope and Characteristics

In addition to the information supplied in the QFS, and for the specific Inflator output(s) in consideration, the Inflator Supplier shall supply Inflator vented tank test (or equivalent test method) curves (if specifically requested), closed tank test curves, mass flow and gas temperature curves, and moles of gas for the output tested. In addition, the Inflator Supplier shall provide the Inflator initial onset rate (e.g., using a small vented tank, initial onset chamber, nozzle exit pressure, or other equivalent method) if requested by the RVEO. The Inflator Supplier shall demonstrate tailorability criteria and repeatability. The Inflator Supplier shall make available on an ongoing basis, information and data to demonstrate lot-to-lot variability during production is minimized, controlled, and meets the requirements of this specification.

3.1.6.4 Shipping Classification

The Inflator Supplier shall provide evidence of shipping 'Competent Authority' approval for target jurisdictions and programs. In addition, the test data utilized to comply with all applicable government shipping regulations, including auto-ignition regulations, in countries where the Inflator(s) are manufactured and transported, shall be summarized (with conclusions) and provided to the RVEO through submission as a subsection of the QFS/DV report (i.e., DOT, CTC, TUV, BAM, CE, UKCA, etc.).

3.1.6.5 Module Performance

Examples of the Inflator performance in a baseline module shall be demonstrated if requested by the RVEO. This demonstration shall be done in a dynamic test configuration (i.e., drop tower, pendulum, linear impactor, or other equivalent device) in an existing and well characterized module that meets the criteria of [Appendix A, Pre-source Qualification \(QFS\) Requirements, Section IV G, Table 1, Module Configuration](#). Modifications to the baseline module are acceptable and encouraged to enhance the new Inflator's performance, so long as they are thoroughly documented. Alternate configurations with documented differences can also be used to show typical design modifications from the established baseline modules to enhance performance.

3.1.6.6 Electrical Isolation of Pyrotechnic Materials

Pyrotechnic materials in the Inflator shall not have direct contact with the external metallic surfaces of the initiator charge cup and header assembly.

3.1.7 Testing and Reporting

3.1.7.1 Ethics in Testing and Reporting

Inflator Supplier shall adhere to the highest levels of ethical standards in all aspects of engineering testing, analysis, and reporting of data.

3.1.7.2 Test Sample Control

All Inflators produced for the sole purpose of validation testing and evaluations (including “extra”/mistake protection stock) shall be serialized in original planned sequence, secured, and stored as “validation parts” and shall not be intermingled with production stock.

All test parts shall be saved for review and shall not be scrapped without prior approval from the RVEO.

3.1.7.3 Testing/Evaluation Errors

If a testing error occurs, validation shall be stopped and a thorough engineering analysis of the “root cause” of the error shall be performed. RVEO review and approval is required before proceeding with validation testing utilizing “extra”/mistake protection stock. Examples of testing errors include (but are not limited to) samples conditioned at the incorrect temperature, reversed firing lines, and instrumentation malfunction. Testing errors do not include sample failures / non-conformances to this performance specification.

3.1.7.4 Data Integrity

All data gathered for all tested Inflators shall be reported, including any testing / evaluation errors as described in [3.1.7.3, Testing / Evaluation Errors](#). Data shall be communicated in its “native collection form” upon request. No truncation or exclusion of data is permitted.

3.1.8 Electrical Connection Interface

The Inflator electrical connection interface shall conform to the [USCAR Standard Connector Pocket Chart Drawing 999-U-002-1-Z02](#) and USCAR-2 Performance Specification for Automotive Electrical Connector Systems.

3.2 Functional Requirements

This section describes the functional and performance requirements of the Inflator. For the environmental conditioning and testing required to validate these performance characteristics, see Section [5, Test Requirements](#).

3.2.1 General Inflator Requirements

Inflator(s) shall demonstrate the ability to successfully complete a ‘Proof of Concept’ test series as outlined in [Appendix A, Pre-source Qualification \(QFS\) Requirements](#).

For dual-stage Inflators utilizing either two separate pressure chambers or a single pressure chamber inflator with an internal segmenting partition, the Inflator and all Inflator segments shall meet all applicable performance requirements and validation conditions singly and in combination, referenced in this specification.

For Inflators to be considered ‘Pre-Qualified’ (QFS) the Inflators should use only approved initiators (PPAP per AIAG process or equivalent) at the time of pre-qualification. Inflators shall use an initiator that has, as a minimum, met all DV requirements per SAE/USCAR-28 Initiator Technical Requirements and Validation of current issue at the time of Inflator DV. Inflators shall use only approved initiators (PPAP per AIAG process or equivalent) at the time of Inflator DV.

3.2.2 Inflator Structural Integrity

Inflator(s) shall maintain structural integrity when deployed in and after exposure to the conditioning environments described in Section [5, Test requirements](#). An Inflator shall not eject any components or fragments during any portion of DV and PV testing. Burst foil pieces are not considered fragments based on the lack of risk as a potential hazard, however, burst diaphragm fragments from pressurized Inflators are considered fragments.

3.2.2.1 Inflator Burst Safety Factor

Over the temperature range of -40 to +85 °C, the Inflator burst safety factor, when tested per [5.2.3.1, Structural Burst Test](#), and calculated per [Appendix C, Statistical Structural Margin Calculations](#), shall be greater than 1.7 for all pressurized chambers. The reliability and confidence interval shall be reported on the data used to calculate the safety factor and shall have a d-value greater than 4.753, indicating 99.9999% reliability with 99% confidence.

