FERMILAB ENGINEERING MANUAL

Fermi National Accelerator Laboratory

Revision History

Author	Description of Change	Revision Date
Author	Initial release of the Fermilab Engineering Manual.	Month Year
P. Czarapata	1. Updates to the links in Footer and Engineering Risk Analysis Excel Worksheet.	May 2019
R. Crawford P. Czarapata A. Prosser C. Sylvester D. Wolff M. Wolter	1. Implemented a new layout. 2. Updated examples in the Appendix. 3. Updated the Engineering Risk Analysis worksheet & related section in the manual. 4. Added information pertaining to software in various chapters. 5. Eliminated the use of "Risk-Based Graded Approach", keeping everything with the term "Graded Approach" for better clarity.	October 2015
T. DiGrazia	1. Update two "Engineering Risk Analysis worksheet" links in the Risk Elements section of Chapter 2 to link to the actual worksheet rather than a screenshot of it within this document. 2. Updated the link in the footer from "Fermilab Website" which took you to the Policies and Forms page, to "FNAL Policies and Manuals Webpage" which now takes you to the Policies and Manuals page.	May 2019

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INTRODUCTION

Overview

Your engineering career at Fermi National Accelerator Laboratory (Fermilab) will test your skill at a number of levels. You will undertake routine design tasks, but you will also take on challenging projects at the cutting edge of technology. The engineering process can be dynamic and fluid at the laboratory, involving frequent interaction between you and those for whom you provide engineering services. The development of specifications can begin as a discussion between scientific staff and the individual engineer or engineers and can evolve into a formal, detailed request. It is your responsibility as a Fermilab engineer to make scientific dreams and what-ifs a reality by providing safe, cost-effective and reliable engineering designs.

Often you will work on projects alone with oversight and guidance provided by senior engineers or scientists. The lead engineer will determine the degree of oversight you will need using the graded approach. On other occasions you will do design work as a member of a team.

Management will ask you to participate in project reviews. You will be involved in internal design reviews and may take part in Department of Energy project reviews with formal presentations covering technical design cost and scheduling. You will usually inherit operational responsibility for your designs and will be asked to assist with problem-solving.

Purpose and Scope

This document provides guidance for properly executing and documenting engineering projects at Fermilab. Anyone undertaking a design effort at Fermilab, regardless of his or her job classification, must follow this document. The specific requirements included in each step of the engineering process differ for projects carrying different degrees of risk, expense or involvement by other departments and institutions. However, for each project, engineers go through the same procedure, an Engineering Risk Analysis, to determine those requirements. This manual explains that procedure. It is important that the Engineering Risk Analysis be completed correctly for all projects at each step as it determines the appropriate level of formality as a project moves forward. Examples in the Appendix demonstrate how Fermilab engineers have conducted more formal processes for past projects.

Engineers at Fermilab must consider quality assurance, potential Environment, Safety, Health & Quality (ESH&Q) issues, reviews and applicable codes and standards for every step in every project.

It is important to note that other processes, programs and manuals, such as the Department of Energy's Critical Decision Process; Fermilab Environment, Safety and Health Manual (FESHM); project management systems; and quality assurance programs, include additional requirements not stated in this manual. Managers will note these additional requirements in project specification.

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The authors of this manual believe that the fundamental engineering steps are the same for a project of any size or phase of development. You may need to repeat some of the process steps multiple times as your design matures.

The manual contains nine sections: Chapter 1: Requirements and Specifications explains the first step in the design process, which defines the objectives and requirements of the project; Chapter 2: Engineering Risk Analysis explains the process of determining the level of rigor required for documentation and review of an engineering project based on technical, cost and schedule risks; Chapter 3: Requirements, Specifications and Risk Analysis Reviews describes the process of reviewing the adequacy of the resulting specification; Chapter 4: System Design explains the steps of the design phase; Chapter 5: Engineering Design Review describes the required reviews the design must undergo; Chapter 6: Procurement and Implementation explains the process engineers follow to make their projects a reality; Chapter 7: Testing and Validation explains the process of verifying that the design meets the requirements; Chapter 8: Release to Operations describes the operating and maintenance documents the lead engineer must produce before the project is complete and becomes operational; and Chapter 9: Final Documentation describes the final documentation the lead engineer must create and archive in order to complete a project.

Responsibilities

This section defines the responsibilities of those involved in the engineering process. These definitions apply to all chapters of the Engineering Manual

Line Management - Responsibility for the quality and effectiveness of the design and engineering process at the laboratory lies primarily with line management. This is based on the same principles used in the Fermilab Safety Management Systems. Line management includes Division/Section/Center heads, their assistants, department heads and supervisors. Members of line management are responsible for adding additional requirements to the engineering process as they see fit to ensure the success and quality of projects executed under their supervision.

Project and System Managers - Project and system managers are responsible for ensuring that tasks are completed using good engineering and quality-control methods. These managers should be aware of the design and engineering process requirement outlined in this document and should verify that engineers fulfill these requirements. Project and system managers work with department heads and lead engineers to determine which projects require special design or safety reviews. They work with department heads in setting up those reviews. Project and system managers are ultimately responsible for system integration.

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Department Heads - The project manager divides some projects into multiple tasks and assigns them to different divisions or sections. When a project is divided, department heads are directly responsible for ensuring that the tasks assigned to their department are completed using good engineering and quality-control methods. In the event that the department head is unavailable, these responsibilities will fall on the lead engineer's supervisor. These managers should be aware of the design and engineering process requirements outlined in this document and should verify that engineers fulfill these requirements. Department heads are directly responsible for using the graded approach under the guidance of the Engineering Risk Analysis section to determine and implement the proper level of formality of a project. They are directly responsible for determining which projects should have special design and safety reviews. The project manager coordinates with the department heads to integrate the tasks.

Lead Engineers - Generally, any engineering effort defined by a set of specifications requires the participation of a lead engineer, the engineer responsible for ensuring that the design meets project specifications. The lead engineer has overall responsibility for the efforts of all engineers working on a single project. The lead engineer is responsible for organizing overall project documentation. He or she provides technical leadership and ensures that all engineering, including system integration, is performed according to the provisions of the Engineering Manual.

Engineers - Engineers are responsible for following the provisions of the Engineering Manual and for fulfilling any additional requirements established by their Division/Section/Center heads and departments. Engineers must ensure their subsystems comply with project specifications and all applicable standards and safety codes.

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SUMMARY OF ENGINEERING PROCESS

- Specifications
  - Must be approved by requester (Word file, email, or verbal)
  - Written down and controlled
- Engineering Risk Analysis
  - Must be approved by department head or lead engineer's supervisor
- Specifications Review (from Chapter 1)
  - Reviews conducted at the department level
  - Reviews can be formal or informal
  - Results of the review must be recorded
- System Design
  - Should include drawings, calculations, component specifications, software overview, etc.
- Engineering Design Review
  - Reviews conducted for the supervisor or department level
  - Reviews can be formal or informal
  - If requested, reviews may also be conducted for the Division/Section or the Project Manager
- Procurement
  - Document technical specifications needed for procured materials, parts and/or purchase requisitions
  - Document all vendor communications
- Implementation
  - Production schedules, delivery dates, progress reports, and QA tests of, parts and subcomponents should be documented
- Testing and Validation
  - Testing plan and results should be documented
    - Testing answers the question "Does the product meet the specifications?"
- Release to Operations
  - Documentation necessary before using the product
  - Any maintenance procedures must be documented and available
- Final Documentation
  - Collect all documentation from previous chapters
  - Create the final report
    - Include any possible lessons learned, safety reports, publications or other extra information

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Chapter 1 REQUIREMENTS AND SPECIFICATIONS

The purpose of this section is to describe the specification process, which defines the desired project result and enumerates the project requirements.

Engineering departments document their agreements with other organizations in the form of engineering specifications detailing the technical and project requirement of the system to be provided. Larger engineering projects with multiple subprojects require the project management to produce an engineering design project plan. This plan clearly defines the level of subproject subject to a separate Engineering Risk Analysis. Each identified subproject follows the chapters of this manual.

It is important to note that managers and project leaders may introduce additional requirements, such as further reviews or documentation, outside the technical specifications described in this manual. The lead engineer must fulfill these requirements during the implementation of the engineering project.

Engineering Specification

In the first step of the design project, the lead engineer prepares the engineering specification based on requirements from the project or system manager. In order to prepare the specification, the lead engineer must consider the elements listed below. For high-risk projects, as determined in Chapter 2: Engineering Risk Analysis, the specification document must include all elements.

- Scope of the work
- Project milestones
- Relevant codes and standards
- Relevant ESH&Q requirements
- Functional or design technical requirements
- Requirements for interfacing to external systems
- Acceptance criteria included or referenced
- Identification of those characteristics of the design that are crucial to the safe and proper functioning of the project
- Any special requests such as design reviews, DOE reviews or additional documentation requirements

The department head and lead engineer, following the guidance of the graded approach described in the Engineering Risk Analysis section, determine the level of formality the specification document needs. This may result in specification ranging from a simple e-mail message from the requester to a detailed document that is subject to the change-control process. Change control is the process that ensures design changes achieve the desired result without adversely affecting other aspects of the system.

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The department head and project management approve specifications before the lead engineer initiates the design. The department head and project management must agree upon changes to the specification. The lead engineer makes the specification accessible to project management and collaboration members throughout the project.

Appendix A includes example requirements and specifications from previous Fermilab projects. They range in complexity from e-mail correspondence to a more formal document, based on the graded approach applied to each project.

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Chapter 2 ENGINEERING RISK ANALYSIS

The purpose of this chapter is to define a graded approach for use in engineering projects. This process helps the lead engineer and department head evaluate project risks and determine the appropriate level of documentation and review a project needs. The project manager may add additional requirements, as defined in Chapter 1: Requirements and Specifications.

The lead engineer and department head complete the Engineering Risk Analysis as part of the specification process. Completion of the Engineering Risk Analysis is a way to quantify project risk early in a project. If a project carries a high level of risk, the engineer may need to perform further risk analysis based on guidelines from other governing organizations.

Risk Elements

Fifteen potential risk elements have been identified and should be evaluated for each project. These risk elements are defined in Table 2 and Table 3.

The department head and lead engineer determine the level of risk for each element and document it using the Engineering Risk Analysis worksheet. Using this worksheet will help make the Engineering Risk Analysis consistent throughout the lab. The department head and lead engineer can use the guidelines in this chapter to determine the overall level of risk and to highlight high-risk categories. This Engineering Risk Analysis applies to the engineering subproject at hand, not the overall project. A subproject is a self-contained engineering task, component or system that generally falls under the responsibility of a single department. Subprojects do not take on the risk level of the larger project.

The engineer should record risk analysis integer values in the Engineering Risk Analysis worksheet, shown in Table 4. The integer values 1 through 5 are defined as follows:

1. Low risk
2. Low to medium risk
3. Medium risk
4. Medium to high risk
5. High risk

Definitions of the risk levels are given below with criteria for risk levels 1, 3 and 5. Levels 2 and 4 are implied to fall between those provided.

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Engineering Risk Elements (A-G)

A: Technology

This defines the degree of technical complexity the Lead Engineer or engineering team will face in executing the project.

1. The project will use off-the-shelf technology.
3. Engineers will purchase and modify off-the-shelf technology.
5. The project will require the development of new technology.

B: Environmental Impact

This defines the potential level of environmental impact.

1. There will be no significant environmental impact.
3. The project may have some environmental impact, but will not require an environmental assessment, as determined by FESHM.
5. The project will require an environmental impact statement.

C: Vendor Issues

This defines the degree of complexity to be expected with vendors. Complicating factors may include long-lead-times and issues with vendor qualification and reliability.

1. Vendors could cause minor issues.
3. Vendors could cause manageable complications.
5. Vendor issues could result in significant schedule delays or cost overruns or could otherwise jeopardize the successful completion of the project.

D: Resource Availability

This defines the availability of internal and external resources to plan and execute the project.

1. Resources will be readily available.
3. Resources could be somewhat restricted.
5. The difficulty of obtaining resources puts the project schedule at high risk.

