

Vacuum Systems Consensus Standard for Department of Energy Accelerator Laboratories

July 20, 2008

Note: This draft is based on June 17th version entitled “Consensus Standard for the Design, Construction, Operation, Inspection, and Maintenance of Vacuum Vessels and Associated Components at DOE Accelerator Laboratories”

Foreword

This document has its origins in discussions that took place at the Accelerator Safety Workshop sponsored by the Department of Energy's (DOE) Office of Science on August 7-9, 2007.

Concern was expressed at that meeting with regard to the interpretation of Title 10, *Code of Federal Regulations*, Part 851, "Worker Safety and Health Program" (10 CFR 851)¹ requirements as they apply to the design standards for vacuum vessels and associated components.

A working group was formed in January 2008 to study these issues and to develop guidance for the design, construction, operation, inspection, and maintenance of vacuum vessels and associated components. The result is this draft consensus standard, which is scheduled to be discussed at the next Accelerator Safety Workshop planned for August 2008. Working group members are:

Argonne National Laboratory

Jeffrey T Collins
William F Toter

Brookhaven National Laboratory

Robert Casey (Chair)
Edwin Haas
Hsiao-Chaun (Dick) Hseuh
Steven Kane
Edward Lessard
Sushil Sharma

Fermi National Accelerator Laboratory

Daniel R Olis
David R Pushka

Oak Ridge National Laboratory

Peter Ladd

Stanford Accelerator Laboratory

R. Keith Jobe

1 "Code of Federal Regulations: Main Page", <http://www.gpoaccess.gov/cfr/>

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I. Introduction

Vacuum vessels, including evacuated chambers and insulated jacketed dewars, can pose a potential hazard to equipment and personnel from collapse, rupture due to back-fill pressurization, or implosion due to vacuum window failure. It is therefore important to design and operate vacuum systems in accordance with applicable and sound engineering principles.

10 CFR 851 defines requirements for pressure systems that also apply to vacuum vessels subject to back-fill pressurization. Such vacuum vessels are potentially subject to the requirements of the American Society of Mechanical Engineers (ASME) Pressure Vessel Code Section VIII (hereafter referred to as the Code). However, the scope of the Code excludes vessels with internal or external operating pressure that do not exceed 15 pounds per square inch gauge (psig). Therefore, the requirements of the Code do not apply to vacuum systems provided that adequate pressure relief assures that the maximum internal pressure within the vacuum vessel is limited to less than 15 psig from all credible pressure sources, including failure scenarios.

Vacuum vessels that cannot be protected from pressurization exceeding 15 psig are subject to the requirements of the Code. 10 CFR 851, Appendix A, Part 4, Pressure Safety, Section C addresses vacuum system requirements for such cases as follows:

“(c) When national consensus codes are not applicable (because of pressure range, vessel geometry, use of special materials, etc.), contractors must implement measures to provide equivalent protection and ensure a level of safety greater than or equal to the level of protection afforded by the ASME or applicable state or local code. Measures must include the following:

(1) Design drawings, sketches, and calculations must be reviewed and approved by a qualified independent design professional (i.e., professional engineer). Documented organizational peer review is acceptable.

(2) Qualified personnel must be used to perform examinations and inspections of materials, in-process fabrications, non-destructive tests, and acceptance test.

(3) Documentation, traceability, and accountability must be maintained for each unique pressure vessel or system, including descriptions of design, pressure conditions, testing, inspection, operation, repair, and maintenance.”

The purpose of this standard is to further define these requirements for vacuum vessels in general and particularly when the Code does not apply but an equivalent level of safety as required by 10 CFR 851 must be provided.

II. Scope

This standard establishes requirements and guidelines for the design and construction of vacuum vessels designed and built after February 9, 2007.² The standard also includes

² 10 CFR 851 came into effect on February 9, 2007. The date that an approved worker safety and health program had to be in place was May 25, 2007.

requirements for operation, inspection, and maintenance of vacuum piping, vessels, and systems.

For connected sections, such as particle accelerator rings, the boundary of the vacuum vessel extends to the bolted flange or weld that connects the sections.

The requirements of this standard apply to all vacuum vessels except those with a total energy less than 100,000 joules (J). This **excludes**:

1. Any vacuum vessel with a volumetric capacity of less than 35 cubic feet (ft³)
2. Any vessel under external pressure whose product $P \times V$ is less than 515 (psi-ft³), where P is the external differential maximum allowable working pressure (MAWP) in pounds per square inch (psi) and V is the volumetric capacity in ft³

In addition, the requirements of this standard **do not apply** to any vacuum vessel with a cross-sectional area less than 28.5 square inches (in²). (This is equivalent to the cross-section of a 6-inch diameter pipe). There is no limitation on the length of the vacuum vessel.