MEOP shall be calculated using data at each deployment temperature for each group of Inflators (i.e., baseline and environmentally conditioned). The maximum MEOP from all data sets shall be used for the safety factor calculation of the Inflator.

All pressure vessel testing shall be conducted with as-designed/produced Inflator components, including exit orifices. Specially designed components shall not be used in any structural testing. Alterations may be made to production parts to accommodate testing; however, these alterations shall not influence the Inflator structural integrity (i.e., no welding exit orifices closed). A detailed description of the structural testing procedure shall be provided at QFS, DV, and PV. Pictures of failure modes for each tested part shall be included in all reports.

The Inflator shall exhibit a ductile failure mode insofar that the Inflator shall not fragment or eject any part of the structural components during the burst test. The Inflator Supplier and RVEO shall jointly determine the burst test configuration. The RVEO shall be the final arbiter of the burst test configuration.

Inflators with multiple structural, dynamically independent, pressurized chambers shall meet the required Inflator burst safety factor for all pressurized chambers tested independently and together. Structural failure in a common component or wall is allowed only if such a failure is the standard operating mode of the component and does not eject components or fragments. External crimps, curls, swages, press-fits such as end closure and initiator retaining features shall be loaded during testing and shall not fail during burst testing. Welds shall not fail in the fusion area.

Design and process parameters of all crimp, curl, swage, press-fit, and weld joint design and process parameters shall be verified by margin studies and/or FEA. Propagation of the primary failure from the parent material into external welds, crimps, curls, or swages is allowed.

The Inflator structure shall comply with all applicable government regulations, including pressure vessel burst regulations, in countries where the Inflator is manufactured and transported, as well as the countries where the vehicle is manufactured and sold as directed by the RVEO.

NOTE: Dynamic burst testing may be used when no reasonable alternative can be found. Prior agreement of the RVEO to the specific test method and pass/fail criteria shall be obtained.

3.2.3 Effluents

The RVEO shall be the final arbiter for each application for all effluent requirements. The limits and requirements listed in this section are subject to change as effluent knowledge evolves.

3.2.3.1 General Effluents

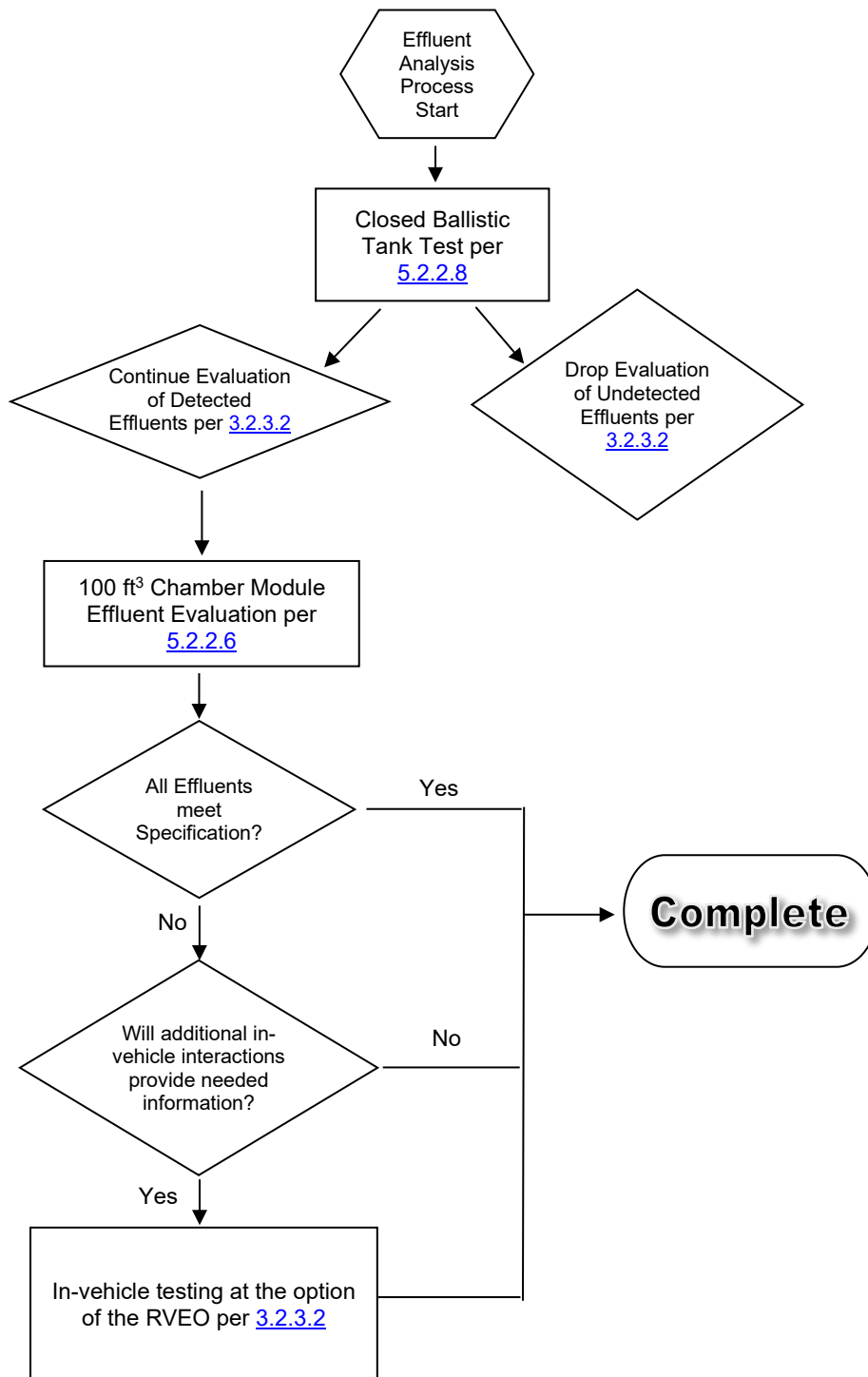
The Inflator Supplier shall characterize and report the presence of all chemical constituents, both listed and unlisted gasses and particulates according to the following sections. Follow [Table 3.2.3.1.A, Flow Chart of Effluent Evaluation](#). All gasses and particulate levels (generated by the Inflator, labels, paints, glues, inks, cushions, housings, deflectors, and other Module components) shall be reviewed with the vehicle manufacturer's engineering and health effect support organization(s). Joint agreement of the Inflator Supplier and responsible vehicle engineering and health effect support organization shall establish vehicle level limits for any gasses or materials not specified or exempted herein. Synergistic effects of the mixture of effluents shall be identified in so far as possible and may be cause to alter the published limits of any listed compound (see [Table 3.2.3.2.3.B, Effluent Compound Limits](#)). Allowable levels may be subject to modification based on the specific vehicle requirements (vehicle interior volume, bag configuration, etc.).