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E: Quality Requirements

This determines the effort required to achieve the quality level the customer assigns to the final product.

1. The quality requirements can be met easily with existing infrastructure.
3. The quality requirements are challenging but can be met with existing infrastructure.
5. The quality requirements are beyond the capability of existing infrastructure.

F: Safety

This defines the safety issues the project team will encounter while completing the project.

1. The project will require standard safety considerations.
3. The project will require increased diligence due to its location, the configuration of the product or the type of work required. This includes work requiring review according to FESHM.
5. The project will require very restrictive safety considerations. This includes work requiring review and personnel safety systems.

G: Manufacturing Complexity

This defines the degree of complexity to be expected when combining the elements of technology, operations and schedule in product manufacturing.

1. The manufacturing processes will be routine.
3. The project will require an existing technology that the manufacturer has not previously used.
5. The project will require new or complex manufacturing methods.

Project Risk Element (H-O)

H: Schedule

This defines how much time the Lead Engineer or engineering team will have to complete the project or subproject.

1. Time will be unlimited.
3. The schedule will be somewhat constrained.
5. The subproject will be on the overall project critical path and has no schedule contingency.

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I: Interfaces

This defines the risk associated with the complexity of integrating multiple subprojects.

1. One department at Fermilab will be involved with a standalone project.
3. Project success depends upon contributions from multiple departments at Fermilab.
5. Project success depends upon contributions from multiple institutions.

J: Experience/Capability

This defines the level of experience and capability project team members will have.

1. Only experts will participate.
3. A blend of experts and inexperienced personnel will participate.
5. Only inexperienced personnel will participate.

K: Regulatory Requirements

This identifies the degree to which oversight by governmental or other regulatory agencies will impact the project.

1. Regulatory agencies will have minor to no involvement.
3. The Department of Energy (DOE) will have direct regulatory involvement.
5. DOE, as well as other state or federal government agencies, will have regulatory involvement.

L: Project Funding

This defines the availability and approval status of project planning and execution funds.

1. A single source within Fermilab will fund the project.
3. A source outside of Fermilab will fund the project.
5. Multiple sources outside of Fermilab will fund the project.

M: Project Reporting Requirements

This indicates the level of reporting to the senior management the project requires.

1. Reports to senior management about the project will not be required.
3. The project will require quarterly performance reports.
5. The project will be highly visible. Top management or outside agencies will schedule visits and issue monthly performance reports.

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N: Public Impact

This indicates how much the project will affect the public or public opinion.

1. The public will not be affected.
3. The public may be somewhat affected and should be informed with news releases.
5. The project may have an impact on the public. The public should be involved through public forums and may participate in advisory councils.

O: Project Cost

This defines how much the project is projected to cost.

1. The project will be within the department operating budget.
3. The project will require divisional budget planning.
5. The project will require laboratory or DOE budget tracking and reporting.

Engineering Risk Analysis Worksheet

The lead engineer fills out the "Risk Elements" page in the Engineering Risk Analysis worksheet for his or her subproject. They will enter in the project name, the name of the lead engineer, the name of the individual who reviewed the analysis, and the date in the corresponding sections at the top of the page, shown in Table 1.

Table 1. Project Information on the Top of the Engineering Risk Analysis Worksheet.

	A	B	C	D	E	F
1		**Engineering Risk Analysis**				
2						
3	**Project:**	Sample				
4	**Lead Engineer:**	Sample				
5	**Reviewed By:**	Sample				
6	**Date:**	Sample				

Next, he/she will enter scores for each Engineering Risk Element (A-G) and each Project Risk Element (H-O), shown in Table 2 and Table 3, respectively.

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Table 2. Engineering Risk Elements Used for the Engineering Risk Analysis.

	Engineering Risk Elements
A	Technology
B	Environmental Impact
C	Vendor Issues
D	Resource Availability
E	Safety
F	Quality Requirements
G	Manufacturing Complexity

Table 3. Project Risk Elements Used for the Engineering Risk Analysis.

	Project Risk Elements
H	Schedule
I	Interfaces
J	Experience / Capability
K	Regulatory Requirements
L	Project Funding
M	Project Reporting Requirements
N	Public Impact
O	Project Cost

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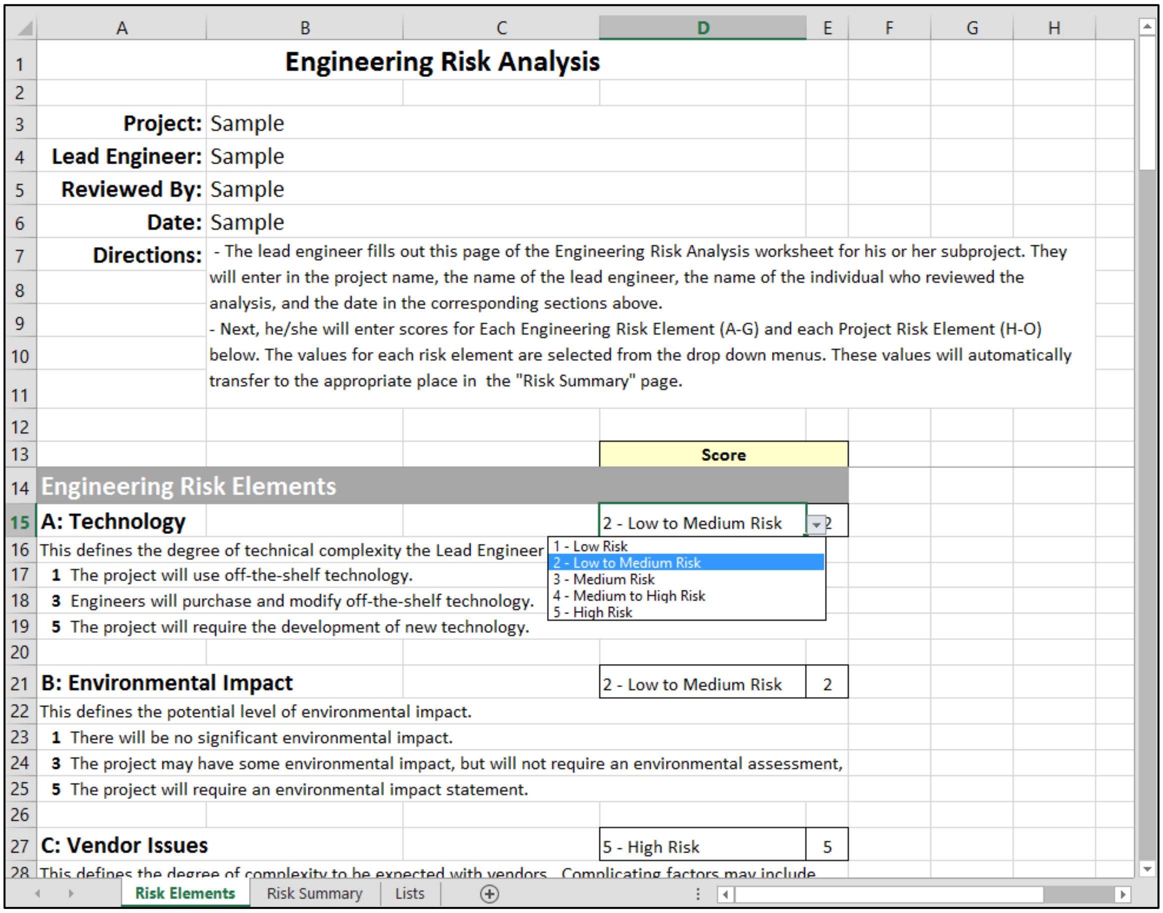
The values for each risk element are selected from the drop down menus, shown in Table 4.

Table 4. Entering Values in the Risk Elements Page of the Engineering Risk Analysis Worksheet.



Engineering Risk Analysis

Project:	Sample
Lead Engineer:	Sample
Reviewed By:	Sample
Date:	Sample
Directions:	- The lead engineer fills out this page of the Engineering Risk Analysis worksheet for his or her subproject. They will enter in the project name, the name of the lead engineer, the name of the individual who reviewed the analysis, and the date in the corresponding sections above. - Next, he/she will enter scores for Each Engineering Risk Element (A-G) and each Project Risk Element (H-O) below. The values for each risk element are selected from the drop down menus. These values will automatically transfer to the appropriate place in the "Risk Summary" page.

Engineering Risk Elements	Score	
A: Technology	2 - Low to Medium Risk	2
This defines the degree of technical complexity the Lead Engineer		
1 The project will use off-the-shelf technology.		
3 Engineers will purchase and modify off-the-shelf technology.		
5 The project will require the development of new technology.		
B: Environmental Impact	2 - Low to Medium Risk	2
This defines the potential level of environmental impact.		
1 There will be no significant environmental impact.		
3 The project may have some environmental impact, but will not require an environmental assessment,		
5 The project will require an environmental impact statement.		
C: Vendor Issues	5 - High Risk	5
This defines the degree of complexity to be expected with vendors. Complicating factors may include		

Drop-down list: 1 - Low Risk; 2 - Low to Medium Risk; 3 - Medium Risk; 4 - Medium to High Risk; 5 - High Risk

Sheet tabs: Risk Elements | Risk Summary | Lists

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The values from the "Risk Elements" page will automatically transfer to the appropriate place in the "Risk Summary" page, shown in Table 5.

Table 5. Risk Element Values in the Risk Summary Table of the Engineering Risk Analysis Worksheet.

	Chapter	Engineering Risk Element							High Risk if	Subtotal	High Risk?
		A	B	C	D	E	F	G			
1	Requirements and Specifications	2	2				3		≥ 10	7	no
3	Requirements, Specifications and Risk Analysis Review	2	2		4	3	3		≥ 16	14	no
4	System Design	2	2	5		3	3	4	≥ 19	19	YES
5	Engineering Design Review	2	2	5		3	3	4	≥ 19	19	YES
6	Procurement and Implementation		2		4	3	3	4	≥ 16	16	YES
7	Testing and Validation	2				3	3	4	≥ 13	12	no
8	Release to Operations						3		≥ 4	3	no
9	Final Documentation		2				3		≥ 7	5	no

Project Risk Element								High Risk if	Subtotal	High Risk?
H	I	J	K	L	M	N	O			
3	3	4	2	2	2	1	3	≥ 25	20	no

Interpreting the scores for the Engineering Risk Element (A-G) section:

- If the subproject has a risk score of five (5) in any area (indicated by a red background), it requires formal control as described within the indicated chapter.
- If the subtotal for one chapter is higher than the indicated "High Risk if" score (indicated by a red background in the "High Risk?" column), the topic covered in that chapter requires formal control.

Interpreting the scores for the Project Risk Element (H-O) section:

- If the subproject has a risk score of five (5) in any area (indicated by a red background), the project manager must be notified.
- If the subtotal is higher than the indicated "High Risk if" score of 25 (indicated by a red background in the "High Risk?" column), the project manager must be notified.
- The project manager may choose to elevate formal control requirements to address elevated Project Management Risk (H-O).

In the example used above, the engineer will use the high-risk control measures in Chapter 4: System Design and Chapter 5: Engineering Design Review because the Vendor Issues risk element has a rating of 5 and because the risk element subtotals for those chapters are high. In addition, the engineer will use the high-risk control measures in Chapter 6: Procurement and Implementation because the risk element subtotal for that chapter is high.

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Chapter 3 REQUIREMENTS, SPECIFICATIONS AND ENGINEERING RISK ANALYSIS REVIEWS

The purpose of this section is to describe the process for the requirements, specifications and Engineering Risk Analysis reviews. These reviews use a graded approach as determined by the department head and lead engineer following the guidance of the Engineering Risk Analysis. The project may require only an informal technical review within the engineering department. High-risk projects require formal technical reviews with subject-matter experts from outside the engineering department or laboratory.

Subsequent design reviews could result in changes to the requirements, which would necessitate an additional requirements, specifications and Engineering Risk Analysis reviews. Managers may call for reviews of the technical aspects or safety of entire systems or of individual components.

