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NASA AEROSPACE
PRESSURE VESSEL SAFETY STANDARD

OFFICE OF SAFETY AND RELIABILITY
AND QUALITY ASSURANCE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

NASA AEROSPACE PRESSURE VESSEL SAFETY STANDARD

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I. PURPOSE

The purpose of this safety standard is to provide criteria for utilizing fracture control techniques to design, fabricate, test, and operate aerospace pressure vessels so that associated personnel will be safe.

II. SCOPE

Pressure vessels and systems covered by this standard cannot be designed, fabricated, or tested to meet the requirements specified by the ASME Boiler and Pressure Vessel code, Section VIII, Divisions 1 and 2, because they are lighter weight to meet flight use requirements. The operational requirements herein are applicable during development, testing, and operations on the ground and during flight.

III. DEFINITIONS

CRITICAL FLAW SIZE: The flaw size which, for a given applied stress, causes unstable crack propagation.

DESIGN BURST PRESSURE: The pressure at which an unflawed pressure vessel should burst if all of the sizing allowables (material strength, thickness, etc.) are at their minimum specified values.

DESIGN MAXIMUM OPERATING PRESSURE: The maximum pressure which can be applied to a vessel by the pressurizing system when pressure regulators and relief valves are set at their upper limits and when the fluid flow rate is maximum.

FLAW OR CRACK-LIKE DEFECTS: Defects which behave like cracks and may be initiated during production, fabrication, testing, handling or service of a component.

FRACTURE CONTROL: The rigorous application of those branches of engineering, manufacturing, and operations technology dealing with the understanding and prevention of flaw propagation that could lead to catastrophic failure.

FRACTURE MECHANICS: An engineering discipline which describes the behavior of flaws or crack-like defects in materials under load.

FRACTURE TOUGHNESS: An inherent material property which describes the resistance to fracture.

INITIAL FLAW SIZES: The maximum flaw size, as defined by proof test or nondestructive inspection, which could exist in a pressure vessel prior to initial introduction into service.

OPERATING PRESSURE: The maximum static pressure a vessel will be operated at without requiring actuation of pressure regulators, relief valves, etc.

PROOF FACTOR: The factor by which the design maximum operating pressure is multiplied by to give the proof pressure.

PROOF PRESSURE: The pressure a vessel is subjected to during acceptance testing to give evidence of satisfactory workmanship and material quality. Proof pressure is the product of design maximum operating pressure, times the proof factor.

PROOF TEST: The test at proof pressure which will give evidence of satisfactory workmanship and material quality or will establish the component initial flaw size.

QUALIFICATION TEST: A test or series of tests conducted on actual typical production pressure vessels which establish that the general design and fabrication are acceptable for the intended use.

STRESS INTENSITY FACTOR: A measure of the stress-field intensity near the tip of an ideal crack in a linear elastic material.

STRESS INTENSITY FACTOR RATIO: The ratio of the initial flaw stress/critical flaw stress intensity factors.

THRESHOLD STRESS INTENSITY FACTOR: The maximum value of the stress intensity factor for a given material for which environmentally induced flaw growth, under static tensile stress, does not occur for the specific environment in question.

VERIFICATION TEST: A proof test conducted to establish the integrity of a pressure vessel after it has been subjected to some adverse condition or after some specific period of operation or storage.

99% EXCEEDANCE, 95% CONFIDENCE LEVEL: The value which will be exceeded in 99% of the measurements made, provided that distribution of random measurements fits some determined distribution function in 95% of the cases.

IV. IMPLEMENTATION

New aerospace pressure vessels certified to the requirements of this safety standard will not be required to meet the design, fabrication, or test requirements of the ASME Boiler and Pressure Vessel Code. Existing pressure vessels are considered to meet the intent of the requirements of this standard provided:

A. There has been a history of failure-free operational service, and

B. The operational and maintenance restraints of the pressure vessels are controlled by NASA-approved procedures or equivalent, or

C. The pressure vessels are operated remotely within the confines of a NASA-designated hazardous test or personnel exclusion area.

V. POTENTIAL FAILURE MODES

Possible causes of failure which are considered by this safety standard include:

A. Growth of existing cracks or flaw-like inclusions.
B. Growth of flaws initiated by fatigue.
C. Growth of flaws caused by stress corrosion.
D. Material contamination or environmentally induced embrittlement.
E. Material incompatibility with the intended environment.
F. High local stresses due to any discontinuities (refer to NASA SP-8083).