Those effluents defined as 'Unlisted' are all other effluents, gasses, and particulates, generated by the Inflator, labels, paints, glues, inks, cushions, housings, deflectors, and other Module components not specifically listed in this document. Unlisted compounds exclude normal, nonhazardous levels of atmospheric gasses.

The RVEO may add to the effluent gas and particulate list as information becomes available and may alter the specified component level allocations to achieve overall vehicle safety system effluent and particulate limits. However, program specific Inflators should be consistent with the information provided in the QFS package.

The reporting of effluent results shall use the tables provided in [Appendix D, Gas and Particulate Reporting Tables and Analysis Methods](#).

Table 3.2.3.1.A - Flow Chart of Effluent Evaluation



3.2.3.2 Gasses

All gas concentrations defined in this section as 'Listed' and those defined as 'Unlisted,' but determined to be present, shall be measured in a tank size per [Table 5.2.1.A, Closed Tank Sizes](#). The results of the gas analysis of the ballistic tank shall be reported as part of QFS package. The results of the ballistic tank evaluation are for reference only. Those compounds detected in the ballistic tank sample at concentrations that exceed 25% of the apportioned vehicle limit as calculated per [Table 3.2.3.2.3.A, Effluent Apportionment](#) (based on calculated dilution factors), and all gasses known to be substantially soluble in water, shall be analyzed in all subsequent effluent tests.

Effluent tests in a 100 ft³ tank should be conducted in modules and at outputs that are consistent with the requirements of [Appendix A, Section IV-G Table 1, Standard Module Configurations](#). 'In-vehicle' tests, conducted in a representative vehicle, may be accepted on a case-by-case basis at the discretion of the RVEO. All parameters of the module configuration (bag size, vents, inflator output, etc.) shall be recorded and reported with the data.

Effluents measurements should be corrected to STP for the dilution effects of tests done at higher altitudes.

Upon deployment, the 'in-vehicle' gaseous and particulate effluent levels from the Frontal System or Side System shall not exceed the vehicle limits and should not exceed apportioned fractions (per [Table 3.2.3.2.1.A, Effluent Apportionment](#)) established for listed compounds (per [Table 3.2.3.2.1.B Effluent Compound Limits](#)), unlisted compounds (where determined to be present), and airborne particulates.

NOTE: Compliance of the effluent data shall be evaluated by use of the average(s) of each group of tests (minimum of three data points for each series). Each data point shall also be reported, and shall not exceed 150% of the respective apportioned limits.

3.2.3.2.1 Gas Sampling and Analysis

Effluent testing shall be performed per [5.2.2.6, Effluent Test Procedure](#), without any devices or materials (in the test tank or in the gas sampling tube) that may alter results or otherwise 'scrub' the gas prior to analysis.

Table 3.2.3.2.1.A - Effluent Apportionment

Frontal		
Driver Airbag	Passenger Airbag	Knee Airbags (<0.75 mole)
1/3	2/3	
1/4	1/2	1/8
Side (per-bag basis)		
Head Thorax or Head Thorax Pelvis (>0.75 mole)	Thorax or Thorax Pelvis or Pelvis or CSIAB (<0.75 mole)	Curtain (assumes non-vented bag)
1/4		
	1/8	1/8

NOTE: Due to the nature of most crashes, Frontal and Side restraint systems will not fire together without substantial 'opening' occurring to the occupant compartment. This opening (or ventilating) of the occupant compartment allows the combined side and frontal apportionment to be considered separately.

NOTE: In cases where the sum of the frontal or side restraint systems apportionments will exceed 1, the apportioned fractions shall be normalized by adding the smallest fractions for each airbag noted above and then normalizing to equal 1, as approved by the RVEO.