Review Documentation

The lead engineer ensures all requirements, specifications and Engineering Risk Analysis reviews are documented. Project documentation includes, at a minimum, a meeting summary describing who attended the review, what issues they discussed, what deficiencies they identified and what recommendations they made. The lead engineer provides a copy of the review results with proposed resolutions to the manager who called the review and files it with the project final documentation. The manager must accept the results of the review before the lead engineer can implement the proposed recommendations or action items. Any additional changes that may arise during implementation require reapproval by the manager.

The lead engineer and the department head determine the type and level of detail of review materials using the graded approach. When documenting a technical review, the lead engineer must consider the elements listed below. For high-risk projects, include all elements in the review documentation.

- Project description
- Project presenters
- Review date
- Review committee members
- Project specification document
- Review findings
- Review recommendations
- Action items

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Department Reviews

At the request of the department head, projects undergo department-based requirements, specifications and Engineering Risk Analysis reviews. The extent of a review depends on the complexity of the project as evaluated using the graded approach.

In consultation with the lead engineer and his or her supervisor, the department head selects engineers or subject-matter experts to serve as reviewers. The department head may also invite additional stakeholders. Reviewers may or may not be members of the same department. Smaller departments, for example, need to ask other departments to provide members.

The reviews focus on whether the requirements are complete and whether the proposed specifications fulfill the requirements.

Project Manager Reviews

Project management may decide to conduct special targeted requirements, specifications and Engineering Risk Analysis reviews for important subprojects or tasks. The project manager works with the department head responsible for a particular task to arrange these special reviews. Together they assemble the review team and establish the review schedule.

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Chapter 4 SYSTEM DESIGN

The purpose of this section is to describe the elements of the system design; which includes the design, document control, engineering calculations, engineering drawings, software, and hardware and interlock safety systems.

Document Numbering System

The local design drafting group and the lead engineer assign to a document a project, system and subsystem category number, as defined in Appendix C.

The laboratory plans to replace this system as Fermilab adopts a new electronic document management system. Historical document numbers will still be accessible through local document-control representatives. Historical documents that are ported to the new system will still be identifiable by the original document numbers.

The document numbering system applies only to mechanical and electrical documents created at the laboratory. See Appendix C, the Drawing Number Index and the CAD Standards for more information.

Engineering Calculations

Engineering calculations are an integral part of the engineering process. The rigor with which the engineer performs, checks and documents engineering calculations depends on a graded approach as determined by the department head and lead engineer following the guidance of the Engineering Risk Analysis. Some projects may require a calculation as simple as an analysis in a log book. High-risk projects require detailed calculations that are subject to review and the change-control process. Appendix C gives an example of a documented engineering calculation.

For informal engineering calculations, any format is generally acceptable. The engineer may document calculations in a lab notebook, on a computer spreadsheet or with specialized computer tools. Refer to Chapter 9: Final Documentation for project documentation archival requirements.

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Engineering calculations associated with high-risk projects must adhere to the following requirements:

- Engineers must document calculations with sufficient detail so that they are reproducible and peer-reviewable. The documentation should include the methodology, assumptions, input parameters and, if commercial software is used, the software version. If the engineer creates the code, the documentation should include the source code listing.
- Calculation results should be realistic and comparable to results from past experience. For complex analyses or those involving computer software, consider using simplified methods to validate the results.
- If the results of the calculations suggest a problem with the project design, the engineer may need to review or revise the engineering specification or Engineering Risk Analysis.
- The department head or project leader must review and approve calculations.
- As the laboratory moves toward electronic documentation, the lead engineer will need to scan all log books and other important paper documents into the documentation database.

Engineering Drawings

In creating or modifying an engineering drawing, the engineer must use applicable drafting standards and requirements, as described in the Fermilab Work Smart Set. The engineer must follow the proper procedure for assigning a drawing number and must track changes to each version of the drawing.

As engineers create or modify drawings, they may need to hold design reviews to validate progress and address any design, quality or safety concerns. Design iterations take place until the engineering drawings are completed.

The lead engineer ensures that a qualified person, other than the originator of the drawings, has properly reviewed and approved them. Engineers follow the procedures of their local design/drafting groups to create, review, approve and release drawings.

Software

This section covers software programs and computer configurations designed to operate experiments, tests, accelerator components and associated equipment. Examples include PLC logic, Field Programmable Gate Arrays and embedded software. Commercially purchased software not modified by Fermilab, such as CAD, e-mail, file storage, public displays, etc., is not included in this scope. Fermilab's Computer Security Policy regulates the use of computers in high-value systems, including personnel safety systems.

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Software design and documentation uses a graded approach as determined by the department head and lead engineer following the guidance of the Engineering Risk Analysis. Documentation as simple as inline comments may suffice for some projects. High-risk projects require detailed software documentation that is subject to the change-control process.

The purpose is to ensure that other personnel can review and maintain installed software. Three documents that help others to do this are the design note, operator instructions and system and software maintenance plans. Software projects that are assessed to be high-risk must include these elements in detail.

Software Design

Design documents describe the algorithms and data structures to be implemented to carry out the functions of the software or firmware. In addition, user interfaces and data collection features should be considered part of the design phase of software or firmware development. The level of detail in design documents must be such that review, development and maintenance tasks can be carried out successfully with the information to be obtained from these documents. Design features or parameters should demonstrably meet any system or module requirements.

Software Design Note

Engineers must prepare a design note describing all software. The note contains:

- System overview and requirements
- Interfacing information
- Primary code and configuration
  - a) Source code or backup code information
  - b) "Module" or program organization description
  - c) "Build and Boot" information, if applicable
  - d) A change-control plan including security
- System analysis, test results and design algorithms

Software for Interlock Safety Systems

Safety Interlocked Systems, or Interlocks, implemented in software have additional design requirements, which are spelled out in FESHM and in International Electrotechnical Commission (IEC) 61508, "Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems".

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Chapter 5 ENGINEERING DESIGN REVIEW

The purpose of this section is to describe the steps of the engineering design review process. Engineering design reviews use a graded approach as determined by the department head and lead engineer following the guidance of the Engineering Risk Analysis. The project may require only an informal technical review within the engineering department. High-risk projects require a formal technical review with subject-matter experts from outside the engineering department or laboratory. Reviews occur at various stages of the engineering process, such as prototyping, conceptual design, preliminary design and final design. Managers call for design reviews of the technical aspects or safety of entire systems or individual components.

Review Documentation

The lead engineer ensures that all design reviews are documented. Project documentation includes, at a minimum, a meeting summary describing who attended the review, what issues they discussed, what deficiencies they identified and what recommendations they made. The lead engineer provides a copy of the review results with proposed resolutions to the manager who called the review and files it with the project final documentation. The manager must accept the result of the review before the lead engineer can implement the proposed recommendations or action items. Any additional changes that may arise during implementation require reapproval by the manager.

For high-risk projects, include all the following elements in the review documentation:

- Project description
- Project presenters and their presentations
- Review date
- Project requirements
- Documents and calculations reviewed
- Procurement specifications
- Review findings
- Review recommendations
- Action items

The lead engineer returns review results that affect the project specification to the originator of the review for resolution. The engineer may need to ask for reapproval of the project requirements and specifications document.

The lead engineer and the department head coordinate the type and level of detail of review materials using the graded approach.

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Department Reviews

At the request of the department head, projects may have department-based technical or safety reviews. The extent of the review depends on the complexity of the project as evaluated using the graded approach.

For smaller projects, a single review may address both design and safety issues. Larger projects may require multiple reviews held over multiple sessions.

In consultation with the lead engineer and his or her supervisor, the department head selects engineers or subject-matter experts to serve as reviewers. The department head may also invite additional stakeholders. Reviewers may or may not be members of the same department. Smaller departments, for example, need to ask other departments to provide members.

The review focuses on the project's ability to meet specifications, ESH&Q requirements and good engineering practices. The department head and lead engineer jointly determine review content and detail.

Project Manager Reviews

Project management teams oversee progress and coordinate the project phases for all major projects at Fermilab. Project management may decide to conduct special targeted technical or safety reviews for important subprojects or tasks. The project manager works with the department head responsible for a particular task to arrange these special reviews. Together they assemble the review team and establish the review schedule. They also establish the required documentation. The lead engineer must provide this documentation to reviewers, allowing them ample time for study before the review.

Division/Section/Center Head Reviews

Division/Section/Center heads are responsible for all of the activities occurring in their areas. This includes the engineering efforts of their own personnel as well as any outside activities that affect their areas. Division/Section/Center heads may decide to conduct technical or safety reviews of any engineering project executed within their areas of responsibility. Project managers and the Division/Section/Center heads work with the department head responsible for the task in question to arrange these special reviews. Together they assemble the review team and establish the review schedule. They also establish the required documentation. The lead engineer must provide this documentation to reviewers, allowing them ample time for study before review.

Software Design Review

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Software/firmware engineers are responsible for organizing and conducting formal design reviews at a level commensurate with the designated quality assurance level. The results of design reviews should be documented and corrective actions should be identified and tracked to completion as appropriate. Once this process has been completed, responsible line management should authorize the process with signatures on the appropriate design flow tracking process documents.

Chapter 6 PROCUREMENT AND IMPLEMENTATION

The purpose of this section is to describe the steps of the procurement and implementation process. With appropriate approval, an engineer or member of the technical staff may procure materials, services, fabrication, and construction elements. The implementation process involves many elements of project management as they apply to an engineering project. Procurement and implementation processes together represent the realization of the project.

Procurement

Engineers should use a purchase requisition, which can include a list of suggested vendors, to initiate the procurement of goods or services. Purchases at a cost above the amount specified in the Fermilab Procurement Policy and Procedures Manual require competitive bids or sole-source justifications. Appendix E includes examples of completed sole-source justifications.

Technical personnel route purchase requisitions to the department administrative personnel and can assist in tracking the status of the procurement.

Technical personnel cannot directly solicit competitive quotes from vendors or enter into binding agreements on behalf of Fermilab. They must work with the Procurement Department of the Finance Section.

Procurement Department of the Business Services Section

The Procurement Department buys standard or off-the-shelf items and establishes service agreements for the maintenance of equipment. The department can assist in obtaining product availability information and information about vendors, including procurement history.

The Procurement Department contracts for items to be built to Fermilab design or performance specifications, including all construction projects. The Procurement Department also procures all services. The department offers assistance in the preparation of specifications and the review of specifications and drawings. Engineers should discuss fabrication issues with the Procurement Department. The Procurement Department should be included in resolving any problems with outside manufacturers or subcontractors.

Procurement Credit Cards

Laboratory management issues procurement credit cards, Procards, to a limited group of employees. They use Procards to buy most commercial goods and off-site services priced up to $2,500 per transaction. The Procurement Department restricts the purchase of some items with Procards. Fermilab encourages Procard use, as it accelerates the procurement process and minimizes paperwork. Administrative personnel know which cardholders can assist with purchasing for their departments.

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Communications to Vendors and Subcontractors

Engineers must keep records of all vendor and subcontractor communications. Refer to Fermilab's records-retention policy for additional information.

Procurement documentation may be as simple as a purchase requisition description. Other projects may require documented vendor communication and detailed, multipage specifications that are subject to the change-control process. Appendix E gives multiple examples of formal procurement specifications.

Task Management

The lead engineer requests the aid of qualified Fermilab task managers when employing workers in contracted trades. The lead engineer communicates special project requirements to the task managers and ensures that tasks are completed properly.

Technical Specifications for Procured Materials or Services

The lead engineer ensures that technical specifications are developed for items that require engineering, design, procurement or custom fabrication effort by outside vendors and contractors. The issuing department approves and controls the specifications.

The lead engineer retains specifications in a file accessible to project and collaboration members. For high-risk procurements, the lead engineer assigns an appropriate document number and record revision dates, keywords and authors. He or she also keeps a record of any change-control documents.