Vacuum vessels with thin or brittle vacuum windows require special consideration not addressed in this standard; however, windows are likely to be the weakest component of the vacuum vessel in terms of an implosion hazard.

Any vacuum vessel that cannot be protected against internal over-pressurization greater than 15 psig is subject to the requirements of this standard.

III. Definitions

Note: The following titles are to be understood as generic.

Authority having jurisdiction (AHJ) – The person or committee identified by the laboratory director as having the experience and knowledge of pressure/vacuum codes and standards to make sound judgments with respect to laboratory pressure safety policy

Engineering evaluation – A document prepared by the responsible engineer that demonstrates that a given system satisfies the requirements of this standard. The evaluation provides a basis for independent review of design and installation, as well as a record of the system design parameters for future system users. The evaluation is expected to address the topics listed in Appendix A of this standard.

Independent design professional – A person responsible for independent review of the design of a vacuum system subject to the requirements of this standard. This person is normally appointed by the division manager or other designated manager and must meet the qualification requirements defined in Section V.

Pressure Safety Committee (PSC) – A committee appointed by the laboratory director or other delegated manager to provide guidance and oversight to the Laboratory with regard to pressure safety. Depending on local practices at each institution, the PSC may review new or modified designs of vacuum/pressure systems subject to this standard and/or serve as the authority having jurisdiction for matters of pressure safety for the Laboratory.

Responsible vacuum system design engineer – The person responsible for the engineering design of a vacuum system. This person is normally appointed by the division manager for the

organization responsible for operation of the vacuum system and must meet the qualification requirements defined in Section V.

Vacuum system – A system consisting of a vessel and its associated piping and components having atmospheric pressure outside the system and a pressure less than atmospheric inside the system. Requirements for vacuum vessels are determined according to the category that describes the vessel:

- Category I Vacuum vessels in which the differential operating pressure can never exceed 15 psi
- Category II Vacuum vessels that can be protected from pressurization exceeding 15 psi through such engineering controls as pressure relief devices
- Category III Vacuum vessels that are not or cannot be protected from pressurization exceeding 15 psi

IV. Responsibilities

The division manager for the organization designing or operating a vacuum vessel is responsible for implementing the requirements of this standard. He/she (or a delegated manager) shall assign a qualified responsible vacuum system design engineer to design the vacuum system in accordance with applicable codes and to prepare the required engineering evaluation. This engineer shall arrange for review as required by an independent design professional or a designated review committee.

The authority having jurisdiction at an institution is responsible for the official interpretation of codes, standards, and practices relating to this standard and the ASME Codes. All issues regarding interpretation and application of this Standard should be referred to this authority for resolution.

The Pressure Safety Committee advises the operating organizations and laboratory director regarding pressure safety issues associated with all laboratory operations. In some organizations the Pressure Safety Committee is responsible for independent review of vacuum/pressure system design and may serve as the authority having jurisdiction for matters of vacuum/pressure safety.

V. Qualifications

Responsible Vacuum System Design Engineer

The responsible vacuum system engineer must possess extensive relevant knowledge, training, and experience. In addition, the engineer must have successfully demonstrated his/her ability to solve or resolve problems relating to the system under review in terms of its nature, complexity, and criticality. Approval from the laboratory authority having jurisdiction is required if the individual does not meet at least one of the following criteria:

- (1) Completion of an engineering Bachelor of Science or similar degree, requiring 4 or more years of full-time study, plus a minimum of 5 years of experience in the design of related vacuum/pressure systems
- (2) Professional engineering registration recognized by the local jurisdiction, plus experience in the design of related vacuum/pressure systems

- (3) Completion of an Associate of Engineering degree, requiring at least 2 years of full-time study, plus a minimum of 10 years of experience in the design of related vacuum/pressure systems
- (4) Fifteen years of experience in the design of related vacuum/pressure systems, which is satisfied by experience that includes pressure system design calculations, sustained and occasional loads, and piping flexibility.

These qualification requirements also apply to any individual serving in the role of an independent design professional responsible for conducting a review.

Pressure Safety Committee (PSC)

Members of the PSC are appointed by the laboratory director or delegate and must be experienced and knowledgeable in the design and operation of vacuum/pressure systems. Technical competence for each member shall be evidenced by 15 years of employment as a safety professional, physicist, or engineer. A Bachelor of Science degree or higher is required. Individual members are not expected to be expert in all topic areas, but the committee as a whole must possess the capability to evaluate all of the topics in Appendix B of this standard. At least one member of the PSC shall possess the qualifications identified for the responsible vacuum system design engineer.