VI. FRACTURE CONTROL PLAN

A fracture control plan shall be developed for each pressure vessel design. The plan must consider and constrain the entire development and operational life of the pressure vessel including: material selection and procurement, design, fabrication, in-process inspection, acceptance and periodic verification procedures, tests, operational service, stress analysis, maintenance, and quality control procedures.

VII. MANAGEMENT

The manager having cognizance over the pressure vessel system shall develop, document, approve, and implement the fracture control plan. The plan shall include:

A. Definition of tasks and assignments of responsibilities to control the development and operational life of the pressure vessel.

B. Requirements for the manager's review of design, materials, manufacturing, processing, and non-destructive testing techniques.

C. Requirements for continuing review, performance appraisal, and control by the manager.

VIII. DESIGNS, LOADS AND ENVIR0NMENTS

Fracture control pressure vessels shall be designed to avoid service failure caused by the propagation of flaws. The design shall consider and account for pressures, temperatures, internal and external environments, and stresses whether imposed by internal or external forces or other sources of stress to which the vessel may normally be exposed. Material properties or characteristics used in design or analysis shall be taken from reliable sources of data, such as: MIL-HDBK 5, or be determined by test.

A. The maximum initial flaw size permitted in pressure vessels shall not be large enough to become of critical size during the vessel's design service life or between reverification tests. The initial stress-intensity factor ratio used in pressure vessel designs shall be selected to ensure that stresses do not become critical during the design life of the vessel.

B. Where technically possible, each pressure vessel shall be designed to accommodate proof and verification testing. Where possible, the proof pressure level shall be selected to demonstrate that the vessel is free of flaws larger than the permissible size or that the stress intensity ratio is acceptable. Where the proof test (see XV. B.) does not provide definitive flaw detection, other flaw detection techniques shall be required. Thermally induced stresses or changes in material properties shall be considered and accounted for in the design of each pressure vessel. A complete internal pressure-time-temperature history of the vessel and the internal and external liquid and gaseous environments which the vessel will be exposed to during test, cleaning, flushing, storage, and service shall be considered in the design.

C. Local yielding caused by stresses resulting from existing residual stresses and/or design or manufacturing discontinuities shall be permitted at the proof-test pressure level. General yielding shall not be permitted at the proof-pressure level unless the pressure vessel is designed to accommodate it (see XV.B.6.).

D. The cumulative static and dynamic loading and thermal and chemical environments anticipated in the various phases of the service life shall be defined and shall include all flight and ground phases. The following factors and their statistical variations shall be considered:

1. The explicitly defined model of the life spectrum.
2. The frequency of application of the various types of loads, load levels, and environments.
3. The environmentally induced loads.
4. The environments acting simultaneously with loads with their proper relationships.
5. The prescribed service-life requirements.

E. The design spectra shall be used for both design analysis and testing. The load-temperature spectra shall be revised as the structural design develops and the aerodynamic, thermodynamic, and loads data improve in accuracy and completeness.

F. Fracture control plans shall specify any requirements for structural instrumentation necessary for the periodic evaluation of remaining service life.

IX. MATERIALS

Material mechanical properties used in the design of pressure vessels shall be statistically significant at the 99% exceedance, 95% confidence level. Values shall be obtained for parent material. Material fracture property bounds for weldments and heat affected zones shall be accounted for in material selection and include:

A. Fracture toughness.
B. Resistance to initiation and propagation of fatigue and environmentally induced cracking.
C. Threshold values of stress intensity under sustained and cyclic loading.
D. The effect of fabrication and joining processes including test of base material and welds.
E. The effects of cleaning agents, dye penetrants, flushing agents and coatings.
F. Crack propagation characteristics, including real-time effects (e.g., time at peak load).
G. Effects of temperature and other environmental conditions.

NOTE 1: Materials and their design maximum operating stress levels shall be selected so that the required life for a given component can be evaluated by non-destructive inspection techniques, proof test, or by a combination of the two:

NOTE 2: Standard test procedures shall be employed for determination of material fracture properties. The test specimens and procedures utilized shall provide test data for the intended application. Test procedures shall be approved by the responsible manager. Property values shall be obtained on a sufficient number of material lots to permit evaluation of lot-to-lot variation. Where lot-to-lot variation has not been experimentally established, data shall be obtained for each lot used in the construction of pressure vessels.

