FESHM 5032: CRYOGENIC SYSTEM REVIEW

Revision History

Author	Description of Change	Revision Date
William Soyars	1. Added section d) to 5.0 PROCEDURES, 1. Safety Review to reference FESHM 5031.4 2. Minor editorial changes 3. Editorial changes to 4.0 SPECIAL RESPONSIBLITIES Div/Sect Heads and Project Manager responsibilities 4. Added paragraph 7.0 to TA 6.1 for further instructions on commercial, packaged He compressors and cold head	February, 2016
Arkadiy Klebaner	Revised to incorporate more detail in the Scope section.	November, 2013
Arkadiy Klebaner	Revised to incorporate comments from experts and minor editorial changes. 1. Modified/simplified the language of the introduction 2. Added reference to FESHM Chapter 2060 3. Changed Division/Section to Division/Section/Center 4. Changed Laboratory Safety Committee to FESHCom	January, 2011

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1.0 INTRODUCTION

Large quantities of cryogenic fluids are used at Fermilab to induce superconductivity in magnets, cool accelerators and experimental apparatus. Upon warming, an enclosed container of cryogenic fluid can become a pressurized since the evaporated fluid occupies approximately 700 times the volume of the liquid. As with room temperature pressure vessels, leaks or ruptures can occur with the subsequent release of energy. In addition, cryogenic fluids and materials pose cold exposure, thermal contraction, brittle fracture, and oxygen deficiency problems. Several Fermilab Environment, Safety and Health Manual (FESHM) chapters pertain to the design and operation of cryogenic systems. Each of these chapters specifies the requirements for dealing with a particular hazard or class of equipment, which may affect the safety of a system.

2060	Work Planning and Hazard Analysis
2070	Environment, Safety, Health, and Quality Training Program
5031	Pressure Vessels
5031.1	Piping Systems
5031.2	Inert Gas Trailer Connections and Onsite Filling Guidelines
5031.3	Gas Regulators and Compressed Gas Cylinders
5031.4	Inspection and Testing of Relief Systems
5031.5	Low Pressure Vessels and Fluid Containment
5031.6	Dressed Niobium SRF Cavity Pressure Safety
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5032.1	Liquid Nitrogen Dewar Installation and Operation Rules
5032.2	Liquid Cryogenic Targets
5032.3	Transporting Gases in Building Elevators
5033	Vacuum Vessel Safety
5034	Pressure Vessel Testing
4240	Oxygen Deficiency Hazards

2.0 SCOPE

This chapter describes procedures for reviewing the safety aspects of cryogenic systems as well as the required occupational training for cryogenic personnel. It pertains to all cryogenic systems including, for example, those used for refrigerating magnets, accelerating structures, hydrogen targets, argon calorimeters, or as a source of gas. It also includes any warm systems connected to cryogenic fluids and used for capturing, processing or storing the gas, as well as cryogenic systems supplying purge gas if the stored liquid inventory is greater than 200 liters. In cases where the scope of the system is in question; contact the Chairperson of the Cryogenic Safety Subcommittee.

3.0 DEFINITIONS

Cryogenic - at a temperature below -150^{o} Celsius (^{o}C).

Cryogenic facility - an area where cryogenic fluids and/or materials are produced, used, or stored.

Cryogenic personnel - those engaged in or responsible for the production, use, transport, or storage of cryogenic fluids and/or materials.

4.0 SPECIAL RESPONSIBLILITIES

The Division/Section/Center Head who controls the area of operation of the system and the Division/Section/Center Head who controls the implementation of the cryogenic system are responsible for carrying out the requirements of this chapter. He/she shall:

a) ensure the responsible Division/Section/Center (DSP) staff ask the chairperson of the Cryogenic Safety Subcommittee to provide names for a qualified review of each cryogenic system by assigning review to a standing Cryogenic Safety Panel.

b) ensure that the standing Cryogenic Panel is aware of its charge and the scope of the review task.

c) ensure that the staff and experimenters in their jurisdiction provide analysis for review in a timely manner.

d) ensure that the analysis and review are completed prior to the initial operation of the system.

e) notify the chairperson of the Cryogenic Safety Subcommittee and the head of the Environment, Safety, Head and Quality (ESH&Q) Section that the analysis and review are completed.

f) maintain current safety documentation for each system in the division/section/center in a designated location.