VI. Requirements

A. Design

The application of sound engineering principles and practices are expected in the design and operation of all vacuum systems. All vacuum vessels shall be designed to ensure that allowable stresses are not exceeded and to ensure that the vessel is stable (resistant to buckling). The design shall be documented in the engineering evaluation as described in Appendix A. All issues regarding interpretation of these requirements should be referred to the authority having jurisdiction by the responsible division manager.

Category I and II Vacuum Systems

Vacuum vessels in these categories are not required to be stamped with ASME Section VIII Div 1 manufacturer's stamp. For vacuum systems in Categories I and II, the allowable compressive stresses shall be calculated using ASME Pressure Vessel Code Case 2286, July 17, 1998.³ Alternatively, vacuum vessels may be designed in accordance with the applicable sections of the ASME Code as it applies to vacuum vessels.

Category III Vacuum Systems

All design requirements contained in the ASME Pressure Vessel Code apply for Category III vacuum systems. Vessels must be stamped with an ASME Section VIII manufacturer's stamp unless the vessel is authorized by the authority having jurisdiction. The provisions of this standard specified for Category III systems define the equivalency requirements for Category III vessels without this stamp.

³ Code Case 2286 is fully incorporated into the 2007 ASME Code Section VIII, Division 2. It should be noted that 10 CFR 851 refers only to the 2004 version of the Code, which DOE has yet to resolve. Code Case 2286 still exists as a Code Case, but it will disappear in about 1 year since it is now the Code itself.

B. Design Review

The engineering evaluation prepared for Category III vacuum systems must be reviewed and approved by a qualified independent design professional (see Section III, Definitions), the Pressure Safety Committee, or a similarly qualified ad-hoc committee.

C. Fabrication

Category I and II vacuum systems shall be fabricated in accordance with sound engineering practices defined by the responsible design engineer. Vacuum systems classified as Category III must be fabricated, inspected, and tested in accordance with written procedures and a formal quality assurance program satisfying DOE O 414.1C requirements.⁴

Welding

Because of the risk of internal over-pressurization, personnel performing welding and brazing activities on Category III vacuum systems shall meet the qualification requirements identified in the American Welding Society (AWS) B2.1.⁵

- a. For all welding to pressure retaining components and attachments to pressure retaining components all welding and brazing procedure specifications (WPS/BPS) and welder and brazer performance qualifications shall meet the requirements of ASME Boiler and Pressure Vessel Code Section IX and/or AWS B2.1.
- b. All welding and brazing of Category III systems must also meet the applicable design and fabrication code(s) that are employed in the design of the system.
- c. Welding or brazing of specially designed seals, structural or electrical joints where pressure containment is provided by components that are not integral to the welding or brazing process may be qualified by the welding/brazing of sample joints on like materials with precise joint configurations and cross sectional areas that duplicate the designed component. These sample welds must be visually inspected and a minimum of 4 cross sections cut and examined by appropriate polishing and etching methods that reveal adequate fusion and penetration, and must contain no injurious defects. Welding or brazing of the final components must be done to a welding/brazing procedure specification that has duplicated essential and non-essential variables identified in ASME IX for process(es) tested. These procedures must contain acceptability standards for the weld/braze joints. Similarly the performance qualifications of welders/brazers for these joints are qualified by producing and passing the actual sectioning test joints within the limitation of the essential and non-essential variables identified in the WPS/BPS. Maintenance of qualification and retests for failures must follow the requirements of ASME IX.

Records demonstrating conformance with these qualifications must be submitted and approved by the responsible vacuum system design engineer. Records of these qualifications must be maintained with the records for the vacuum system.

⁴ DOE O 414.1C Quality Assurance, <http://www.directives.doe.gov/cgi-bin/explhcgi?qry1863498282;doe-130>

⁵ Need reference link.

Inspection

All Category III vessels shall be visually inspected during fabrication, testing, and operation by a qualified person to determine that the vessel has been constructed in accordance with design requirements and good engineering practice.

- Material condition and material property certifications shall be inspected upon receipt of materials used for construction of the vessel
- All welds and vessel materials shall be visually inspected
 - Prior to and following all tests
 - Prior to initial operation
 - Periodically for operating vessels and systems subject to corrosion or degradation

These requirements apply except when internal components cannot be inspected without unwarranted effort. The authority having jurisdiction makes this determination.

Because of the additional risk of internal over-pressurization, personnel inspecting Category III vacuum vessels and systems should meet qualification requirements defined by the American Society for Non Destructive Testing (ASNT) Specification SNT-TC-1A.

Records demonstrating conformance with these qualifications must be submitted and approved by the responsible vacuum system design engineer. Records of these qualifications must be maintained with the records for the system.

Testing

All vacuum vessels shall be tested by pumping out the vacuum volume and shall be shown to meet the vacuum design specification. Following the test the responsible engineer shall examine the vessel and determine that no effect in excess of limits established by the engineer was experienced.