A procurement specification must include, at a minimum:

- Scope of the work
- Performance requirements
- Applicable codes and standards
- List of required submittals
- Quality-assurance plan
- Acceptable products or acceptable substitutions
- Expected execution of the specified product or service

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In addition, consider including the following items:
- Design approval
- Interface points
- Inspection and test requirements
- Installation requirements
- Documentation and training requirements
- Spare or replacement part requirements
- Safety and health plan
- Project management plan
- Warranty terms and conditions

The design review for high-risk projects must include technical specifications for procured materials or services.

Civil Construction Specifications

Civil construction specifications follow the Construction Specifications Institute's Master Specification Format numbering system.

The content of a civil construction specification must include, at a minimum:
- Scope of work
- Performance requirements
- List of required submittals
- Quality-assurance plan
- Acceptable products or acceptable substitutions
- Expected execution of the specified product or service

Appendix E includes several sample specifications, sole-source justifications, and bid evaluation sheets.

Implementation

In the implementation phase, the lead engineer is responsible for providing cost and schedule progress updates to project management. The department head and, for large projects, the project manager inform engineers of any additional requirements associated with project management.

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Listed below are actions that the lead engineer must complete during the project implementation.

- Track financial and personnel resources and ensure they are sufficient to meet the project schedule.
- Assess progress and discuss quality, safety and technical concerns at regular meetings with key personnel.
- Integrate changes resulting from design reviews.
- Track delivery dates and identify items critical to maintaining the schedule.
- Perform quality-assurance verification of delivered parts and subcomponents.
- Verify the requirements, connections and interfaces between the project and all external systems.
- Work with groups involved with or affected by the installation to reserve space and to coordinate work activities.
- Coordinate with support staff to ensure proper fabrication and installation of the project components.

For high-risk projects, the department head or project manager ensures that the lead engineer develops, reviews, approves, implements and controls implementation procedures. Implementation procedures include quality-assurance, fabrication, acceptance test plan, and assembly and installation procedures. In some cases, Fermilab or Division/Section/Center policy may require additional levels of approval for a particular procedure or set of procedures.

Software Development

The development is the process of writing and maintaining the source code for software or firmware that will implement the functionality described in the design engineering process. The development of the code may include the use of software or firmware tools, such as integrated design environments, that facilitate the activities of the engineer. When used, the configuration and version information of these tools should be recorded as part of the process documentation.

Various levels of code may be produced in the process of implementing a design. For example, in firmware development, the process will likely include VHDL source code, intermediate synthesis and placement and routing files, and programming bit stream files. It is at the discretion of the engineer to determine whether these intermediate files are to be retained as part of the maintained code base. The high-level source code, such as VHDL or C, must be maintained under a suitable version control process. In addition, programming files or executable code should be under version control as well.

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Chapter 7 TESTING AND VALIDATION

The purpose of this section is to describe the testing and validation process. This process uses a graded approach as determined by the department head and lead engineer following the guidance of the Engineering Risk Analysis. Testing and validation demonstrate that the component or system satisfies the project requirements and component specifications. The lead engineer should use standard test methods from national standards organizations when available.

The lead engineer must consider taking the steps listed below to validate a device or system. For high-risk projects, include all steps in the testing process.

- Devise a strategy for testing the device or system.
- Document the testing plans, processes and procedures.
- Conduct the tests.
- Analyze the test results and compare them to system requirements.

The test documentation must include the following elements:

- Descriptive title and scope of the test
- Date of the test
- Designation of the last revision
- Name of the individual responsible for testing the system, updating the testing procedure, and documenting exceptions
- Description of the test plan, including a list of equipment and instruments required to conduct the test
- Brief description of the importance of the test and its intended use
- Test acceptance criteria
- Safety precautions and hazard analysis
- Environmental concerns and considerations
- Required instrumentation calibrations
- Calculations and analysis of test results

The test documentation may also include the following elements:

- Definitions of terminology
- Description of sampling procedures and data-logging
- Detailed description of testing procedures
- Environmental conditions, such as temperature, pressure and humidity, under which the test was conducted
- Any required concurrence of safety professionals
- Start-up checklists
- Accuracy, precision, systematic bias, repeatability, reproducibility and uncertainty of test results

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If the device or system meets requirements, the lead engineer should continue to the next step in the engineering process.

If the device or system fails to meet requirements, the lead engineer must conduct a special requirements and specifications review with those affected. He or she uses the review to determine the implications for the overall project and to determine the next course of action.

The lead engineer must include test methods, procedures and reports in the project's final documentation.

Software Testing and Validation

Testing and validation activities are necessary to confirm that a given software/firmware design meets the requirements of the project. These steps may apply to individual components as well as systems comprised of integrated components. A test plan should be produced to allow the identification of specific activities that will demonstrate that the requirements are met. The results of formal testing should be documented in a report that quantifies the test results.

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Chapter 8 RELEASE TO OPERATIONS

The purpose of this section is to describe the operating and maintenance documents the lead engineer must produce before the project is complete and becomes operational. This process uses a graded approach as determined by the department head and lead engineer following the guidance of the Engineering Risk Analysis.

Operating Documents

The department head and lead engineer determine which operating procedures are required. The lead engineer compiles any required operating procedures, which may be developed by vendors or by Fermilab project engineers. The lead engineer archives the documents, which the department head or designee then controls and distributes.

The operating procedures should describe steady-state and transient operating conditions.

Software Operator Instructions

Engineers provide operator instructions that are clear, succinct and readily available. The instructions must include:

- Functional descriptions of all operational modes
- Clear means to display operating status
- The location of default or custom operator settings, if applicable

Maintenance Documents

The department head and lead engineer determine which maintenance procedures are required. The lead engineer compiles any required maintenance procedures, which may be developed by vendors or by Fermilab project engineers. The lead engineer archives the documents, which the department head or designee then controls and distributes.

The maintenance procedures should include any required written lock-out tag-out (LOTO) or other ESH&Q procedures related to maintenance.

Consider the following items while preparing written LOTO procedures:

- An explanation of special precautions
- Checklists of steps to be taken and acknowledged in a prescribed order
- A description of normal and current conditions
- An explanation of the approval process for exceptions to or deviations from the procedure
- A determination of whether a controlled copy needs to be present during use

For additional information, read FESHM Chapter 2100, Fermilab Energy Control Program.

Software System and Maintenance Plans

Engineers should create maintenance plans that take into consideration:

- Source code or configuration comments in code or logic
- Comments wherever the functions of the software are not reasonable obvious to another programmer

Hardware and software tools should be maintainable for the life of the project. The lead engineer maintains code versions to allow others the ability to fall back to previous operating code should the new code present problems. The lead engineer and department head maintain software security to prevent unwarranted changes.

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Chapter 9 FINAL DOCUMENTATION

The purpose of this section is to describe the final documentation the lead engineer must create and control in order to complete a project. This process uses a graded approach as determined by the department head and lead engineer following the guidance of the Engineering Risk Analysis.

Project Documentation

The final documentation incorporates all documents required by this manual. These documents must be produced before archiving final documentation for the project. This must include the following documents:

- Project report
  - All projects require a final written Project Report
  - The detail of the report depends on the complexity of the project
  - The report consists of system diagrams, explanations of important technical decisions, and explanations of how to operate the system
  - The report includes an explanation of how the project interfaces with other systems, if applicable
- Copies of any published papers, technical memos, reports, etc.
- Lessons Learned
- All documents from prior steps in the process

Archiving and Control

The lead engineer stores engineering documents to allow future engineering teams to review the history of a project.

A project might require formal archival and control of documentation within a Division/Section/Center or within an overall project document management system. In other cases, archiving may be as simple as saving the project documents to a lab Server. Whatever method used, it should be properly backed up and should allow for easy retrieval of the project documentation. Figure 1 shows an example of how to organize Lab Server folders by Engineering Manual Chapters for a given engineering project.

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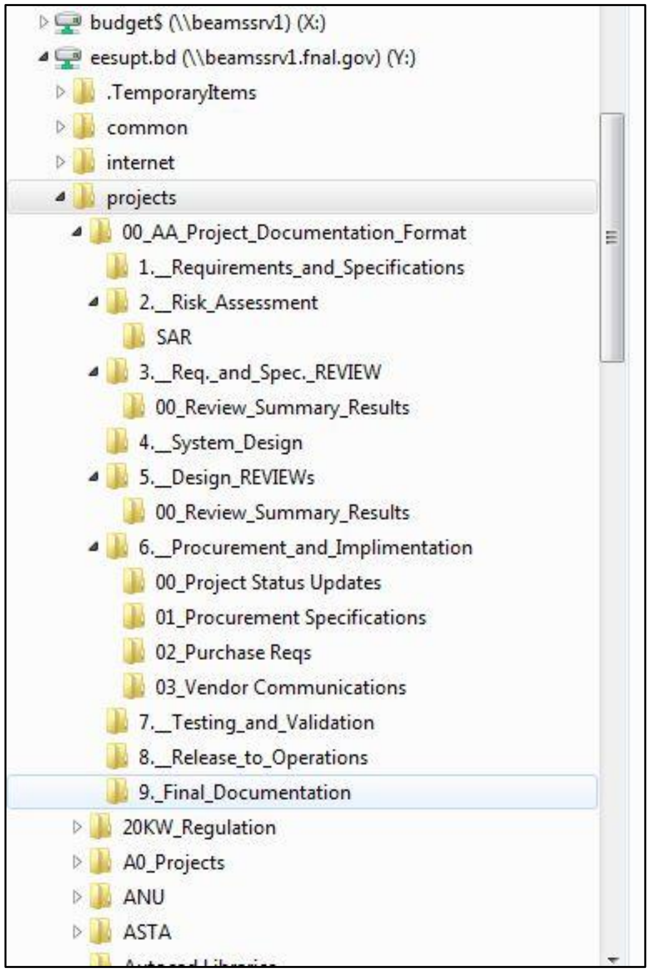

Figure 1. Example of Lab Server Folders to Organize Project Documentation.

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APPENDIX

This appendix includes several examples of documents required by the Fermilab Engineering Manual, organized by Manual chapter. The examples range from very simple, such as specifications approved via email, to very complex, such as full technical manuals. These examples are included here to act as a guide for future engineering projects.

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Appendix A: Chapter 1 Examples

HINS (2007)

The following is an example of requirements and specifications. The specifications were sent and approved via email.

Date sent: Fri, 30 Nov 2007 16:21:47 -0600
From: Iouri Terechkine <terechki@fnal.gov>
Subject: Re: HINS
To: wolff@fnal.gov

Hi, Dan.

1. Solenoid protection is OK except we use 500 V as hipot at 4.2 K and 1000 V at the room temperature. At 1 Ohm of the dump (which is OK), we can see more than 300 V in the coil.

2. HTS lead protection is probably sufficient - I do not have much experience here, but 1 mV means 4 micro-Ohm at 250 A and results in 0.25 W of energy deposition, that sounds OK.

3. You did not mention two dipole corrector windings that go with type 2 solenoids. Each corrector will require its own pair of leads, but they will be vapor-cooled leads. Maximal current level in correctors is 250 A. Protection of the correctors is similar to protection of the HTS leads, so as it was made by you for the HTS leads, superconducting coil protection circuit and copper lead protection circuit must be made.