The ESH&Q Section shall audit the D/S/P's on their compliance to this chapter.

The Cryogenic Safety Subcommittee shall serve the D/S/P's in a consulting capacity on all cryogenic system matters. The subcommittee may propose appropriate modifications to this chapter as necessary. Changes in policy and responsibility shall be recommended by the Fermilab ES&H Committee after consulting with the D/S/P's. Changes in procedure shall be recommended by the Cryogenic Safety Subcommittee. Furthermore, the subcommittee shall:

a) when necessary, provide a panel of qualified reviewers, the chair of which are formally appointed by the Fermilab ES&H Committee .

b) audit the progress of the review.

c) maintain a list of excepted classes of cryogenic pressure vessels and ensure that this list is on file with the ESH&Q Section.

A review panel is responsible for completing an accurate safety review in a timely and efficient manner. Upon completion, the panel shall inform the Division/Section/Center Head(s) and the chairperson of the Cryogenic Safety Subcommittee of its conclusions.

5.0 PROCEDURES

As specified by the scope, cryogenic systems within the scope of this chapter shall be reviewed in accordance with the D/S/P's charge to the panel. As a minimum, this would include reviews before initial system operation, after a shutdown and warmup to room temperature of longer than two months, or anytime a change in system configuration has been made. A change in system configuration is not an engine swap or the pumping of a vacuum jacket. System configuration changes are more substantive such as adding a new (including temporary) line, off normal operations not described in procedures, or unusual maintenance operations not previously documented.

1. Safety Review

   a) The analysis and review shall be directed to all aspects of the system which could present a hazard to personnel.

   b) The analysis shall demonstrate that the system can be brought into operation safely. It should also demonstrate that safe operation can be maintained.

   c) The following requirements pertain to reviews of cryogenic pressure vessels:

      (i) The provisions of Chapter 5031 shall be followed for all cryogenic pressure vessels falling under the scope of American Society of Mechanical Engineers Boiler and Pressure Vessel Code Section VIII, Rules for Construction of Pressure Vessels. Other cryogenic vessels shall be reviewed as required by the Cryogenic Review Panel assigned to that system.

      (ii) In the case of vacuum insulated vessels, the inner vessel shall be considered a cryogenic pressure vessel (Chapter 5031) and the outer vessel shall be considered a vacuum vessel (Chapter 5033).

   d) The review shall verify that reliefs are in compliance with FESHM 5031.4 Inspection and Testing of Relief Systems.

2. Occupational Training

   Occupational and safety training plays a key role in the safe and efficient operation of cryogenic systems. Training may take the form of safety orientations, safety qualification

courses or training by supervisors as prescribed by Fermilab's ESH&Q Training Program (Chapter 2070). Both formal and on-the-job training shall be documented.

a) Cryogenic personnel shall have sufficient education, training, and supervision to assure that they can safely perform their duties. Furthermore, personnel shall be instructed in cryogenic hazards peculiar to the facility at which they work. Assistance from a person knowledgeable of these hazards shall be available to any individual newly assigned to perform cryogenic work at a facility until the supervisor determines that the individual can perform his or her duties unassisted.

b) Cryogenic personnel should attend the Fermilab safety courses, "Oxygen Deficiency Hazards," "Cryogenic Safety" and "Pressurized Gas Safety" or their equivalents. Other courses, as described in Chapters 2070 and 4130 may also be appropriate. General training in cryogenic principles may also be beneficial, particularly to personnel involved in operations.