Table 3.2.3.2.1.B - Effluent Compound Limits

Effluent Compound	Vehicle Level Limit (ppm, maximum)
Ammonia (NH ₃)	50.0
Benzene (C ₆ H ₆)	22.5
Carbon Monoxide (CO)	461
Carbon Dioxide (CO ₂)	30000
Chlorine (Cl ₂)	1.0
Formaldehyde (HCHO)	2.0
Hydrogen Chloride (HCl)	5.0
Hydrogen Cyanide (HCN)	4.7
Hydrogen Sulfide (H ₂ S)	15.0
Nitric Oxide (NO)	75.0
Nitrogen Dioxide (NO ₂)	5.0
Phosgene (COCl ₂)	0.3
Sulfur Dioxide (SO ₂)	5.0
Acetylene	25000 (LEL)
Ethylene	27000 (LEL)
Methane	50000 (LEL)
Hydrogen	40000 (LEL)

3.2.3.3 Inflator Particulate

For each Inflator technology, the Inflator Supplier should demonstrate that airborne particulate from the 100 ft³ chamber meet the following requirements. In addition, the Inflator shall show no evidence of internal filter failure over the deployment temperature range specified in [5.2.2.5, Conditioning of Inflators](#).

3.2.3.3.1 Airborne Particulate Measurement and Analysis

Inflators shall meet the following airborne particulate effluent levels when tested in a closed tank and determined per [5.2.2.6, Effluent Test Procedure](#):

1. Total vehicle particulate shall not exceed those limits specified in [Table 3.2.3.3.1.A, Effluent Airborne Particulate Limits](#). Each Inflator should not exceed the apportioned limits determined per [Table 3.2.3.2.1.A Effluent Apportionment](#).
2. Particulate fraction of less than 10 micron shall be determined per SAE J1794 Restraint Systems Effluent Test Procedure, section 6.2, and reported.

Table 3.2.3.3.1.A - Effluent Airborne Particulate Limits

	Vehicle Level Limit
Total Particulate	125.0 mg/m ³
Sub 10-micron particulate	Fraction to be reported only

3.2.3.3.2 Tank Wash Particulate Measurement and Analysis

The particulate effluent levels shall be determined from samples collected per [5.2.2.8.3 Sampling Tank Contents \(Tank Wash\) Procedure](#). The following information shall be supplied from the sample(s).

1. Large particle weight (see [5.2.2.8.4 Tank Wash Solution and Particulate Analysis](#)), Water Soluble and Water Insoluble fractions of the particulate shall be individually determined and reported.
2. Total particulate (excluding large particulate) shall be determined and reported.
3. Total tank wash particulate from each deployment shall not exceed 1.0 g, at room temperature.
4. The pH of the tank wash solution, diluted to 1000 mL, shall be measured and reported. The pH shall fall in the range of 4 to 10.5.
5. Full speciation including metals, soluble salts and mass balance, accounting for a minimum of 90% of the measured sample weight, shall be determined per [5.2.2.8.5, Tank Wash Solution and Particulate Speciation](#), and reported.
6. The speciation of the tank wash solution shall include a full metals scan, cation analysis, and anion analysis. A mass balance of the speciation analysis shall be provided (calculated fractional weights of each species found verses the total particulate sample mass).
7. Chemical species that have reacted post deployment, such as some carbonates and hydrated salts, etc., shall be corrected and reported as the un-reacted original weight.

NOTE: Tank wash particulate measurement and analysis shall be reported using the tables found in [Appendix D, Gas and Particulate Reporting Tables and Analysis Methods](#).

3.2.4 Inflator Flaming

For the purposes of this test, deflectors, diffusers, shrouds, housings, etc., used as a standard component for applications of the Inflator to suppress external flaming, redirect gasses, minimize bag damage, and/or modify system performance, may be utilized. Components that block clear photographic documentation of the Inflator's performance (i.e., closed bags) shall not be allowed. The configuration of the device under test shall be clearly documented as part of the test report.

Testing shall be conducted per [5.2.3.8, Flaming Test](#) with a minimum high speed video frame rate of 1000 fps.

Inflator Supplier shall provide digital video files showing the actual during-deployment and post-deployment flaming tests (high speed video for during-deployment and standard speed video for post-deployment flames).

Inflators deployed at +23 °C:

- a. shall not have flames of any length or duration other than item c,
- b. shall not have burning particles other than item c,
- c. shall not have flames/sparks exceeding 5 ms in duration at or around the initiator, inclusive of the connector interface pocket or adjacent area.
- d. shall not have any gas leakage residue at or around the initiator, excepting minimal witness marks caused by item c.
- e. Burning of gasses and propellants shall not occur outside of the Inflator.
- f. When directed by the RVEO, the Inflator shall not produce 'bag luminescence' visible in standard video (standard frame rate), using an uncoated bag per program direction, or [Appendix A, Table IV G-1](#), other than item c.

Inflators deployed at +85 °C:

- a. should not have flames of any length or duration other than item e,
- b. shall not have flames exceeding 50 mm in length,
- c. shall not have flames exceeding 20 ms in duration,
- d. shall not have burning particles other than item e,
- e. shall not have flames/sparks exceeding 5 ms in duration at or around the initiator, inclusive of the connector interface pocket or adjacent area.
- f. shall not have any gas leakage residue at or around the initiator, excepting minimal witness marks caused by item e.
- g. Burning of gasses and propellants shall not occur outside of the Inflator.
- h. When directed by the RVEO, the Inflator shall not produce 'bag luminescence' visible in standard video (standard frame rate), using an uncoated bag per program direction, or [Appendix A, Table IV G-1](#), other than items b, c, and e.

Inflators, during the time immediately post-deployment (10 s to 2 min minimum), with an external ignition source applied:

- a. shall not have flames of any length or duration due to ignition of residual gases by the applied external ignition source,
- b. shall not have burning particles.

The RVEO shall be the final arbiter of acceptable configurations and results of all flaming testing.