For ordinary vacuum vessels the test pressure shall be full atmospheric pressure differential. For vacuum vessels not intended to be pumped out to the full atmospheric pressure differential of 15 pounds per square inch differential (psid), the test pressure shall be 110% of the maximum allowable external differential pressure, but not more than full atmospheric pressure (15 psid).

For a vacuum vessel within a pressure vessel, the test differential pressure shall be 110% of the maximum allowed working pressure differential. Thin windows and other delicate equipment may be removed while testing the vacuum vessel.

All vacuum tests shall be documented with a brief description of the test and documentation shall include two signatures: the responsible person and one witness. Records of these tests must be maintained.

D. Pressure Relief

Pressure relief devices used in Category II or III vacuum systems must be high quality and shall bear the ASME "UV" certification mark except as noted below. Calculations shall be performed and documented to demonstrate adequate sizing for venting capability of the pressure relief device(s).

In special applications where ASME-certified relief devices are not be available for Category II systems, operability tests demonstrating function and flow capacity of the relief device must be

performed and documented. A vacuum system using a non-certified pressure relief device that has not been tested⁶ must be treated as a Category III system.

Spring-actuated pressure relief devices shall be inspected and tested prior to installation and thereafter in accordance with the schedule required by National Board of Boiler and Pressure Vessel Inspectors (NBIC). Burst disks shall be visually inspected as required by the NBIC. Ongoing inspections and tests for these devices are typically conducted at regular intervals not to exceed 5 years. Engineered or administrative controls are required to assure that the pressure relief devices are not altered or removed during the operating lifetime of the vessel. Safety wires/labeling are examples of this type of control. The particular pressure relief requirements shall be noted in the engineering evaluation.

E. Existing Vacuum Systems

It is not the intent of this standard to apply these requirements retroactively to existing vacuum systems. The department responsible for the current operation of a vacuum system constructed prior to Feb. 9, 2007⁷ should ensure that it can be operated in a safe manner and that the vacuum system was designed and operated in a manner consistent with applicable engineering practices.

Questionable vessels or those with unknown histories shall be re-tested as defined in this standard. Operability of relief devices on pre-existing systems should be confirmed if such evidence does not exist (It is assumed that such evidence exists for National Board–certified pressure relief devices.) Bench-top tests of similar relief devices are acceptable if the relief device cannot be tested as installed. A written record of the decisions, judgments, tests, administrative controls, and hazard analysis that were necessary to approve these types of vessels shall be maintained in the system records file.

F. Records

Pertinent design drawings, sketches, calculations, reviews, tests, inspections, material certifications, qualification records, and operating history required by this standard must be documented and retained throughout the operation of the system. Records of safety reviews associated with the system must be retained throughout the operations and for 5 additional years following shut-down of the system. For purposes of this requirement, inactive systems in storage are treated the same as an active system until it is officially “disposed.”

⁶ As noted in Section E, bench tests approved by the authority having jurisdiction are an adequate determination of acceptable pressure relief.

⁷ Systems designed after February 9, 2007 are required to be compliant with the requirements of 10 CFR 851 or the equivalency requirements described in this standard.

Appendix A: Engineering Evaluation Requirements

Engineering evaluations are required for all vacuum systems subject to this Standard. The responsible vacuum system design engineer prepares the evaluation, which must include the following:

- Design drawings, sketches, and calculations, including a stress/collapse analysis of all exceptional parts of the vessel
- A fabrication procedure, including a list of planned and completed inspections and any other quality control procedures taken.
- Acceptance tests planned or completed
- Description of and capacity requirements for pressure relief systems and associated tests
- A description of personnel hazards associated with vessel operation and the methods used for protection. The hazard analysis shall address vessel application, operating limits and controls, possible effects in the event of vessel failure and inherent safeguards provided.
- The basis for the vacuum system classification (Category I, II, or III)

Appendix B:
Independent Review Requirements for Category III Vacuum Vessels

All Category III vacuum vessels designed to this standard must be reviewed by an independent design professional, the Pressure Safety Committee, or other similarly qualified ad hoc committee. The basis for the independent review is the engineering evaluation in Appendix A. The independent review addresses the following topics, as applicable:

Design Specifications and Description

- Physical layout
- Piping and instrumentation drawings
- Design parameters including:
 - Maximum design/allowable working pressures
 - Pressure vessel, piping and component ratings
- Stress calculations
- Maximum release rate and pressure relief capabilities
- Materials used and their suitability for application
- Quench protection description, if appropriate

Reviews and Hazard Evaluations

- Test plans and results, if any
- Department safety review(s) results
- Evaluation of oxygen deficiency hazard
- Stress analyses for custom-made equipment
- Failure scenarios that can over-pressure the vacuum volume

Procedures

- Fabrication procedure and inspections
- Operating and emergency procedures