4. Additional taps are required for the correctors, I guess: for each corrector two taps around each winding and two taps at the voltage supply level. (totally for both correctors 8 taps)

Greetings
Yuri

wolff@fnal.gov wrote:

\>CH Section Solenoids
\>
\>Current: 250 amps maximum UNIPOLAR (manually swap cables if
\>necessary
\> to reverse)
\>Inductance about 250 mH
\>Dump resistor: 1.0 ohms
\>Quench detection level: 1.0 volt
\>Quench detection delay: 100 ms
\>Hipot voltage: 300 volts
\>Current regulation and ripple: +/- 1%
\>
\>HTS lead protection:
\> HTS section detection level: +/- 1 mV absolute, 1 second
\> time constant
\> "Normal" section detection level: 3 micro-ohm to
\> 10 micro-ohm, 1 second time constant
\>
\>6 Load-taps are necessary for power supply and quench/lead protection
\> 2 on the super-conduction coil itself for voltage monitoring

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```
>       2 on the interface between the HTS leads and the "Normal"
>       section for voltage monitoring
>       2 high current connections for power supply (and lead monitoring)
>
>What do you think so far?
>
>
>On 29 Nov 2007 at 11:04, Iouri Terechkine wrote:
>
>
>>    Hi, Dan
>>    For the CH section of the front end, solenoids are self-protected.
>>This was checked by testing without using a dump resistor. Nevertheless,
>>we always try not to explore this feature too much because of  LHe
>>boiling out, possible thermal stress and quite high (although not yet
>>dangerous) voltage in the coil. The optimal dump resistor value is ~ 0.6
>>Ohm. Dissipated energy is not going to exceed ~ 5 kJ (~ 50 % of the
>>energy stored in the solenoid). So, although it is posssible not to use
>>dump resistors here, I would still prefer using them.
>>    In the next sections (SS-1) using a dump resistor (1.8 Ohm for the
>>SS-1)  will be a must because without it the voltage goes too high. For
>>SS-2 section the situation is even harder, and it is still to find out
>>what protection scheme to use for these solenoids.
>>    Greetings
>>    Yuri
>>
>>
>>wolff@fnal.gov wrote:
>>
>>>Yuri,
>>>
>>>The documentation you provided for the quench response for the HINS
>>>solenoids and dipoles does not explicitly state that dump resistors
>>>are NOT needed in the quench protection system.
>>>
>>>We are presently going on the assumption that dump resistors are NOT
>>>needed.
>>>
>>>Can you confirm this for us?
>>>
>>>Dan
```

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Recycler Kickers (2006)

The following is an example of requirements and specifications. The requirements are clearly laid out for each part of the kicker.

Specifications for the New Recycler Kickers
Paul Derwent AD/Recycler

Revised 10/24/06 9:36 AM

The following table lists the agreed specifications for the Recycler kicker systems. This specification will cover the Recycler injection kicker, Extraction kicker, Main Injector injection kicker, Recycler Abort and cleanup kicker.

Accelerator Physics Specifications

<u>Injection Kicker</u>

Kick Angle	1.015 mrad (0.301 kG-m integrated field), need bending the beam outside of the RR ring, B-field is up
Orientation	Horizontal
Locations	4.5865m ***before*** MRK104 (center of kick to marker)
Physical and field aperture	33 mm V x 81 mm H elliptical shape, minimum clear aperture (same as current Recycler kickers)
Field Flattop time	1.552 μs (82 52.809 MHz buckets)
Field Rise Time	38 ns maximum (2 buckets (1/52.809)) (82 bunches from Booster)
Field Fall time	38 ns maximum
Flattop ripple and tilt total	+/- 1%
Flattop repeatability	+/- 0.5% over 8 hours
Min Kick strength	
Circulating beam head/tail	+/- 1% of nominal
Kick overshoot/Undershoot	+/- 1% of nominal

Mechanical Requirements (Derived from Physics Specifications and Other constraints)

Physical beam line space	Distance to be determined
Vacuum	< 10^{-7} Torr, 6" Conflat flange, install bellows down stream end.
Ceramic Vacuum chamber	Same as existing RR kickers cross section
Power Supply & Cooling Location	MI 14 (**new building**)
Number of injection per cycle	12
Time between transfers	.067 seconds
Time between machine loads	1.33 seconds

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MiniBooNE Switch Magnet Extraction Power Supply (2002)

The following is an example of requirements and specifications. It is organized by system subpart.

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 Batavia, Illinois 60610-0500
March 4, 2002

MiniBooNE Switch Magnet Extraction Power Supply
Controls Specification

Power Supply Operating Summary:

MiniBooNE Switch

1.6 kamp
450 - 500 volts
~20 kwatts
16.7 ms, ½ sinewave pulse (30Hz Nominal)
15 Hz max. rep. rate
Charge recovery accomplished by flipping Cap
Single cap bank
NO parallel SCR switches
2, series SCRs per switch (to implement cap flip)
1 quad 500MCM cable connecting load
 1,000MCM to tunel – 1,000MCM from tunel

Miscellaneous Notes:

1. All trips and faults shall be latched.
2. Reset pulses shall not override trip or fault conditions.
3. Circuits for sensing relay contacts shall use ***24 volts*** and draw at least ***15ma***.
4. Fault will always Inhibit HV power supplies, turn off HV of power supplies and drop the safety relay.

Interlocks and Safety:

Notes:
* Given the stored energy of this power supply, a written LOTO procedure shall be provided that describes how to safely enter the power supply for the purpose of repair or maintenance.
* Only a hard ground sticks will be provided to accomplish the final grounding of the capacitor bank.
* All 120VAC power will be derived from the 480VAC Disconnect/Transformer dedicated to the MiniBoone Extraction Pulser.
* All the below mentioned trips should generate a "Fault".

1. Door Interlocks – Single circuit for Switch Relay rack. Switch will be mounted on both the front door and rear door. Door circuits will be 24 volts DC.

2. Safety relays and discharge resistors. Relay mounted gravity safe. ***24V*** power for relay shall be derived directly from 480vac power. The auxiliary contacts on these relays shall be used to inhibit pulsing when the relays are in the de-energized (safe) state. The relays and resistors need to be mounted such that they can visually be inspected while executing the power supply LOTO procedure.

3. Accelerator Electrical Safety System Input

Provision for external Electrical Safety System interlock will be provided but NOT used.

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Analog Signals:

All analog signals shall have at least 100 KHZ bandwidth.

1. Cap Bank Terminal "A" to GND Voltage [100V/V]
2. Cap Bank Terminal "B" to GND Voltage [100V/V]
3. Cap Bank Terminal "A" to "B" Voltage [100V/V]
4. Magnet Current [200A/V]
5. Power Supply Voltage (3) Available locally only [100V/V]
6. Power Supply Current (3) Available locally only [5.0A/V]

DIGITAL STATUS BITS, TRIPS AND FAULTS:

C217 Status Bits

Bit 15 – Remote/Local
Status only.

Bit 14 – Pulser Door Interlock
Bit 13 – Pulser Over Current [Current > 1,600 Amps]
Bit 12 – Pulser Over Voltage [Voltage > 500 Volts]
Fault – Charging power supply should be tripped OFF and Inhibited. Shorting relay should be dropped.

Bir 11 – Pulser Fan
Status only Fan should be serviced at the next opportunity.

Bit 10 – Magnet Temperature [Temp > 147degF]
Fault – Charging power supply should be tripped OFF and Inhibited. Shorting relay should be dropped.

Bit 9 – SCR/IGBT Heat Sink Temp [Temp > 147degF]
Bit 8 – IGBT Fault [See IGBT Fault definition below]
Fault – Charging power supply should be tripped OFF and Inhibited. Shorting relay should be dropped. Lacal status bits show which of 4 caused the fault.

Bit 7 – PS #1 Summary Fault
Bit 6 – PS #2 Summary Fault
Bit 5 – PS #3 Summary Fault
See Lambda EMI Summary Fault definition below
Fault – Charging power supply should be tripped OFF and Inhibited. Shorting relay should be dropped. Indicates a power supply problem which will be locally displayed.

Bit 4 – Safety Relay Pulled In
Safety Relay Status, delay turn on until safety relay is pulled in.

Bit 3 – ESS
Reserved for Electrical Safety System.

Bit 2 – NO EOC (End of Charge) before Trigger
Bit 1 – MORE Than 15Hz Trigger
Fault – Charging power supply should be tripped OFF and Inhibited. Shorting relay should be dropped. Expect timeline problems.

Bit 0 – PS ON/OFF
Status only

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Lambda EMI Power Supply Summary Fault Definition:

:
a. PS Over Temp.
b. External Interlock (Not used at this time).
c. Load Fault - Indicates output overload, over-voltage, or open curcuit conditions.

IGBT Fault definition:
a. Over Current Trip Level - 380A min 560A Typ
b. Short Curcuit Trip Level – 500A min 840A Typ
c. Over Current Delay Time – 5usec
d. Over Temp Trip Level – 100 °C min, 110°C Typ, 120°C Max
e. Over Temp Reset Level - 85 °C min, 95°C Typ, 105°C Max
f. Supply Under Voltage Protection Trip Level – 11.5V min, 12.0V Typ, 12.5V Max
g. Supply Under Voltage Protection Reset Level – 12.5V Typ

Output Trip Summation

Two output drivers should be provided to indicate MiniBooNE Switch Magnet Extraction Power Supply health to the external world.

Regulation Requirements

The pulser will be under Voltage control. The pulse-to-pulse stability shall be within +/- 1.0 %. Provisions shall exist for switching to a local program controlled by a ten-turn pot.

Timing Signals

Firing Pulse: A firing pulse shall be provided external to the control system (FNAL time line generated pulse delayed from the MiniBooNE Cycle Reset. The control system will generate all other signals necessary to operate the system including recharge.
Maximum Rep Rare: A trigger inhibit shall be generated to lock out all other triggers for 66 msec after a trigger is accepted. If a trigger comes in during this period a fault shall be generated and latched.
Manual Trigger: A push button should be included to locally inject a trigger signal to test the system under local control.

Transient Recorders

Transient recording capability shall be provided for diagnostic purposes. At least 16 analog channels of sufficient bandwidth shall be captured in the event of a fault. The buffer size shall be capable of storing at least the last 2 power supply pulses.

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Main Injector Neutrino Upgrade concrete Reinforcement (2008)

The following is an example of requirements and specifications. It organizes the specifications by the different steps of the project.

Main Injector Neutrino Upgrade (MINU) 6-6-49

SECTION 03200

CONCRETE REINFORCEMENT

PART 1 GENERAL

1.01 SECTION INCLUDES

A. Reinforcing steel bars, welded wire fabric and accessories for cast-in-place concrete.

1.02 RELATED SECTIONS

A. Exhibit A - Section 12.0 - Submittals, Shop Drawings and Material Samples.

1.03 REFERENCE TO STANDARDS

A. ACI 301 - Structural Concrete for Buildings, latest edition.

B. ACI 318 - Building Code Requirements for Reinforced Concrete, latest edition.

C. ACI 315 - Details and Detailing of Concrete Reinforcement, latest edition.

D. ANSI/ASTM A82 - Cold Drawn Steel Wire for Concrete Reinforcement.

E. ANSI/ASTM A185 - Welded Steel Wire Fabric for Concrete Reinforcement.

F. ASTM A615 - Deformed and Plain Billet Steel Bars for Concrete Reinforcement.

G. AWS D12.1 - Welding Reinforcement Steel, Metal Inserts and Connections in Reinforced Concrete Construction.

H. ACI SP-66 - Detailing Manual.

I. CRSI MSP-1-86 - Manual of Standard Practice.

1.04 SUBMITTALS

A. Submit under the provisions of Exhibit A, Section 12.0 - Submittals, Shop Drawings and Material Samples.

B. Shop Drawings: Indicate bar sizes, lengths, splices, spacings, locations, and quantities of reinforcing steel and wire fabric, bending and cutting schedules, supporting and spacing devices and type of steel.

C. Manufacturer's Certificate: Certify that products meet or exceed specified requirements.

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1.05 QUALITY ASSURANCE

A. Perform Work in accordance with CRSI 63, 65 and Manual of Standard Practice, ACI 301, ACI 315, ACI 318 and ANSI/ASTM A185.

B. Maintain one copy of each document on site.

C. Submit certified copies of mill test report of reinforcement materials analysis, indicating physical and chemical analysis.

1.06 COORDINATION

A. Coordinate work with the Construction Coordinator.

B. Coordinate with placement of formwork, formed openings and other Work.

PART 2 PRODUCTS

2.01 REINFORCEMENT

A. Reinforcing Steel: ASTM A615, 60 ksi yield grade; deformed billet steel bars, unfinished.

B. Welded Steel Wire Fabric: ASTM A185 Plain Type; unfinished (Flat stock).

2.02 ACCESSORY MATERIALS

A. Tie Wire: Minimum 16 gage annealed type.

B. Chairs, Bolsters, Bar Supports, Spacers: Sized and shaped for strength and support of reinforcement during concrete placement conditions, including load bearing pad on bottom to prevent vapor barrier puncture.

C. Special Chairs, Bolsters, Bar Supports, Spacers Adjacent to Weather Exposed Concrete Surfaces: Plastic coated steel type; size and shape as required.

2.03 FABRICATION

A. Fabricate concrete reinforcing in accordance with CRSI Manual of Standard Practice, ACI 315, ACI 318 and ANSI/ASTM A185.

B. Locate reinforcing splices not indicated on drawings at point of minimum stress.

PART 3 EXECUTION

3.01 PLACEMENT

A. Place, support and secure reinforcement against displacement. Do not deviate from required position. Reinforcement shall be tied at a minimum of 50 percent of the bar intersections. Tack welding of reinforcing for maintaining position and welding of splices shall not be permitted.

B. Do not displace or damage vapor barrier.

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C. Accommodate placement of formed openings.

D. Conform to ACI 318 for concrete cover over reinforcement, unless noted otherwise on drawings.

E. Wall reinforcement shall not be placed in the work until one side of the wall forms has been erected, aligned and braced. As the wall reinforcement is placed, it shall be secured to the wall form with the proper clearance between the steel and forms.

F. Slab reinforcement shall be supported by manufactured steel bolsters only. Concrete brick may be permitted only in slab on grade or footing construction.