3.2.5 Auto-Ignition Performance

The Inflator(s) shall maintain structural integrity, shall not fragment or have any separation of components, and Inflator traceability identifier shall be legible (excepting components that melt or are consumed) when auto-ignition is induced by external heating per [5.2.3.2 High Temperature Oven \(HTO\) Test](#), [5.2.3.3 Bonfire Test](#) or [5.2.3.4 Slow Heat/Autoignition Test](#).

3.2.5.1 High Temperature Oven (HTO) and Auto-Ignition Performance

Additionally, Inflator(s) shall retain all stored gas (pressurized inflators) and shall not deploy during +107 °C heat soak environment. Gas venting for each pressurized Inflator shall be >+130 °C, or the mean-3σ gas venting temperature shall be >+115 °C. All pyrotechnic mixtures (such as propellants, auto-igniting materials, combustible gasses, etc.) of the Inflator shall have an auto-ignition temperature >+130 °C (as measured from the surface of the Inflator nearest the thermal path to the specific pyrotechnic mixture in question) when the Inflator is tested per [5.2.3.2, High Temperature Oven \(HTO\) Test](#). Additional quantities of Inflators can be used to minimize σ as required.

3.2.6 Accelerated Heat Aging

After exposure to environments as specified per [5.2.3.5 Accelerated Heat Aging Test](#), the Inflators:

- a. shall not leak per [5.2.2.1, Leak Test Procedure](#),
- b. shall maintain an initiator bridge wire resistance as specified per SAE/USCAR-28 Initiator Technical Requirements and Validation Specification of current issue, or as approved by the RVEO,
- c. shall not show any loss in the measured strength or ballistic integrity of the propellant as demonstrated by ballistic performance and/or accepted break or crush strength measurement methods of live teardown Inflators (limited dusting that does not appreciably affect ballistic performance is excepted).

In addition, those Inflators deployed in a closed tank or open air:

- a. shall deploy as intended when tested per [5.2.2.8, Closed Tank Test](#) or [5.2.2.7, Open Air Test Procedure](#),
- b. should meet tank wash requirements per [3.2.3.3.2, Tank Wash Particulate Measurement and Analysis](#),
- c. shall meet all requirements per [3.2.9, Inflator Performance and Variability Limits](#), where ballistic curves are obtained.

3.2.7 High Humidity/Heat Age

After exposure to environments as specified in [5.2.3.6, High Humidity/Heat Age Test](#), the Inflators:

- a. shall not leak per [5.2.2.1, Leak Test Procedure](#),
- b. shall maintain an initiator bridge wire resistance as specified per SAE/USCAR-28 Initiator Technical Requirements and Validation Specification of current issue, or as approved by the RVEO,
- c. shall not show any loss in the measured strength or ballistic integrity of the propellant as demonstrated by ballistic performance and/or accepted break or crush strength measurement methods of live dissection Inflators (limited dusting that does not appreciably affect ballistic performance is excepted).

In addition, those Inflators deployed in a closed tank or open air:

- a. shall deploy as intended when tested per [5.2.2.8, Closed Tank Test](#) or [5.2.2.7, Open Air Test Procedure](#),
- b. should meet tank wash requirements per [3.2.3.3.2, Tank Wash Particulate Measurement and Analysis](#),
- c. shall meet all requirements per [3.2.9, Inflator Performance and Variability Limits](#), where ballistic curves are obtained.

3.2.8 Sequential Test Series

After the completion of the Sequential conditioning series (or any individual or combination of environmental conditionings), the Inflator(s):

- a. shall not leak per [5.2.2.1, Leak Test Procedure](#),
- b. shall maintain an initiator bridge wire resistance as specified per SAE/USCAR-28 Initiator Technical Requirements and Validation Specification of current issue, or as approved by the RVEO,
- c. shall not show any loss in the measured strength or ballistic integrity of the propellant as demonstrated by ballistic performance and/or accepted break or crush strength measurement methods of live dissection Inflators (limited dusting that does not appreciably affect ballistic performance is excepted).

In addition, those Inflators deployed in a closed tank or open air:

- a. shall function as intended when deployed per [5.2.2.8, Closed Tank Test](#) or [5.2.2.7, Open Air Test Procedure](#),
- b. should meet tank wash requirements per [3.2.3.3.2 Tank Wash Particulate Measurement and Analysis](#),
- c. shall meet all requirements per [3.2.9, Inflator Performance and Variability Limits](#) where ballistic curves are obtained.

Inflators shall be exposed to environmental conditions in the following sequence for DV/PV:

1. Thermal Shock
2. Dynamic Shock (Low G/High G)
3. Vibration - Temperature Cycle
4. Humidity Resistance
5. Salt Spray
6. Drop Test

Inflators shall be exposed to environmental conditions in the following sequence for QFS:

1. Dynamic Shock (Low G/High G)
2. Vibration - Temperature Cycle
3. Humidity Resistance
4. Drop Test

3.2.8.1 Thermal Shock Resistance

Expose Inflators to environments per [5.2.3.7.1, Thermal Shock Resistance Test](#).

3.2.8.2 Dynamic Shock Resistance

Expose Inflators to the shock profile per [5.2.3.7.2, Dynamic Shock Test](#).

3.2.8.3 Vibration/Temperature Resistance

Expose Inflators to the environments per [5.2.3.7.3, Vibration - Temperature Cycle Test](#).

3.2.8.4 Humidity Resistance

Expose Inflators to the environments per [5.2.3.7.4, Humidity Resistance Test](#).

