



FESHM 5032: CRYOGENIC SYSTEM REVIEW

Revision History

Author	Description of Change	Revision Date
William Soyars	<ul style="list-style-type: none">• In 3.0, require posting of certain cryogenic system review documentation to Teamcenter• Reference to ORC FESHM 2005 for recommendation process• Recommendation notifications sent to DSO and D/S Direct Support Manager instead of Chief Safety Officer• Added paragraph 8.0 to TA 6.1 for further instructions on dilution refrigeration system	November 2017
William Soyars	<ul style="list-style-type: none">• Added section d) to 5.0 PROCEDURES, 1. Safety Review to reference FESHM 5031.4• Minor editorial changes• Editorial changes to 4.0 D/S/C Head responsibilities• 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	<ul style="list-style-type: none">• Modified/simplified the language of the introduction• Added reference to FESHM Chapter 2060• Changed Division/Section to Division/Section/Center• Changed Laboratory Safety Committee to FESHCom	January 2011



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1.0 INTRODUCTION AND SCOPE

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 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.

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.

The requirements of this chapter apply to all operations at Fermilab as well as installation and operations in leased spaces.

2.0 DEFINITIONS

Cryogenic - at a temperature below -150° Celsius ($^{\circ}$ 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.

3.0 RESPONSIBILITIES

The Division/Section Head or Project Manager (D/S/P) who controls the area of operation of the system and the D/S/P 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 D/S/P staff asks 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.
- 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) maintain current safety documentation for each system in the D/S/P in a designated location.
 - (i) FESHM documentation requirements shall be met (e.g. Engineer Notes for Pressure Vessels, Piping, ODH).
 - (ii) Teamcenter shall be used for flow sheets (Piping and Instrument Diagrams), Valve-Instrument-and-Equipment Lists (VIE), and Technical Appendices 6.2, 6.3, and 6.4.
 - (iii) A designated location shall be used for any other safety documents. Teamcenter may be used.
 - (iv) An engineering process document management system shall be used to track and locate all documents associated with the review.

The ESH&Q Section shall audit the Divisions/Sections/Projects on their compliance to this chapter.

The Cryogenic Safety Subcommittee shall serve the D/S/P 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 (FESHCom) after consulting with the D/S/P Heads. 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 vessels and piping and ensure that this list is on file with the ESH&Q Section.

Each review panel is responsible for completing an accurate safety review in a timely and efficient manner. Upon completion, the panel shall inform the D/S/P(s), Division Safety Officer, D/S Direct Support Manager, and the chairperson of the Cryogenic Safety Subcommittee of its conclusions. This may occur through the process defined in FESHM 2005, *Operational Readiness Clearance (ORC)*. The review panel may recommend to the D/S/P Head(s) that the ORC process be established, such as when it is judged that additional safety aspects beyond the scope of FESHM 5032 are present and/or when additional subject matter expert review is desired.

4.0 PROGRAM DESCRIPTION

As specified by the scope, cryogenic systems within the scope of this chapter shall be reviewed in accordance with the D/S/P 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 FESHM 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 (FESHM 5031, 5031.5, 5031.6) and the outer vessel shall be considered a vacuum vessel (FESHM 5033).
 - (iii) For membrane cryostats, the provisions of FESHM 5031.7 shall be followed.
- d) The review shall verify that reliefs are in compliance with FESHM 5031.4, *Inspection and Testing of Relief Systems*. The review should consider how testing requirements will be met.

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 (FESHM 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" "Pressurized Gas Safety" "Lockout/Tagout Level 2", and "Compressed Gas Cylinder Safety" or their equivalents. Other courses, as described in FESHM 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.

5.0 REFERENCES

2060	Work Planning and Hazard Analysis
2070	Environment, Safety, Health, and Quality Training Program
2100	Fermilab Energy Control Program (Lockout/Tagout)
2005	Operational Readiness Clearance
4240	Oxygen Deficiency Hazards
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
5031.7	Membrane Cryostats
5032	Cryogenic System Review
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
5033.1	Vacuum Window
5034.1	Retesting Procedures for DOT Gas Storage Cylinders Including Tube Trailers
5034	Pressure Vessel Testing



6.0 TECHNICAL APPENDICES

6.1 CRYOGENIC SAFETY ANALYSIS PROCEDURE

Documentation shall 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 shall 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 shall be prepared. These devices would normally include valves, gages, transducers, brakes, pressure and temperature switches, and rupture disks. In the physical system installation, all of these devices shall 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 shall be prepared.

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 Operating procedure preparation shall include a description of the system design features for Lockout/Tagout (LOTO) and configuration control. Note the specific LOTO and configuration control procedures are outside the scope of this chapter and covered by FESHM 2100. However, the cryogenic system review shall review the design features of the system with respect to LOTO and configuration control for reasonably expected future maintenance and system upgrades. Examples of design features include:
 - Energy isolation (e.g. Can the instrument air supply for a fail-closed control valve be locked out and vented?)
 - De-energization (e.g. Are there suitable vent and drain valves that can be used to depressurize the system and prevent re-energization in the event of a leak?)
 - Verification (e.g. Can de-energization be verified using vents or pressure indicators/transducers?)



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

2.4 The qualification and training requirements of cryogenic personnel, beyond those required in this chapter, 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 6.2, *Failure Mode and Effects Analysis*.

3.2 A what-if analysis shall be performed. The recommended scope and method is described in Appendix 6.3, *What-If Analysis*.

3.3 A hazard analysis shall be performed. The recommended scope and method is described in Appendix 6.4, *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 chapters of FESHM are followed shall be prepared. Particular attention will be paid to those chapters of FESHM noted in paragraph 1.0 of this chapter.

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 listed in 5.0, REFERENCES.

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 per established procedure.



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) that have not been modified from the original equipment manufacturer's design.

7.1 A FMEA of the packaged system is not required. However, the What-If analysis is 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.

8.0 Exclusions: For commercial, packaged dilution refrigerator (DR) system (cooling power from Helium-3 and Helium-4 heat of mixing) that have not been modified from the original equipment manufacturer's design.

8.1 For a dry DR, see section 7.0 for exceptions concerning the cryogen-free precooling cryocooler portion. For a wet DR, normal rules apply for the liquid helium and/or liquid nitrogen precooling portion.

8.2 A FMEA of the packaged DR system is not required. However, the What-If analysis is required. The What-If analysis shall include response of valves in the event of power or cryocooler failure.

8.3 Flow sheets related to the DR cold circuit are not required. However, flow sheets and associated components list related to DR warm gas handling including all system reliefs, are required.

8.4 Sequences for valve activation under automatic control during cooldown, normal operation, mixture recovery/warmup and any other automated control scripts are required.



6.2 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 FESHM 5032, *Cryogenic System Review*.

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 Technical Appendices for What-If and Hazards Analysis).

See the worksheet in FESHM 5032, *Cryogenic System Review*.



6.3 WHAT-IF ANALYSIS

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 HAZARD ANALYSIS in Appendix 6.4).

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 HAZARD ANALYSIS

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 FESHM 5031, *Pressure Vessels*, where the hazard identified is over-pressurization of the vessel, and FESHM 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 and What-If Analyses. 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.