3. A technical appendix describing procedures which shall be followed by those preparing a safety analysis is attached.

6.0 TECHNICAL APPENDICES

6.1 Technical Appendix A - CRYOGENIC SAFETY ANALYSIS PROCEDURE

Documentation will be prepared to demonstrate to the review panel that aspects of the system which could present a hazard to equipment or personnel have been examined.

1.0 System Design Documents

1.1 A system equipment and operation description shall be prepared that will serve as an overview of the system for the review panel and as an introduction for the trainee.

1.2 Complete and accurate flow sheets will be prepared. The final flow sheets must be signed off as checked and approved.

1.3 An active component list (instrument and valve summary), labeling and describing all active devices of the system will be prepared. These devices would normally include valves, gages, transducers, brakes, pressure and temperature switches, and rupture disks. In the system, all of these devices will be tagged and identified with permanent tags.

1.4 A list of the system control loops and interlocks and a description of normal operations of each loop or interlock.

2.0 System Operating Documents

2.1 Operating procedures shall be prepared for the system. All revisions to the operating procedures which could present a hazard to personnel shall be submitted to the review panel.

2.2 Any checklists required for startup, shutdown or normal operation of the system shall be provided for review.

2.3 The qualification and training requirements of cryogenic personnel, beyond those required in this chapter (5032), shall be defined by line management and documented.

3.0 Safety Analysis Documents

3.1 A FMEA (Failure Mode and Effect Analysis) shall be performed. The recommended scope and method is described in Appendix A, *Failure Mode and Effects Analysis*.

3.2 A what-if analysis shall be performed. The recommended scope and method is described in Appendix B, *What-If Analysis*.

3.3 A hazard analysis shall be performed. The recommended scope and method is described in Appendix C, *Hazard Analysis*.

3.4 FMEA, what-if, and hazard analyses may, in some cases, be substituted for each other with the agreement of the reviewers. An adequate review may not require the completion of all three analyses.

3.5 Documentation necessary to demonstrate that other sections of the Fermilab ES&H Manual are followed shall be prepared. Particular attention will be paid to those sections of the manual noted in the introduction to this chapter (5032).

4.0 Engineering Documents

4.1 Calculations and/or test results demonstrating the adequacy of the relief system shall be prepared.

4.2 Calculations and/or test results shall be prepared to verify that stress levels in materials are acceptable per the applicable FESHM chapter or ANSI Code.

4.3 Material certifications, test data, or data sheets shall be provided for any unusual materials used in the system.

4.4 Other calculations as required by sound engineering practice shall be prepared.

5.0 Maintaining Safe Operation

5.1 Documents shall be kept current.

5.2 Plans for maintenance and operations shall be prepared before operations begin.

5.3 Operator training and qualification records shall be kept.

6.0 Inspections

6.1 Inspections by the review panel shall be performed during the review in order to further acquaint the panel with the system and to clarify technical points concerning safety of the system.

6.2 Inspections by the review panel shall be performed as required during operations to verify continued system safety.

7.0 Exclusions for systems that consist only of commercial, packaged helium compressor and cold head (i.e. cryocoolers)

7.1 A FMEA of the packaged system is not required

7.2 Flow sheets of the packaged system are not required.

7.3 System control loop descriptions internal to the commercial equipment are not required.

7.4 An active component list of the packaged system is not required.

6.2 Technical Appendix A – FAILURE MODE AND EFFECTS ANALYSIS

INTRODUCTION

A Failure Mode and Effects Analysis (FMEA) requires the system be analyzed for all single and probable multiple (equipment or operator) failures that could cause personnel injury or significant equipment damage. The system must remain safe for all reasonable postulated equipment failures or operator errors. The analysis is most profitably carried out in parallel with the design effort. FMEA is a design tool, not an ad hoc documentation requirement.

PROCEDURE

A FMEA is primarily component oriented. Each component of the system should be reviewed in each possible failed state, individually, to evaluate its possible safety consequences to the system. The component list should include all active components. Typical are valves, gauges, transducers, brakes, interlocks, and pressure and temperature switches. See the worksheet in the 5032 Cryogenic System Review Form.