G. Where walls or other items are shown as built integrally with other sections, but are placed as separate pours, keys and dowels shall be provided. Dowels shall be same size and at same spacing as reinforcing, unless noted otherwise.

H. Provide 6 x 6 - W 2.9 x W 2.9 electrically welded wire fabric, ASTM A185 reinforcing (flat stock only) in all concrete slabs on ground unless shown otherwise.

I. Provide corner bars of same size and spacing as main reinforcement at all intersections and corners, unless noted otherwise.

J. Where openings occur in walls or slabs, and unless otherwise noted on the plans, provide two (2) #5 bars each face at all sides and extending at least 2 feet beyond corners and two (2) #5 bars each face at least 3 feet long diagonally across each re-entrant corner. Space 3" between bars.

K. The Subcontractor shall give sufficient notice to the Construction Coordinator for inspection of the reinforcing prior to the placement of the concrete.

L. The reinforcing for the concrete placement shall be completed before ordering concrete.

3.02 FIELD QUALITY CONTROL

A. Field inspection shall be performed in accordance with requirements set forth by the Construction Coordinator.

END OF SECTION 03200

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Appendix B: Chapter 3 Examples

NML Superfluid Cryogenic Plant Technical Specification Review (2010)

The following is an example of a charge for a technical specification review. It includes the review date, review panel and questions for the panel.

Appendix A

Charge to the NML Superfluid Cryogenic Plant Technical Specification Review Panel

Arkadiy Klebaner

February 10. 20010

Review date: February. 19, 2009

Review Place: Outfield, MW9, Fermilab

Review Panel: Joe Collins, Rich Stanek (Chair), Don Rhode, and Tom Peterson

Review Documents: Use this link to access review document on the web

The New Muon Lab (NML) facility is a test bed to measure the performance of superconducting radiofrequency (SRF) cavities in a cryomodule (CM). The facility houses a linear accelerator (linac), a multi-cavity Cryomodule Test Stand (CMTS) and a Horizontal Test Stand (HTS). The detailed NML Test Facility cryogenic functional requirements are presented in the NML Cryogenic Functional Performance Specification. The Accelerator Division Cryogenic Department is planning to procure a superfluid cryogenic plant. The plant in conjunction with the CTI-4000, recently acquired from SLAC, will provide cryogenic services to the NML facility.

Arkadiy Klebaner is calling this review to obtain an independent assessment of the NML Superfluid Cryogenic Plant Technical Specification and associated documentation readiness for effective procurement.

The reviewers are requested to provide their findings, recommendations and suggestions and to submit a written report to the project team within two weeks after the review. Your input will be used to finalize the specification and associated procurement documents.

Technical questions for the reviewers:

a. Are the specified key performance criteria consistent with the NML Cryogenic Functional Performance Specification? Specifically comment on capacities and operational constraints.

b. Is the specified scope of supply clear and concise?

c. Are the specified interface points explicitly sufficient? List any ambiguous, redundant, or incomplete interface points;

d. Are the specified technical performance requirements adequate, reasonable and achievable? Specifically comment on modes of operation, components mechanical and electrical performance requirement, and acceptance tests;

e. Is the list of mandatory design approvals adequate to assure cost effective procurement?

f. Are the specified QA requirements reasonable?

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g. Are the specified PM requirements reasonable?

h. Are the specified items to be included in the offer sufficient and reasonable;

i. List any ambiguous, redundant, excessive, and/or incomplete requirements?

j. Suggest cost reduction items;

k. Comment on the list of potential vendors;

l. Review the vendor selection criteria and determine if these criteria are appropriate for the task;

m. Review the RFP evaluation worksheet and determine if this approach is appropriate for the task;

n. Suggest areas of improvement.

Finally, the reviewers are invited to comment on any aspect of the technical specification and associated document they feel requires additional attention.

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Fermilab Main Injector Dipole Power Supply Design (1995)

The following is an example of a review write-up. It includes a list of reviewers, the purpose of the review, recommendations, and a summary of the review

Review of the Fermilab Main Injector Dipole Power Supply Design

2 November 1995

Reviewers:

John Budnick

Alexandr Kristalinski

Jan Ryk

Gerry Tool

Age Visser

Introduction

The Fermilab Main Injector (FMI) project will construct a new 150 GeV accelerator, and all required interconnections and interfaces to the existing accelerator complex, to replace the present Main Accelerator ring in support of the Fermilab High Energy Physics research program. The Fermilab Main Injector Dipole Power Supply system is a critical subsystem of the project. The design of this subsystem has been finalized and the next phase of the project is procurement of the equipment and components to build the system. The purpose of this review is to

1. evaluate whether the design is cost-effective (no direct review of the cost estimate)
2. determine if the design will satisfy the design requirements
3. determine if any significant R & D remains to be accomplished prior to commitment of funds to procure this equipment
4. evaluate whether the schedule appears realistic
5. identify any issues of concern to the review committee.

Review Procedure

Advance copies of review material were supplied to the reviewers by the Fermilab Accelerator Division E/E Support Department, and an interactive presentation with extensive discussion of the material was provided by the design engineers on 1 November 1995. In addition, a tour of the prototype power system and a typical building and facilities to be used for housing the equipment was conducted.

Review

The review was limited to the Main Injector Dipole Power Supplies and directly related parts of adjacent systems, such as feeder configuration and related aspects of the ac power distribution, ignoring the quadrupole power supplies and other magnet power systems. External control of the system was not reviewed.

The review committee was very impressed with the quality of the review material, the presentations and the state of the prototype system and its testing. The design engineers were very knowledgeable about the important issues to be addressed and have done a very thorough job of considering them during the design phase. Answers to questions from the reviewers indicated a high level of competence and experience in the design engineering team.

Definition of System Requirements and Specifications

The DC regulation, ripple and dynamic performance specifications appear reasonable as inferred from Main Ring operation. Although some uncertainty as to the true beam effects due to ripple current exists, the decision to conservatively allow "no more than the present Main Ring" seems wise in the absence of solid independent statements of requirements from accelerator physicists.

Design Suitability for Meeting the Requirements

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The design was guided by the operating experience gained from the existing Fermilab Main Ring power supply. The expected current regulation is at least equal to or better than that of the present system. We expect the serviceability and reliability of the Main Injector system to be much better than that of the present Main Ring equipment.

The choice of switchgear with a 600 A load disconnect, 1200 A vacuum circuit breaker (VCB), and solid state monitoring and protection system is sound.

Cost Effectiveness of the Design

Careful attention to the 12-pulse vs 24-pulse design choice appears to have been given early in the design phase, with the result that a lower cost and less complicated 12-pulse power supply was chosen. Cost effectiveness of the rectifier transformers is being considered in very close detail.

Equipment design and component ratings appear to be conservatively chosen without driving the cost up unnecessarily, while yielding high expected reliability.

Consideration was given to the reuse of existing components where appropriate. The review committee agrees that the choice of design and procurement method being used is appropriate.

State of the R & D Effort

Possible problem areas have been thoroughly investigated through simulation studies and rigorous tests on prototype equipment. Strong emphasis has been placed on reliability and maintainability. The ongoing effort to verify whether dry transformers may be used is well organized.

Schedule

Given that all major components for construction are readily obtainable and that a transformer procurement decision is made before January, 1997, we do not see any major schedule conflicts with the goal of initial power system operation with the magnet load by January, 1998.

Extension of the transformer type decision date past January, 1997 may lead to insufficient time to respecify, bid and obtain oil filled transformers if dry transformers are determined to be unsatisfactory. We believe this allows only 6 months to evaluate the suitability of dry transformers if the present overall schedule is to be maintained.

Outstanding Issues and Recommendations

The approach being taken of buying and testing a prototype pair of tranformers before committing to the dry transformer system seems appropriate. In addition, it is recommended that manufacturers and utility system users of distribution transfomers in this voltage class be contacted about their reliability and corona experience, since the corona problem should be unrelated to pulsed operation.

Section 17.1.10 of the Transformer Specification should include a specified discharge level not to be exceeded during the corona testing.

Any cost comparison made in the process of choosing between transformer types should include *all* lifetime maintenance and testing costs for both types over an expected payback period related to the choice. For example, if ongoing corona checking is going to be part of the dry transformer decision, then this must be costed alongside oil sampling and testing. Oil transformer maintenance costs need to be backed up with solid data representing the true cost of leak repair, faulty sensors and relays, and other costs unique to oil transformers.

It is recommended that a complete set of spare power supply transformers be purchased.

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The 4-bay disconnect switches at each of the Service Buildings are not needed in the power distribution scheme. They should be deleted from the design since they present a possible maintenance and failure item without providing any necessary function.

It is recommended that hipot levels during operation reflect the maximum levels that the equipment is expected to experience during operation. For example, the bus-to-bus voltage stress during operation may exceed 2300 V, so it is recommended that the preoperation hipot procedure for bus-to-bus reflect this level. All system components appear to be designed and proof tested after manufacture to support this philosophy.

Summary
The review committee was very impressed with the level of detailed attention that has been given to the requirements to design and procure a reliable, maintainable, cost effective Dipole Power Supply System. The quality of information provided and the expertise displayed by the presenters were first rate. The high quality of documentation already existing for this project made the review process run very smoothly.

We have not discovered any shortcomings in the Dipole Power Supply design that should negatively impact successful operation of the Main Injector. The design quality, expected reliability and ease of maintenance appear excellent. Satisfaction of electrical safety requirements have obviously been built into the design, but we assume safety considerations will be given further review by the Fermilab equipment safety review process.

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NML Superfluid Cryogenic Plant Technical Specification Review Report (2010)

The following is an example of a specifications review write-up. It includes a list of reviewers, specifications and technical questions & responses.

NML Superfluid Cryogenic Plant Technical Specification Review Report

Rich Stanek (Chair), Tom Peterson, Joe Collins, Don Rohde
February 25, 2010

A review of the documentation associated with the procurement of the NML Superfluid Cryogenic Plant was held on Friday February 19, 2010. Present were the following individuals:
Review Panel: Rich Stanek, Tom Peterson, Don Rohde and Kurt Mohr, Joe Collins and Bill Koncelik.
AD Cryo Dept: Arkadiy Klebaner, Jay Theilacker, and Alex Martinez.
The review meeting consisted of a general discussion of issues associated with this procurement, followed by a review of the Acquisition Plan, the Technical Questionnaire, and the Bid Evaluation Criteria Score Sheet. Finally, the Technical Specification was reviewed on a page by page basis and comments collected. The Panel then had the opportunity to answer specific questions contained in the Charge Letter (see Appendix A).

The strategy of the Project Team was to write a Performance Specification that allows vendors to use their standard components and processes as long as they meet the technical requirements. In addition, the Technical Specification lists the various codes (such as ASME BPV) and standards as well as Lab policies (such as the Fermilab ES&H Manual) that must be followed. The Project Team maintains control of the procurement action by requiring formal Design Reviews and meetings at various stages, inspection and hold points, detailed documentation and written approval from Fermilab on anything that is deemed a modification or exception. This procurement package was based on an Industrial Study for a new refrigerator system commissioned in 2006. The Panel agreed that this was a reasonable approach.