X. ANALYSES

Analyses shall be performed to verify adequacy of pressure vessels. Where adequate theoretical techniques do not exist or where experimental correlation with theory is inadequate, the analyses shall be supplemented by tests. The following analyses shall be provided as applicable:

A. Static and dynamic loads and thermal stresses.
B. Fatigue-life for unflawed structures.
C. Characteristics and probable locations of critical structural defects.
D. Flaw growth for predicted operational loads.
E. Test requirements including materials tests, structural development and qualification tests, and proof tests.

XI. FABRICATION

Established and verified procedures shall be used to preclude damage or material degradation during processing and fabrication. These procedures shall include:

A. Pertinent fracture control requirements and precautions in applicable drawings and specifications.

B. Detailed fabrication instructions and controls to properly implement the fracture control requirements and provide special precautions guarding against processing damage or other structural degradation.

C. Validation of the quality of finished parts, including the fracture control practices to be implemented in the preceding steps to account for mechanical fracture properties and physical conditions that could contribute to flaw initiation or growth.

XII. QUALITY ASSURANCE

The quality assurance system shall ensure that materials, parts, subassemblies, assemblies and completed tanks with associated accessories conform to applicable drawings and specifications; that no damage or degradation has occurred during fabrication, processing, inspecting, testing, shipping, storage or operational use; and that defects which could cause failure are detected, evaluated and corrected. The system should focus on control and prevention of defects as well as their detection. As a minimum, the following quality control considerations shall be included in the fracture plans:

A. Appropriate inspection points and nondestructive inspection techniques shall be used to verify and ensure compliance with specifications pertinent to fracture control. In choosing inspection points and techniques, consideration should be given to material, structural configuration, accessibility for inspection, and predicted size, location, and characteristics for critical initial flaws.

B. Non-destructive testing techniques which have validated capabilities to reliably detect critical flaws for conditions of the anticipated life cycle shall be selected. Where such validating information is not available, capability shall be based on analysis of critical flaw sizes during the life cycle of the vessel. Techniques which permit the confidence of flaw detection to be expressed quantitatively, on a statistical basis, are desired.

C. Procedures shall be established to ensure that unplanned events which could be detrimental to the fracture resistance of components selected for fracture control are reported and evaluated through formal review.

D. Procedures for identifying each pressure vessel with appropriate specifications, such as: operating pressure proof pressure, drawing number, etc. are required. No degradation of pressure vessel quality stall occur as a result of stamping, marking, or tagging. A serial number shall be used to correlate a given task with such data and the logs required in paragraph XIII. below.

XIII. DOCUMENTATION LOGS

Documentation logs shall be developed and maintained throughout the life of each pressure vessel. This documentation shall be kept current and shall be available to the pressure vessel operator, fracture control analyst, safety engineer, or cognizant agencies for review, evaluation, and information, and shall contain the following as a minimum:

A. A time and cycle history of tank pressurizations for both tests and operations, including the fluid media used.

B. A temperature history correlatable with the pressure history.

C. Descriptions of any storage and/or maintenance conditions and analyses supporting the design and modification which might influence future use capability.

D. Number of pressurization cycles allowed for the pressure vessel.

E. Results of any inspections conducted on the pressure vessel.

XIV. PROTECTIVE DEVICES

Provision shall be included in the fracture control plan for the use of devices to limit the maximum pressure imposed on a vessel to that pressure consistent with the maximum allowable flaw size or stress intensity requirement noted in paragraph VIII. Pressure relief capability shall be provided for vessels whose contents or operation are capable of causing an increase in internal pressure. For those vessels whose pressure can only remain constant or decrease, active relief capability is not required provided pressure fluctuations due to external ambient temperature changes can not cause the maximum safe operating pressure to be exceeded. Where mechanical protective devices are required, the size selected shall accommodate the maximum possible internally generated gas flow without exceeding design maximum operating pressure. In addition, consideration shall be given to the effects of thrust or torque imparted to the pressure vessel or associated equipment by actuation of the relief device.

XV. TESTS

Tests shall be performed to confirm the design approach, manufacturing processes, and service life. Qualification tests shall be conducted on flight-quality hardware to demonstrate the structural adequacy of the design.

