FESHM 5033: VACUUM VESSEL SAFETY

Revision History

Author	Description of Change	Revision Date
Thomas Page	Added the new FESHM template.	March, 2013

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1.0 INTRODUCTION

Vacuum vessels, including evacuated chambers and insulating jackets on dewars, pose a potential hazard to equipment and personnel from collapse, rupture, or implosion. This chapter specifies the procedure to be followed in designing, fabricating, testing, and operating vacuum vessels in order to reduce hazards.

All vessels within the scope of this chapter shall have a written Engineering Note, as described in this chapter.

2.0 SCOPE

This chapter applies to any vacuum vessel used at Fermilab except:

1. Any vacuum vessel whose inside diameter or cross section diagonal is under twelve inches with no limitation of length.
2. Any portions of beam pipes buried underground.
3. Any vessel with a volumetric capacity of less than 35 cubic feet.
4. Any vessel under external pressure whose product P x V is less than 515 (psi) (cu. ft.), where P is the external differential MAWP and V is the volumetric capacity.
5. Thin vacuum windows for beam lines are specifically excluded from this chapter, and are covered under FESHM Chapter 5033.1.

3.0 DEFINITIONS

The Code -ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1 and 2. The revision of the Code to be applied to a given vessel is the latest revision at the start of the vessel's design.

Vacuum Vessel - any vessel having atmospheric pressure outside the vessel and a pressure less than atmospheric inside the vessel, or any vessel which is operated with a differential pressure greater on the outside than on the inside, except those operating under an external pressure greater than one atmosphere, which are covered under FESHM Chapter 5031.

Engineering Note - a written analysis demonstrating that a given vessel satisfies the requirements of this chapter.

Qualified Person – a person who, by possession of a recognized degree or certificate of professional standing, or who, by extensive knowledge, training and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter.

External Design Pressure - The external design pressure or maximum allowable external working pressure (MAWP) shall be greater than or equal to the maximum expected operating pressure differential. Reference ASME Code, Section VIII, Div. 1 Part UG28(e)

Volumetric Capacity – the internal vacuum volume of the vessel. (Does not include volume occupied by pipes, valves, instruments, or other objects.)

4.0 SPECIAL RESPONSIBILITIES

The Division/Section/Center (D/S/C) head that controls the area of operation of the vessel is responsible for carrying out the requirements of this chapter. The D/S/C Head, or designee, shall arrange for the review of required Engineering Notes by a qualified person and shall certify vessels comply with this chapter by signing the Engineering Notes. The D/S/C Heads shall maintain an open, updated file on all vacuum vessels within the scope of this chapter located in their areas of operation. After certification, the Fermilab engineering standard conformance label shall be attached to the vessel. The original Engineering Note shall be placed into the Laboratory Vacuum Vessel master file maintained by the ESH&Q Section.

The ESH&Q Section shall audit the divisions, sections and centers on their compliance to this chapter.

The Mechanical Safety Subcommittee (MSS) and/or Cryogenic Safety Subcommittee (CSS) shall serve the D/S/C heads and ESH&Q Section in a consulting capacity on all vacuum vessel matters. These committees may propose appropriate modifications to this chapter as necessary. Changes in policy and responsibility shall be recommended by the Laboratory Safety Committee after consulting with the D/S/C heads. Changes in procedure shall be recommended by the Mechanical Safety Subcommittee and/or Cryogenic Safety Subcommittee.

5.0 PROCEDURES

Vacuum vessels shall be designed to ensure that allowable stresses are not exceeded and to ensure that the vessel is stable (resistant to buckling). This chapter includes adherence to the ASME Boiler and Pressure Vessel Code. The ASME Code is not mandatory for vessels with an external pressure not exceeding 15 psi under Section VIII Paragraph U-1(c)(2)(h), but the design rules may be applied. Under Section VIII, Paragraph UG-28(f), such vessels may be code stamped.

Vacuum vessels covered by this chapter are not required to be U-stamped, but shall be designed according to the appropriate design rules in the Code revision current at the time of design, unless a determination has been made that another standard is more applicable. The D/S/C head or designee shall make that determination in consultation with the MSS and CSS.

For the purposes of this chapter, applicable portions of the ASME BPV Code include:

- Section VIII Div. 1 Parts UG-28, UG-29, UG-30, UG-32, UG-33, UG-34, UG-37 to UG-42, UG-80
- Section VIII Div. 1 Appendix 9
- Section VIII Div. 1 Appendix 13,13-14
- Section VIII Div. 2, Part 4.4, 4.12.8
- Section VIII Div. 2, Part 5.2, 5.4
- Code Case 2286-1

The Code explicitly excludes vessels with internal pressure less than 15 psig, but portions of the Code will be used to satisfy this chapter:

a. ASME Code allowable stresses shall be used. For materials not included in tables of Section II, allowable stresses shall be calculated as described in the ASME Code, Sec. II, Appendices.
b. Stresses and vessel stability shall be calculated as described in the Code. Finite Element Analysis (FEA) may be used to refine stress calculations or model vessel geometries not described in the Code.
c. Stresses shall meet allowable stress criteria described in the Code.
d. The external pressure for buckling failure predicted by Finite Element Analysis (FEA), used for shapes not specifically covered in the Code, shall not be less than 3.5 times the MAWP.