One important issue is that the load conditions have changed since the original Functional Requirements Specification (FRS) was written and approved, due to the changes in the Project X design. There are now requirements for CW operation as well as 650 MHz elliptical cavities and cryomodules. As stated below, the Panel recommends that the FRS be updated to reflect these changes. In addition, the procurement package should be structured to obtain proposals for:

- The Cold Box (including all turbo-machinery, controls, etc. as specified in this Technical Specification) plus the Warm Vacuum Compressors (WVC). This part of the proposal should include all the necessary components, instrumentation, interfaces, and "hooks" for the eventual incorporation of the temperature/capacity upgrade option (to 1.8K) so that the addition of another stage of cold compressors and turbines is "plug and play". It is assumed that the Warm Compressor System interface will also be defined by the SELLER in such a way as to allow the BUYER the ability to exercise this option choice or not.
- The temperature/capacity upgrade-**option** in the form of the actual turbine and cold compressor, both with their ancillary equipment and controls.
- The Warm Compressor System **option** including oil removal and gas management, as well as the interface and connection to the Cold Box.

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Functional Requirements Specification (FRS)

The Panel notes that the FRS was written and approved at a time before major changes to the design of Project X and the associated cryomodules were instituted. Specifically, changes such as Continuous Wave (CW) operation and the use of 650 MHz frequency cavities/cryomodules are not reflected in the FRS. There has also been a significant change to the available refrigeration in the NML Cryomodule Test Facility with the addition of the SLAC CTI-4000 coldbox. However, the change in available refrigeration does not affect this procurement in any way.

Throughout the review it was obvious that the Project Team took these changes into consideration and planned accordingly. The major impact of the changes is felt mostly in the Refrigeration Load design and the design of the Valve Box which are not part of this procurement. As long as the option for temperature/capacity upgrade is adequately accounted for, this can be done at a later date if necessary. For completeness and accuracy of the documentation, the Panel recommends that the FRS be modified to reflect the most current design requirements.

Acquisition Plan (AP)

The Panel comments that the timeline for this acquisition looks tight given the amount of work required by vendors to respond to the Request for Proposal (RFP). It is appropriate that the Lab's Procurement Staff has been involved since the beginning of this process and was represented at this Review. There was also discussion regarding whether it would be beneficial to limit the list of potential vendors to those that had actual recent experience with superfluid helium plants. However, the conclusion was that the requirements of this procurement and the evaluation process would be sufficient to assure that only technically competent vendors would be considered. Procurement will set the minimum criteria when it publishes the RFP on the Federal Business Opportunities website so as to discourage nonqualified vendors from slowing down the process with superfluous questions.

One specific recommendation

1. Scope of Work, Item 2. "Equipment (vacuum compression system, option for a warm compression system, gas management valves, oil removal system, refrigerator coldbox with three turbines and two cold compressors, local controls with PLCs and operator panels)." We suggest changing this wording to "...refrigerator coldbox with most likely three turbines and two cold compressors..."

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Technical Questionnaire (TQ)

There was discussion as to whether the TQ should be sent out with the RFP but returned sooner than the vendor Proposals in order to screen potential vendors. In the end, the decision was to have it returned with the Proposals as originally planned. It was noted that the TQ refers to the cryoplant as the PLANT while the TS used the term DEVICE. It was agreed that they would both use the terminology PLANT. The TQ will be modified to specifically allow and take credit for partnerships in which one of the partners has actual superfluid helium plant construction experience.

The Panel recommends the following:

1. Remove bullet 4.8 (Domestic Content Percentage) since this will be covered in the procurement Terms and Conditions and is not technical in nature.
2. Add a line asking if the vendor is ISO 9001 certified and if so, if they are prepared to provide a copy of their certification and their QA or policy manual. If they answer "Yes" they should be able to skip any QA related questions that you don't specifically want to see/record for other reasons.

Bid Evaluation Criteria Score Sheet (BECS)

The Bid Evaluation Criteria Score Sheet looks to be in good shape. Depending on the composition of the Evaluation Team, it may be necessary to create a dictionary or set of instructions to be used in evaluating the individual line items to assure a consistent scoring system across the Evaluation Team. The one area where the BECS may need additional strengthening is in evaluating the amount of subcontracting that is part of the Proposal with the idea that the main contractor should not just be an integrator of multiple subcontractors but also have the technical expertise to assure that the design is appropriate and the components work well together as a system. The Panel recommends the following weight factors:

A1 Technical Proposal 30%
A2 Relevant Capabilities and Experience 20%
A3 Management and Quality Assurance 10%
B Price Evaluation 40%

Specific recommendations include:

1. Eliminate one of the two lines "Site Proximity" or "Ease of Oversight" as they appear to be related to the same criteria.
2. Add a line to Technical Proposal for "Cold Box" in order to evaluate the integration aspects of the various components and the cold box physical arrangement.

The Panel also suggests that whoever is on the Evaluation Team fill out individual score sheets first, before coming together as a team to come to consensus. The Procurement Agent should also be part of this process to maintain awareness of the technical evaluation process and the issues it might raise.

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Technical Specification (TS)

The Technical Specification represents the requirements under which vendors should work to generate their proposals. In general, the layout of the TS is logical and should be easy for vendors to follow. The TS reflects the philosophy of the procurement action. Performance requirements are laid out, governing codes and standards are specified and the BUYER (Fermilab) is given full information about the proposal and the right of approval for any exceptions. The Project Team should assure that all acronyms (such as WPS, PQR, WQR and PMP) are defined somewhere in the document.

Specific recommendations, notes and items to consider include:

1. Change all references of DEVICE to PLANT to be consistent with the TQ.
2. Figure 1: The Warm Compressor System (WCS) is an option in this procurement and that should be reflected in this figure.
3. Section 5.1.1 (u): Include the word "limited" (along with "reasonable") in the description of the BUYER manpower available for installation, commissioning and acceptance tests.
4. Section 5.2: Add the words "Exceptions to this specification are not permitted except by written approval of the BUYER".
5. Section 6.3.3 NOTE: The Panel notes that this wording reflects only one cryomodule in CMTS when in fact there will be two test stands (one in cooldown/operation) and another one in installation or removal mode, so thermodynamically the statement is correct as it stands.
6. Section 6.3.10 and 6.3.11 should be combined.
7. Section 7 CONSIDER: Use headers to organize and indicate the sections of the requirements that pertain to specific components. It is not necessary to change the numbering system.
8. Section 7.3: This section deals with "upgradeability". These requirements need to be reviewed to assure that within the framework of what the vendor is providing the upgrades for future capacity and operating temperatures do not require cutting into the cold box or any substantial work (other than adding the turbo machinery components)
9. Section 7.5.7: The Panel recommends providing the vendor with more specific pressure drop information specifically on parts of the system that are not under the SELLER's control.
10. Section 7.5.8: The Panel recommends clarifying the Plant 2K output pressure requirement. The Panel believes there is a need for pressurized, subcooled 2 K helium.
11. Section 7.5.21 NOTE: The Panel notes that this requirement does not accommodate quick cooldown around 100K to minimize Q disease but that this is consistent with the FRS which does not require it.
12. Section 7.5.27 CONSIDER: Consider whether the ability to pump down the LINAC 2K circuit to operating pressure in less than 15 hours depends on the conductance of the load system and whether this needs to be specified.
13. Section 7.6 NOTE: There was discussion regarding further clarifying the requirement for the WVC to be rated for sub-atmospheric conditions and the wording has been changed accordingly.
14. Section 7.7.3 CONSIDER: Does the word "unusual" refer to "upset" conditions"?
15. Section 7.7.65: The Panel recommends reviewing the instrumentation requirements to assure that is there sufficient instrumentation to indicate when filters need to be changed.
16. Section 7.7.89: Change "absorbent" to "adsorbent".

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17. Section 7.10.40: Change Table 13 to reflect "BUYER Standard Components" as opposed to "Recommended Choice".
18. Section 9.1: The Panel questions whether all fabrication must be held up until all of this section receives BUYER approval. Review the design approval list to separate items for initial design approval from later fabrication approvals.
19. Section 9.1.5 (j): BUYER approval of shipping fixtures is not needed since the procurement is FOB Fermilab and shipping is the SELLER's responsibility.
20. Section 9.1.28: Replace "PM" with "Project Management"
21. Section 10.1.5: This section seems to contradict previous requirements for leak testing. Check for consistency and adjust the wording if necessary.
22. Section 11: The Panel recommends the following wording for Section 11

    11 SHIPPING

    11.1 GENERAL

    11.1.1 The **PLANT** shall be packed and shipped appropriately to avoid any damage during transit to the **BUYER**.

    11.2 SHIPPING PLAN

    11.2.1 The **SELLER** shall prepare and implement a shipping plan covering packaging and transportation of the **PLANT** and its components to the **BUYER'S** site.

    11.2.2 The Shipping Plan shall be reviewed by the **BUYER** before shipment.

    11.3 SHIPMENT

    11.3.1 The **SELLER** shall be responsible for all costs of packaging and shipment of the **PLANT** and its components to the **BUYER** site.

    11.3.2 The **SELLER** shall ship the **PLANT** and all its components DDP –Delivered Duty Paid (Fermilab Site – Batavia, IL, USA).
23. Section 16.1.1: Delete or move to QA section.
24. Section 18.2.3: Change "responsive to" to "consistent with the".
25. Section 18: After a thorough review by the Quality Assurance experts on the Panel, the recommendation is to modify Section 18 by adding the following:
    a. If the **SELLER** has a Quality system currently certified to ISO 9001 requirements, elements of the QAP may be satisfied by specific reference to appropriate policies or procedures as indicated below. BUYER may request copies of these procedures as a part of the QAP.
    b. Add wording to each applicable bullet point which allows for satisfying that requirement with the appropriate ISO 9001 policy or procedure certification
26. Section 21.4.2 and 21.5.1: Should be made consistent. Are they redundant?
27. Section 22.1.3: Work with the Procurement Officer to decide how much of this information is reasonable to expect. Delete requirement for what is not needed.
28. Provide an independent check of the accuracy of Table 14.

Although there are multiple recommendations for improvements to the Technical Specification many of these are minor adjustments and some are suggestions for the Project Team to consider. Overall, the Technical Specification is well written and should generate viable vendor proposals.

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Response to Specific Technical Questions

These questions were part of the Charge to the Review Panel. Answers here may in some cases be redundant with other recommendations listed above.

a. Are the specified key performance criteria consistent with the NML Cryogenic Functional Performance Specification? Specifically comment on capacities and operational constraints.

Response: The performance requirements are consistent with the FRS however the FRS should be modified to reflect the latest design parameters. There does not appear to be any particular new parameter that would change the required capacity or operational constraints that has not been accounted for in either the procurement scope or one of the options.

b. Is the specified scope of supply clear and concise?

Response: Yes, the scope of supply is clearly delineated in the specification.

c. Are the specified interface points explicitly sufficient? List any ambiguous, redundant, or incomplete interface points;