3.2.8.5 Salt Spray Resistance

Expose Inflators to the environments per [5.2.3.7.5, Salt Spray Test](#).

NOTE: Corrosion of the components is acceptable, unless the corrosion impacts the Inflator ability to meet functional requirements stated in [3.2.9, Inflator Performance and Variability Limits](#).

3.2.8.6 Drop Resistance

Expose Inflators to the environments per [5.2.3.7.6, Drop Test](#).

3.2.9 Inflator Performance and Variability Limits

When Inflators are tested per [5.2.2.8, Closed Tank Test](#), the following requirements shall be met:

1. Ballistic curves per the following shall be provided to the RVEO by the Inflator Supplier for all tests:
 - a. Baseline deployments at each temperature (full and staged output for dual-stage Inflators).
 - b. Scatter plots for each group with overlays of the mean curve, mean $\pm 3\sigma$ curves and performance windows (see [Appendix F, Ballistic Examples](#) for examples).
 - c. Data tables showing performance against the specified windows established per [Table 3.2.9.A, Inflator Variability Limits](#).
 - d. Environmentally conditioned Inflators deployed at each temperature, with comparison plots for each group with overlays of the mean baseline curve and performance windows.
2. The tolerances shown in [Table 3.2.9.A, Inflator Variability Limits](#), shall be met at room temperature, hot temperature, and cold temperature by the baseline Inflators full and staged output(s). Mean $\pm 3\sigma$ of the baseline deployment groups at each temperature shall fall within each defined window, except TTFG, which shall be evaluated for each individual curve.
3. The tolerances shown in [Table 3.2.9.A, Inflator Variability Limits](#), shall be met at room temperature, hot temperature, and cold temperature by environmentally conditioned Inflators full and staged output(s). The individual ballistic curves of each Inflator shall fall within each defined window.
4. A program specific closed tank mean curve shall be determined from an appropriate 'baseline inflator tank deployment' series, such as the baseline tests of the PV or other appropriate data set and approved by the RVEO. Dual-stage Inflators shall have full and staged output curves defined. Ongoing production Lot Acceptance Tests (LAT) shall be measured against the tolerances determined from [Table 3.2.9.A, Inflator Variability Limits](#) for the vehicle specific baseline mean curve(s). Each individual LAT Inflator curve shall fall within each defined window.

Table 3.2.9.A - Inflator Variability Limits

Inflator Variability Parameters (for Closed Tank Tests)		Attribute Limits			
Slope calculated using the best fit line along the curve as calculated from a minimum of nine equally spaced points from 10 to 50% pressure		Nominal $\pm 12.5\%$			
Time to First Gas (TTFG) (attribute based only)	TTFG	Passenger Driver Side Knee (recommended)	<5 ms <4 ms <2 ms <2 ms	Ambient Cold	<7 ms <6 ms <4 ms <4 ms
Time at P=10% of peak	$T_{10\% \text{ of peak}}$	$T_{(10\% \text{ of peak})} \pm (30\% * T_{(10\% \text{ of peak})})$			
Time at P=25% of peak	$T_{25\% \text{ of peak}}$	$T_{(25\% \text{ of peak})} \pm (20\% * T_{(25\% \text{ of peak})})$			
*Pressure at P=50% of peak	$P_{50\% \text{ of peak}}$	$P_{(50\% \text{ of peak})} + (15\% * P_{(50\% \text{ of peak})}) / - (12.5\% * P_{(50\% \text{ of peak})})$			
*Alternative Time at P=50% of peak	$T_{50\% \text{ of peak}}$	$T_{(50\% \text{ of peak})} \pm (12.5\% * T_{(50\% \text{ of peak})})$			
*Pressure at P=75% of peak	$P_{75\% \text{ of peak}}$	$P_{(75\% \text{ of peak})} \pm (12.5\% * P_{(75\% \text{ of peak})})$			
*Alternative Time at P=75% of peak	$T_{75\% \text{ of peak}}$	$T_{(75\% \text{ of peak})} \pm (12.5\% * T_{(75\% \text{ of peak})})$			
*Time at P=90% of peak	$T_{90\% \text{ of peak}}$	$T_{(90\% \text{ of Peak})} \pm (12.5\% * T_{(90\% \text{ of peak})})$			
*Alternative Pressure at P=90% of peak	$P_{90\% \text{ of peak}}$	$P_{(90\% \text{ of peak})} \pm (12.5\% * P_{(90\% \text{ of peak})})$			
Peak Pressure	$P_{\max}$	$P_{\max} \pm (10\% * P_{\max})$			

**Evaluation of either P=50%, 75%, and 90% or T at P=50%, 75%, and 90% is allowed at the Inflator Supplier's discretion (based on curve slope at P=50%, 75%, and 90%). Only one attribute (P or T) at each percent is required to meet the criteria.*

The RVEO shall have the option to modify the $\pm$ tolerance variability requirements if acceptable module performance can be demonstrated across the full range of ballistic variability. The RVEO shall be the final arbiter of acceptable Inflator variability.