DOCUMENTATION AND PHILOSOPHY

The FMEA should individually list each postulated failure mode for each component. Each failure entry should explain the hazard, describe why it is safe, or make a recommendation that will eliminate the hazardous condition.

To be useful, the FMEA must be complete. Every failure of every component must be addressed. Normally this would include only single level failures. Probable multiple failures should also be examined. Other methods will better examine long sequential failure modes (see What-If and Hazards Analysis, Appendix B & C).

See the worksheet in the 5032 Cryogenic System Review Form.

6.3 Technical Appendix B – WHAT-IF ANALYSIS

INTRODUCTION

This analysis technique examines the consequences of system failures and upsets, as well as procedural errors. This method of analysis examines subsystem rather than components and looks at the effects of external influences on the system. The purpose of this analysis is to unearth any hidden flaws in the design or procedure errors which could present a hazard to personnel and equipment.

Using the flow sheets and procedures, "what-if" type questions are asked of the system. These questions are categorized as follows:

a) Each component must be reviewed for unsafe conditions arising from loss of electrical power, loss of instrument air, loss of cooling water, and loss of liquid nitrogen, as appropriate.

b) Each system should be reviewed to uncover safety problems arising from contamination in the process stream. In particular, for hydrogen systems, extra effort must be made to limit introducing oxygen into the process.

c) Every cold subsystem in the system should be reviewed for safety hazards involving loss of insulating vacuum. Particular attention here should be paid not only to the loss of vacuum, but also damage occurring during a subsequent warmup as cryo-pumped gas evolves, pressurizing the vacuum space.

d) Cryogenic systems should be reviewed to demonstrate that a system will remain safe after refrigeration is lost due to loss of compressors, engines, or heat exchangers.

e) Each system should be analyzed for the effects of nature (rain, wind, fire, etc.) which have some reasonable chance of occurring.

f) Each system should have its assumptions subjected to the scrutiny of a What-If Analysis; i.e., what if the air system fails.

g) Where the failure of equipment poses a hazard "What-If" questions should be asked regarding equipment reliability; i.e., what if the drive shaft fails on an expansion engine.

h) Where there is an operator interacting with the system, "What-If" questions should be asked. (In general, if the Failure Mode and Effects Analysis has been completed, the operator should be able to position any single element (valve) without a hazard.)

i) Each subsystem should be examined for likely multiple failures. (This section may be done in the format of a Hazards Analysis in Appendix C.)

PROCEDURES

1. Work with flow sheets and system procedures (operating, repair, etc.).

2. Go through each step of the procedure and examine the consequence of each action specified.

3. Questions of multiple failures may also be asked (i.e., what if step n of a procedure is initiated and there is a failure of device m?) These questions should be restricted to probable failures.

4. Use the What-If worksheet to itemize each question raised and examined.

5. Complete the consequences and recommendation section.

6.4 Technical Appendix C – HAZARD ANALYSIS

INTRODUCTION

The technique of Hazards Analysis requires the identification of a particular hazard and an analysis of the involved systems and procedures in order to determine if and how the hazard might occur. The technique is already in use under Fermilab Environment, Safety and Health Manual Chapter 5031, Pressure Vessels where the hazard identified is over-pressurization of the vessel, and Chapter 4020, Oxygen Deficiency Hazards where the hazard is reduction of the oxygen content of the atmosphere to below 144 millimeters of mercury (19.5%). Since a Hazards Analysis begins with an effect and works backwards to the cause, it is the opposite of the FMEA (Failure Mode and Effect Analysis) and What-If Analysis. For that reason, it may often substitute for these analyses when it can be performed well. Multiple failures that are much more difficult to treat in the FMEA and What-If format are readily analyzed in a Hazards Analysis.

PROCEDURES

Hazards to be analyzed must first be identified. Hazards to be considered include thermal, fire, electricity, flying objects, oxygen deficiency, rotating machinery, and any others associated with a particular system.