Weld configurations not specifically approved or prohibited by the Code may be submitted with stress analysis calculations for approval by the Note reviewer.

Safety Relief Devices

If the vacuum vessel can be pressurized beyond its rating, either intentionally or inadvertently, relief devices shall be included in the design. Consideration shall be given for relief of over-pressure from all possible sources, including release of gases or fluids (by design or by accidental rupture of internal components), heat, fire, etc.

All relief devices with a relieving pressure of 15 psid or greater shall be UV-stamped. Reclosing type relief valves with a relieving pressure under 15 psid are not required to be UV-stamped.

Non-reclosing and recloseable type relief devices such as rupture discs, flip-lids, and parallel relief plates with a relieving pressure under 15 psid are not required to be UV-stamped. All relief devices shall be certified by the manufacturer for relieving pressure and flow rate, or if designed by FNAL, shall be tested according to the Code part UG127 and a test report included in the Engineering Note. Calculations of relief valve sizing shall be included in the Engineering Note. Reference ASME Code Parts UG125-136 and CGA Handbook of Compressed Gases Chap. 5

Implementation of Procedure

1. *Preparation of Engineering Note*: An Engineering Note shall be prepared by an engineer or designer for all existing or new operational vacuum vessels at Fermilab; whether purchased, in-house built, an experimenter's vessel, a used vessel, or located in an unmanned area. The format of the Engineering Note is shown in Exhibit A-1. Its purpose is to allow a reviewer to check the design and installation and to inform a future user of the vessel parameters. The Engineering Note shall include design calculations for in-house built vessels and experimenter built vessels, and the manufacturer's data reports for purchased vessels if available. The Note shall also include precautions and operating procedures necessary for the safe use of the vessel.

2. *Review of Engineering Note*: All vacuum vessel Engineering Notes shall be reviewed by an independent, qualified reviewer, other than the author, for concurrence to this chapter. The reviewer shall be from a group not reporting to the preparer of the Engineering Note or his supervisor.

3. *Amendment of Engineering Note*: Any subsequent changes in usage, operating temperature, valving, etc., which could affect the safety of the vessel, requires an amendment to the original Engineering Note. This amendment shall be reviewed in the same manner as the original Note.

4. *Similar Vessels*: Vacuum vessels that are similar to previously constructed and approved vessels need not have the full engineering analysis repeated. Adequate documentation can be provided by referencing the approved engineering analysis and noting any differences. Acceptance testing is still required. For the purposes of this paragraph, similar vessels mean that the same kinds of materials and construction techniques are used and similar operating parameters will be used. The geometry must be similar, however, this paragraph may be applied if geometry differences do not affect the engineering analysis or safety.

5. *Director's Exception*: Exceptions to the provisions of this chapter shall be allowed only with the signature of the Laboratory Director or his designee documented in the Engineering Note. The need for such exceptions is to be minimized by adherence to the provisions of this chapter. Exceptions are to be identified and submitted to the Director for review as early in the design process as possible. These exceptions shall only be allowed after the Director has assured himself that sound engineering practice will be followed during design, fabrication and test of the vessel. The ESH&Q Section shall maintain copies of exceptions for the Director. An exceptional vessel is hereby defined as one which cannot meet the tenets of this chapter and therefore requires a Director's Exception.

6. A technical appendix describing procedures for an Engineering Note analysis is included.

6.0 TECHNICAL APPENDIX TO VACUUM VESSEL SAFETY

6.1 PROCEDURES AND REQUIREMENTS FOR DESIGN, FABRICATION, INSPECTION AND TEST

1. Purchased Vessels: All vacuum vessels purchased by Fermilab or its experimenters shall be made (designed and fabricated) in accordance with the "Procedure" section of Chapter 5033.

2. In-House Built Vessels: All vacuum vessels built at Fermilab or experimenter's shops shall be made (designed and fabricated) in accordance with the "Procedure" section of Chapter 5033.

3. Vessels with Thin Windows: If the thin windows can be detached from the vessel, the vessel falls within the scope of this chapter and shall be made (designed and fabricated) in accordance with the "Procedure" section of Chapter 5033. For testing, a cover plate shall be substituted for each thin window.

   A vacuum vessel with a thin window that cannot be detached is covered by this chapter, but only the vessel itself, not the thin window. The thin window is covered under Chapter 5033.1 for thin windows. For testing of such a vessel, the maximum allowable differential pressure of the thin window shall not be exceeded, and the vessel shall be rated at that pressure.

4. Welding Information:
   Welding shall be done using qualified weld procedures and welders under the rules of the ASME Boiler and Pressure Code, Section IX. The Weld Procedure Specification (WPS), Procedure Qualification Record (PQR), and Welder Performance Qualification (WPQ) shall be attached to the Engineering Note.