Important Note: Care should be taken to compare the 'Time' based windows to the "Time at pressure x" calculated from each individual curve. It is not correct to construct an acceptance bar and to plot the curves graphically judging pass/fail on the curve breaking the acceptance bar as has been customary. Although true for all time-based windows, this is most apparent in the T at P90 (Time to 90% pressure) window where a horizontal bar would be evaluated against a pressure curve that is flattening and may be shifted up or down depending on the maximum pressure achieved. The T at P90 acceptance window creates a column of time. The calculated mean of the baseline deployments at 90% pressure, $\pm 3\sigma$ column of time, must be evaluated against the calculated T at P90 point for each inflator ballistic curve. In the case of the environmentally conditioned inflator curves, each individual curve's calculated T at P90 point must fall in the baseline's T at P90 $\pm 10\%$ column of time. It is much easier to evaluate the compliance of data by charting the acceptance windows and comparing the calculated values. Plotted curves and acceptance bars are of great value for other evaluations and should continue to be provided.

3.2.9.1 Additional LAT Evaluation

The performance of each production LAT Inflator is to be evaluated against the program compliance windows as follows:

1. Calculate the specified Time and Pressure points for each curve as described in [3.2.9 Inflator Performance and Variability Limits](#).
2. Evaluate the Time and Pressure points of the LAT against the Time and Pressure windows for compliance.

In the event one or more pressure or time points fall outside of any of the defined LAT limits, the following additional evaluation can be done at the discretion of the Inflator Supplier with the concurrence of the RVEO supplier quality group:

1. Randomly select a minimum of 15 additional Inflators from the lot in question for each temperature where a LAT evaluation did not meet the defined limits.
2. Condition each group of Inflators at the appropriate temperature and deploy in a closed tank.
3. Perform the following two evaluations:

Evaluation 1:

- a. Calculate mean curve from each group of deployed Inflators.
- b. From the mean curve, calculate the Time and Pressure points for each required acceptance criteria.
- c. Recalculate the accepted program Time and Pressure windows to $\pm 33\%$ of their original value.
- d. Compare the Time and Pressure points calculated from the mean curve of the lot in question to the recalculated program Time and Pressure windows for all points.

Successful evaluation to this criterion is demonstrating a mean shift of less than 33% of the original program windows for each Time and Pressure window.

Evaluation 2:

- a. Using the mean curve from each group of Inflators, calculate the specified Time and Pressure windows per [Table 3.2.9.A, Inflator Variability Limits](#).
- b. Calculate the $\text{mean} \pm 3\sigma$ values for each Time and Pressure point for each group of deployed Inflators.

Successful compliance to the specification is to have all $\text{mean} \pm 3\sigma$ Time and Pressure values (Step 2) fall within the calculated limits (Step 1).

NOTE: Evaluation 1 is intended to evaluate the mean centeredness of the lot in question. Evaluation 2 is to evaluate the individual lot's variability. In both cases the intent is to provide an ongoing measurement of the inflator's ability to perform to output characteristics consistent with those that were agreed to in the specific program development and validation.

3.2.10 Propellant Stability

The Inflator Supplier shall supply test data showing that all propellants, gasses, and pyrotechnic materials contained within the Inflator will remain within the specified performance requirements per [3.2.9, Inflator Performance and Variability Limits](#), for a minimum of an Inflator target life of 15 years. This shall be demonstrated by the successful completion of the informational requirements of [Appendix A, Pre-Source Qualification \(QFS\)](#), Sections [III-G](#) and [IV-K](#), a DV, and PV per this specification.

The Inflator Supplier shall provide basic ESD, Friction and Thermal Shock data in the unaged and aged conditions of all propellants, gasses (if applicable) and pyrotechnic materials contained within the Inflator.

Prior to conducting an inflator-level PV, the evaluation of Propellant Stability in Simulated Regions of High Absolute Humidity (see Appendix A, [IV-K](#)) shall be performed on propellant produced with mass production equipment at the production-intent facility and has been PPAP approved per AIAG or IATF 16949 process. The results of this evaluation shall be provided to the RVEO for review.

Requirements as described in [Appendix A, Pre-Source Qualification \(QFS\) Requirements](#), are an attempt to assess the risk associated with stability over the lifetime of a propellant system; however, Inflator Suppliers are obligated to understand if the propellant will change in such a manner that causes risk of Inflator rupture or other safety issues to customers. This may include other testing protocols not included in this specification.

3.2.11 Hermeticity

For pyrotechnic Inflators, hermeticity (leak) limits shall be defined by successful completion of an 'Induced Moisture Margin Study.' The acceptable 'leak' limit is calculated based on the following assumptions:

1. daily respiration of +33 °C, 80% RH air (refer to MIL-STD-810G),
2. differential pressure based on a diurnal temperature range of +38 °C (refer to MIL-STD-810G),
3. all water is retained (i.e., no water is expired on each cycle),
4. cycles (one per day for 15 years),
5. instantaneous min to max temperature change,
6. 6-hour duration at each condition,
7. circular duct of the shortest possible length.

The calculated leak rate shall allow less moisture intrusion into the Inflator than is demonstrated by the Induced Moisture Margin Study to degrade the Inflator performance by less than or equal to 10%.

The leak rate limit shall be set at a maximum of the calculated requirement, or $1 \times 10^{-4} \text{ cc/atm}\cdot\text{sec}$ (assuming 100% Helium) or equivalent, whichever is less.

For stored gas inflators, hermeticity limits shall be determined by considering both an induced moisture margin study for any pyrotechnics not inside the pressurized region and the gas loss of the pressure vessel(s). The overall hermeticity limit shall be set at the resulting calculated value limiting the potential degradation of the Inflator performance over the 15 year vehicle life to less than or equal to 10%.

3.2.11.1 Leak Detection

All inflator(s) shall contain helium or an equivalent substance which shall be detectable if a leak is present in the pressure vessel or pyrotechnic chamber per [5.2.2.1, Leak Test Procedure](#). Alternate procedures are acceptable (i.e., bombing, etc.) where process reliability and sensitivity are demonstrated to the RVEO.