A. Specimens shall be tested to demonstrate the absence of critical flaws. Proper loads and environments shall be sequenced to simulate the operational service. Appropriate proof loads shall be included in their proper sequence. To confirm this demonstration, periodic inspections shall be conducted at intervals specified in the fracture control plan.

B. As a minimum, all pressure vessels shall be subjected to an acceptance proof test. Fracture mechanics theory and test data shall be used, where appropriate, to establish proof-test conditions which will verify that no flaws present could cause failure during the pressure vessel's service life or reverification period. Periodic inspections shall be performed as specified in the fracture control plan to confirm the absence of such defects.

1. The proof-test conditions, where required for flaw definition, shall account for all significant factors which could influence service-life performance. These factors include, but are not limited to, combined loadings, temperatures thermal cycles and stresses, and atmospheric or chemical environment effects.

2. When the linear elastic fracture mechanics theory is inapplicable (i.e., for thin gages or stresses close to yield), appropriate tests shall be performed on preflawed laboratory coupons which simulate the structure (e.g., thickness and heat treatment) to establish valid proof-test conditions which permit prediction of service-life characteristics.

3. For integral tankage, where conventional proof-testing (i.e., pressure loading only) does not include all critical flight-load conditions, a combined pressure and external loading test shall be conducted unless it can be demonstrated that nondestructive inspection can provide adequate flaw definition.

4. All proof tests are to be considered hazardous and conducted remotely. Suitable facilities shall be utilized during development, qualification and acceptance testing. A pre-proof-test inspection shall be performed to establish the initial condition of the structure. It is preferred that a nonhazardous, liquid, pressurizing medium be used in proof testing.

5. Post-proof-test inspection is mandatory where the proof test does not provide, by direct demonstration, assurance of satisfactory performance over the specified service life.

6. For pressure vessels not designed for general yielding, the maximum allowable proof-test stress shall be equal to the yield stress producing 0.2% permanent strain. As a minimum, the proof test shall apply pressures and/or stresses which exceed maximum design operating pressure in critical sections of the test article. When a proof test is conducted at a temperature different from the critical design condition, suitable correction shall be made to the

the proof loading to account for the difference in structural strength and fracture characteristics at the two temperatures.

XVI. OPERATIONS AND MAINTENANCE

The following must be included in the fracture control plan:

A. Required inspection intervals for pressure vessels based on flaw-growth analyses and the results of development and qualification tests.

B. Probable location and character of defects and critical flaw sizes for pressure vessels scheduled for periodic inspection. Characteristics should be based on total experience gained over the fracture control program, including data derived from fabrication, structural development, and structural qualification, tests.

C. Inspection procedures to reliably detect critical structural defects and determine flaw size under the conditions of use.

D. Requirements for environmental conditioning or control needed for physical and corrosion protection during maintenance or storage cycles.

E. Requirements for periodic verification tests, if necessary, and the conditions under which reproof or re-inspection are required in the event of inadvertent violation of any fracture control constraint.

F. Written procedures for the operation of pressure vessels. These procedures shall be consistent with safety requirements and personnel exclusion requirements at the facility where the operations are conducted. As a minimum, they shall contain requirements for system safety analyses to insure compatibility, of the pressure vessel with system operating characteristics. For initial tests in new installations, tests should not exceed 50% of normal operating pressures until operating characteristics can be established and stabilized.

G. Procedures for recording and analyzing operational data as it is accumulated to update fracture control information and to determine any areas that require corrective action. Analyses shall include prediction of remaining life and reassessment of required inspection intervals.

H. Systems which are connected to pressure vessels For either operational, test, or maintenance purposes, shall be compatible with the pressure vessel constraints imposed by this safety standard. The design requirements for these systems are not covered herein.

XVII. STORAGE

When pressure vessels are to be put into storage, the following must be provided for:

A. Prevention of mechanical damage, such as scratches, dents, dropping, etc.

B. Protection against exposure to adverse environments which could cause corrosion or stress corrosion.

C. Prevention of induced stresses due to storage fixture constraints.

XVIII. REFERENCE DOCUMENTS

Documents listed below are included for information purposes only and are not intended to be a part of this standard.

NASA SP-8040, Fracture Control of Metallic Pressure Vessels
NASA SP-8082, Stress-Corrosion Cracking in Metals
NASA SP-8083, Discontinuity Stresses in Metallic Pressure Vessels
MIL-HDBK 5, Metallic Material and Elements for Aerospace Vehicle Structures

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