   Code-stamped vessels do not require welding documentation.

5. Existing Vessels In Service: All such vessels in service need an Engineering Note.

6. Used Vessels: Used Vessels shall be classified as an existing vessel and will have their previous service taken into account during the review process. Questionable vessels or those with unknown histories shall be re-tested per the "Inspection and Testing" section of this chapter.

7. Non-manned Area Vessels: If a vacuum vessel cannot be made in accordance with the preceding requirements, it may be installed in a non-manned area with suitable administrative and physical controls to restrict access when operating the vessel and restraints to minimize damage in case of failure. The vessel must be clearly and indelibly identified for use in non-manned areas only and be sufficiently secured to prevent its removal from the non-manned area. An Engineering Note shall be completed for all such vessels.

8. Inspection and Testing: The vessel shall be inspected during fabrication by the designer/engineer for compliance to the standard. All vacuum vessels shall be acceptance tested by pumping out the vacuum volume. Before this test is performed, the Engineering Note shall be reviewed by the assigned reviewer.

   For ordinary vacuum vessels the test pressure shall be full atmospheric pressure differential of 15 psid.

   For vacuum vessels not intended to be pumped out to the full atmospheric pressure differential of 15 psid, the test pressure shall be 125% 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 125% of the maximum allowed working pressure differential.

   Thin windows and other delicate equipment may be removed for the test of the vacuum vessel. The test shall be documented with a brief description and the signatures of two witnesses.

6.2 ENGINEERING NOTE

An Engineering Note (see technical appendix for note format) shall be prepared by the designer addressing the topics below for the vessel, series of vessels, or vessel system, as appropriate. Its purpose is to allow a reviewer to check the design and installation and to inform a future user/re-tester of the appropriate vessel parameters. The note shall be signed and filed as noted in Chapter 5033 under "Special Responsibilities."

1. Description and Identification

   Obtain a vessel identification number from the D/S/C safety officer. Describe the vessel, its purpose, site location, and how the maximum allowable working pressure (MAWP), internal or external, was established.

   All drawings deemed pertinent to the safety review shall be listed and included. Include in the note a copy of the information on the engineering standard conformance label.

2. Design Verification

   Provide the design calculations. For externally manufactured vessels, a copy of their design calculations is acceptable.

3. System Relief Verification

   When relief devices are included in the design, provide a schematic of the vacuum vessel relief system and appropriate calculations or test results to prove that the vacuum vessel will not be subject to pressures over its calculated MAWP or under its maximum external differential

pressure. (Note: If the MAWP is greater than 15 psi, a FESHM Chapter 5031 Engineering Note is required.) Prove that the relief valve(s) cannot be isolated from the vacuum vessel except as allowed by ASME Code (Reference Sec. VIII Div. 1 Appendix M and Div. 2 Appendix A). The relief calculation shall take in account a failure of any piping or vessel inside the vacuum vessel, and shall be sized according to the maximum system flow rate of that piping, and/or a reasonably expected leak rate from the inner vessel.

4. Operating Procedures

Provide cautions and operating procedures for the vessel if required for safe operation.

5. Welding Information

Attach the required welding records. Code-stamped vessels do not require welding records.

6. Extended Engineering Note for Exceptional Vessels:

The Note shall be prepared using the same or similar format as noted on Exhibit A-1, but in addition shall include the following information.

a. *Reason for Exception*: D/S/C Head or designee shall provide a statement showing the necessity of a Director's Exception.

b. *Analysis/Collapse Test*: The system designer shall provide a stress/collapse analysis of all exceptional parts of the vessel. Include data, formula or test results that demonstrate the anticipated safety factor. Source of information shall be referenced.

c. *Fabrication*: The system designer shall provide a fabrication procedure, a list of planned and completed inspections and any other quality control procedures taken.

d. *Hazard Analysis*: The system designer shall provide 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.

e. *Acceptance Test*: An acceptance test shall be performed per this chapter.

Engineering Note for Existing Vessels, Used Vessels and Non-manned Area Vessels

The D/S/C head or his designee shall provide a written record of the decisions, judgments, tests, administrative controls and hazard analysis that were necessary to approve these types of vessels under this chapter.

In the event that the Engineering Note cannot be approved, operation shall be discontinued until appropriate modifications or administrative safeguards are instituted, or Director's Exception is granted.

6.3 DESIGN REFERENCE DATA BY TM NUMBER AND SUBCATEGORY

A Design Chart for Long Vacuum Pipes and Shells TM-1378 (SCN 0121.585).
Design Charts for Spacing of Vacuum Line Supports TM-1377 (SCN 0121.585).
Design Charts for Vacuum Plates TM-1052 Rev A. (SCN 5540.100).

7.0 FORMS

There is an Engineering Note Cover Page form to be included in the Vacuum Vessel Engineering Note.

- Vacuum Vessel Engineering Note

This form can be found on the ES&H website or the ES&H document management database under FESHM Chapter 5033.