3.2.11.2 Pressurized Inflators

All stored gas pressure bearing components (body, welds, burst disk(s), etc.) shall remain intact with no cracks, fractures, or mechanical failures and shall not leak at a rate greater than that determined per [3.2.11, Hermeticity](#), after exposure to pressure cycling per [5.2.3.9, Pressure Cycle Durability Test](#) and tested per [5.2.2.1, Leak Test Procedure](#). The Inflator burst disk(s), body, and all welds under high pressure shall be evaluated.

3.2.12 Dual-Stage Inflator - Additional Requirements

3.2.12.1 Dual-Stage Inflator Tunability

Following deployment of the primary stage of dual-stage Inflators, the Inflator's secondary stage shall have the capability of being delay deployed over a range of 0 to 150 ms.

The Inflator's primary to secondary output ratio should be tunable from 50/50 maximum to 80/20 minimum of the total available ballistic output.

3.2.12.2 Sympathetic Ignition of Secondary Stage

When deployed at any temperature from -40 to +85 °C, the secondary stage of a dual-stage Inflator shall not sympathetically ignite or otherwise inadvertently deploy from 0 to 150 ms, or during the restraint cycle of the primary stage, whichever is greater.

The secondary stage of a dual-stage Inflator shall be allowed to ignite or deploy as a result of residual heat or some other repeatable and reliable method, from 150 ms to a maximum of 150 seconds based on an ambient test. Repeatable and reliable automatic or sympathetic ignition of the second stage shall be demonstrated over the full operational temperature and output range of the Inflator. This demonstration shall include a minimum of six tests at each temperature -40 °C, +23 °C, and +85 °C. The mean deployment time +3σ shall be less than 30 seconds at +23 °C.

Any automatic or sympathetic ignition of the second stage shall be well characterized to provide no potential for increased injury to an occupant in a representative module by a minimum of three worst-case static occupant position tests using a primary/secondary output split as agreed to by the RVEO.

Following deployment of the primary stage, a delayed ignition (or deactivation) of the secondary stage beyond 150 seconds in an ambient test (in a manner that will not cause hazard, decrease the protection of the system to the occupant(s), or cause audible alarm to occupants or emergency personnel) shall be permissible only as agreed to by the RVEO.

3.2.12.3 Dual-Stage Inflator Offset

Unless otherwise specified, for dual-stage Inflators, tests shall be conducted by deploying both the primary and secondary stages simultaneously (0 ms offset).

4. VALIDATION

Any change to a DV- or PV-qualified Inflator's structure, part configuration, propellant load (increased), manufacturing method, or any other change that could alter the outcome of any tests included in the DV or PV test (series) contained herein shall require re-validation. Re-validation may be accomplished through a subset of the requirements (delta DV or PV) containing only tests where the outcome is influenced by those changes. Any delta DV or PV shall be agreed to in advance by all affected parties at the RVEO.

Laboratory and test facilities shall be accredited by the American Association for Laboratory Accreditation (A2LA), the Standards Council of Canada (SCC), ISO or other locally accepted laboratory accreditation program.

4.1 Design Verification/Production Validation Report Format

DV and PV Test reports shall include as a minimum the following items:

1. Summary: The summary shall include a clear and complete description of the device in test, cut away drawings of the device in test, indented bill of materials (including part numbers, rev. levels, etc.), a summary description of tests, ballistic summary charts (scatter plots, mean and variability plots, tabular performance charts as defined in [3.2.9, Inflator Performance and Variability Limits](#)), and analysis of test results.
2. Deviations: All deviations from the specified test protocol and performance requirements, design issue resolutions and any other relevant supporting information generated during the execution of the DV or PV shall be included or summarized in a subsection of the completed test report. All deviations and agreements or approvals by the RVEO that alter the requirements of this document shall be documented and included as a subsection/appendix titled, 'Deviations' in the DV or PV report.
3. Test Plan: The test plan shall include a configuration document detailing the exact configuration tested, future product changes not included in the current test configuration (if applicable), test schedule (projected or actual dates), and test plan (including test location and equipment).
4. Appendices: Appendices should include detailed build records, conditioning records, detailed test results, equipment description and certification (if required), and any other supporting data. Appendices may be bound as a separate volume.

4.2 Deviations From Test Procedure

Deviations from specified test requirements and procedures shall be approved in writing by the RVEO prior to beginning the test procedure. In the case that the deviation occurs during the conditioning and/or testing of the device, the RVEO shall be notified as soon as practical, verbally and in writing, as to the circumstances of the deviation. The RVEO shall determine if further testing is required to maintain the intent of the test requirements. All deviations and supporting information shall be included in the test report.

4.3 Design Verification Process

4.3.1 DV Program Sequence

Following is the recommended Design Verification (DV) process:

1. Inflator Supplier completes requirements as outlined in [Appendix A, Pre-Source Qualification \(QFS\) Requirements](#) and reviews with the RVEO for approval.
2. Inflator Supplier completes configuration document/test plan and makes them available to the RVEO for review.
3. The RVEO reviews the QFS information and DV test plan. All proposed changes to the plan should be submitted for review to the RVEO for agreement prior to implementation.
4. DV Build proceeds. The RVEO should be given the opportunity to attend the DV Build and subsequent testing.

NOTE: Proceeding with a DV without RVEO review and approval is at the supplier's own risk and may result in refusal to accept the test report and/or additional testing.