Response: Yes the specified interface points are explicit and sufficient to provide the necessary information to the vendor. The Panel has already recommended that it remain clear that safe shipping, installation and commissioning of the PLANT remains the full responsibility of the SELLER.

d. Are the specified technical performance requirements adequate, reasonable and achievable? Specifically comment on modes of operation, components mechanical and electrical performance requirement, and acceptance tests;

Response: There are a few comments which were discussed in the meeting:

a) Tables 2, 6, 7, 8, and 9 provide ranges of temperature and pressure for each helium circuit. It seems that the cycle designers at the vendor will need more information. For example, Table 6: Mode A - Linac at 2.0 K Interface Parameters, lists for 5-8K, a supply pressure of $.3 \leq P \leq 1.8$ MPa, a supply temperature of ≤ 5 K, a return pressure of $0.3 \leq P \leq 1.8$ MPa, and a return temperature of ≤ 8 K. No circuit pressure drop is provided, so this could mean that cycle designers must consider a supply pressure of 1.8 MPa and a return pressure of 0.3 MPa. This would also include a supply pressure of 0.3 MPa and almost no pressure drop, a return pressure of about 0.3 MPa. We agreed that an upper limit on flow resistance of the circuits will be provided to the vendor.

b) Plant 2 K output pressure needs clarification. It is likely that the system will require pressurized, subcooled 2 K helium for control of liquid level in the cryomodules by means of a valve at the feed box.

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e. Is the list of mandatory design approvals adequate to assure cost effective procurement?

Response: Yes the design approvals and scheduled reviews are adequate and consistent with sound engineering processes. During the design review process, it will be necessary to discuss in-depth the technical details of the PLANT and its thermodynamic processes to assure that the solution chosen by the SELLER meets all the technical requirements. The Project Team is well aware of this need and agrees with the approach.

It is recommended that the BUYER require digital pictures of the PLANT be taken during fabrication, collected and transmitted to the BUYER. This can be covered either in the wording of the Purchase Order or the Technical Specification.

f. Are the specified QA requirements reasonable?

Response: Yes, the specification has obviously been written with an eye toward Quality Assurance. Validation and verification have been written in with proper care and attention to critical stages of the construction. Insuring that the SELLER has an acceptable QAP means possible issues like suspect counterfeit parts should not be an issue. The requirements enforce good follow-up as well, including training, calibration, acceptance testing and long-term maintenance requirements.

We recommend that the SELLER be given the ability to use their ISO 9001 certification if they have it – both on the questionnaire and on the proof-of-quality sections as shown in our document markup.

We believe that the requirements set forth in this document and, in fact, this entire review process are a testament to the fact that the BUYER is looking to receive a quality product.

g. Are the specified PM requirements reasonable?

Response: The Project Management requirements appear reasonable. Requiring a detailed schedule with milestones and periodic written reports will assure that the BUYER is aware of any impending schedule issues. The list of drawings and documents required to be provided at each stage of the review process is very detailed. The requirement for hold and inspection points is a powerful QA tool and as required by the TS should be suggested by the SELLER and approved by the BUYER.

h. Are the specified items to be included in the offer sufficient and reasonable;

Response: Yes, from a procurement perspective, the specified items to be included in the offer are sufficient and reasonable.

i. List any ambiguous, redundant, excessive, and/or incomplete requirements?

Response: Notes from the discussion follow:

a. Paragraph 7.6.4 provided what appeared to be an excessive requirement: "The WVC shall be equipped with an appropriate oil removal system." Full oil removal at 1.2 atm discharge of the WVC seems potentially difficult due to the large volumetric flow rate at this low pressure. In the discussion the answer was that the vendor has options within the framework of

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"appropriate" oil removal; Fermilab will review and approve (or not) the vendor's oil removal plan. We agreed that Paragraph 7.6.4 may remain as is.

b. Paragraph 6.3.10, "The DEVICE'S cold compressor operation and performance depends on the buffer volume upon which it is pumping," will be combined with the following paragraph describing cold compressor pumped volumes.

c. The shipping fixture and plan are the Seller's responsibility and should not be approved by the Buyer.

d. Rather than calling out FESHM 5032 in the specification (13.1.7), the list provided in 19.2 "Design" and especially 19.2.2 provides the Seller with documentation requirements.

e. The list of items for initial design approval (9.1) prior to any fabrication was too restrictive, in that it included items which are not needed until late in the project. Arkadiy will review the design approval list 9.1 to separate items for initial design approval from later fabrication approvals.

f. How would the vendor use the rather complex table of information in Table 11? Which items are warm while others cold depends on our valve box design. The vendor is just supplying a refrigerator which makes 2 K refrigeration and thermal shield refrigeration into a test load in various modes. We agreed that it is acceptable to include the Table as background information for the vendor.

j. Suggest cost reduction items;

Response: Because the procurement is being done as a performance specification with very little hard specification for exact components, the SELLER should be able to tune the design choices to provide the best solution at the lowest competitive bid. One way to achieve cost reduction might be to ask vendors for their specific suggestions. It may be that there is some aspect of the procurement (such as the level of documentation required) that can be reduced without jeopardizing the final product.

k. Comment on the list of potential vendors;

Response: The list of potential vendors is adequate considering Fermi's knowledge of the market and response to the Fermilab RFI issued. Fermilab does not expect to receive any additional qualified vendors. Although, the RFP will be issued on the Federal Business Opportunity Web Site to again test this assumption.

l. Review the vendor selection criteria and determine if these criteria are appropriate for the task;

Response: The vendor selection criteria are appropriate for the task as long as the weight assigned to the cost is at least 40%.

m. Review the RFP evaluation worksheet and determine if this approach is appropriate for the task;

Response: The evaluation worksheet is appropriate for the task. We reviewed the evaluation worksheet and agreed on point assignments of 30 (technical proposal), 20 (relevant capabilities and

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experience), 10 (management and quality assurance), 40 (price). We agreed to add a cold box line in the technical proposal section to assess the vendor's proposal for cold box vacuum shell and external features.

n. **Suggest areas of improvement.**

Response: The most important area for improvement deals with the recommendation of revising the Functional Requirements Specification to match the latest requirements of Project X, tuning the Technical Specification to assure that the addition of an additional stage of cold compression and turbo expanders is "plug and play", and getting pricing options for both the Warm Compression System (WCS) and the additional turbines/cold compressors. In this way, we can choose the best package of equipment that fits within the budgeted funds.

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Appendix C: Chapter 4 Examples

NML Feed Box J-T Valve (PVJT) (2008)

The following is an example of engineering calculations. It is organized into different sections to show the initial conditions, variables, calculations and conclusions.

Fermi National Accelerator Laboratory ENGINEERING CALCULATIONS Worksheet	Calculation # xxxx-DC-xxxxxx Date: 11/25/2008 Rev.: A Page# 1of 3

TITLE:

NML Feed box J-T valve (PVJT)

PURPOSE:

To determine flow coefficient of the NML Feed Box J-T control valve. The valve will be used to control liquid helium level of superconducting RF cavities within up to three Type III Plus cryomodules cryogenic string.

REFERENCES:

1. TESLA TDR (http://tesla.desy.de/new_pages/TDR_CD/start.html)
2. Masoneilan Control Valve Sizing Handbook Bulletin OZ1000, Dresser Industries, Inc., July 2000
3. NIST Technical Note 1334
4. TESLA Cryomodule Operating Experience and Design Choices, J.G. Weisend II, presentation, Fermilab, October 22, 2001
5. Fermilab drawing 5520.320-ME-458097 ILCTA CRYOMODULE ONE AND FEEDBOX

INITIAL CONDITIONS and ASSUMPTIONS:

- Single Type III Plus cryomodule static heat load - 4 [W] (a)
- Single Type III Plus cryomodule dynamic heat load - 12 [W] (b)
- Cryomodule operating pressure – 1600 [Pa] (c)
- Single phase supply pressure – 228,402 [Pa] (d)
- Inlet temperature – 2.20 [K] (e)
- Maximum number of cryomodules – 3 (f)

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LIST of VARIABLES and UNITS:

- h_{fg} – latent heat of helium, [J/g]
- $\dot{m}$ – mass flow rate, [g/sec]
- C_v – valve flow coefficient, [-]
- C_f – 1, critical flow factor, [-]
- Y – expansion factor, [-]
- P_1 – upstream pressure, [Pa]
- P_2 – downstream pressure, [Pa]
- P_c – helium critical pressure, [Pa]
- ΔP_s – differential pressure to saturation, [Pa]
- ΔP – actual pressure drop, [Pa]
- T_1 – inlet temperature, [K]
- ρ_1 – inlet density, [g/cc]
- Q_{stat} – cryomodule static heat load, [W]
- Q_{dyn} – cryomodule dynamic heat load, [W]
- Q_{tot} – cryomodule total heat load, [W]
- Q_{max} – maximum heat load for all cryomodules, [W]
- X – Vapor fraction (Quality), [g/g]
- H_1 – inlet enthalpy, [J/g]
- N_{mod} – number of cryomodules, [-]

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CALCULATIONS:

1. *Helium properties and parameters*

P_1 = 228,402 [Pa] (1)

P_2 = 1600 [Pa] (2)

T_1 = 2.2 [K] (3)

$h_{fg}(P_1)$ = 23.349 [J/g] (4)

H_1 (P_1, T_1) = 4.560 [J/g] (5)

X = 0.16 [g/g] (6)

P_c = 219875 [Pa] (7)

ρ_1 = 0.150 [g/cc] (8)

2. *Cryomodule total heat load*

$Q_{tot} = Q_{stat} + Q_{dyn} = 4 + 12 = 16$ [W] (9)

3. *Maximum heat load*

$Q_{\max} = N_{\text{mod}} Q_{tot} = 3 \cdot 16 = 48$ [W] (10)

4. *Maximum required helium flow rate*

$\dot{m} = Q_{max}/(h_{fg}(1\text{-}X)) = 48/(23.349(1\text{-}0.16)) = 2.447$ [g/s] (11)

5. *Differential pressure to saturation*

$$\Delta P_s = P_1 - P_1\left(0.96 - 0.28\sqrt{\frac{P_1}{P_c}}\right) = 228{,}402 - 228{,}402\left(0.96 - 0.28\sqrt{\frac{228402}{219875}}\right) = \quad (12)$$

163,221 [Pa]

6. *Actual pressure drop*

$\Delta P = P_2 - P_1 = 228{,}402 - 1600 = 226{,}802$ [Pa] (13)

7. *Critical flow (cavitation or flashing) valve flow coefficient*

$$C_V = \frac{\dot{m}}{(0.757 C_f \sqrt{\rho_1 \Delta P_s})} = \frac{2.477}{\left(0.757 \cdot 1\sqrt{0.150 \cdot 163221}\right)} = 0.02 \quad (14)$$

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CONCLUSION: A control valve of Cv=0.02 is necessary to provide helium flow in support of up to 3 Type III Plus cryomodules operation.
Originator's Signature: ______________________________
Reviewer's Signature: ______________________________

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Document Numbering System

The following is an example of the Fermilab Document Numbering System. It explains the correct way to number a new document and references to various policies and standards.

DOCUMENT NUMBERING SYSTEM

The local design drafting group and the Lead Engineer will assign a project, system and sub-systems category number. The document numbering format currently used at the lab is:

AAAA.AAA-BB-CCCCCC

where

AAAA.AAA is the document category and subcategory number
BB is the document type and size
CCCCCC is the sequential document number

For example, a document number may be 8875.111-MD-422012.

<u>Document category</u>

8875.111-MD-422012

The first 4 characters make up the document category. The first two associate the document with a particular facility or major program. The second two generally indicate a system and subsystem. For more details, refer to http://bss.fnal.gov/techpubs/drawlist.html

Subcategory Number

8875.111-MD-422012

The second number denotes the sub-category number. Older drawings may not contain a document sub-category number. This number may be between one and six characters long. Typical sub-category numbers contain three characters.

See the System Design Appendix for a complete list of document category and sub-category numbers.

<u>Document type</u>

8875.111-MD-422012

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The third section of the document number describes the type of document being created. Typical document numbering that engineers use include:

Bn Printed Circuit Board, size n
artwork, master drawing, assembly drawing, outline drawing, parts list
for example: n = P, i.e., BP; PC board and front panel artwork

Mn Mechanical Drawing, size n (A to F)

En Electric Drawing, size n

Ln Layout Drawing, size n

P Parts list

ES Engineering Specifications, covering materials and processes

TS Technical Specification,
covering basic site and construction parameters, such as the site coordinate system

WL Wiring List

DC Design Calculations

See the System Design Appendix for a complete list of document types.

Sequential document number

8875.111-MD-422012

The sequential document number contains one to six characters.

The Fermilab Publications Office maintains the master list of document numbers. The Publications Office assigns blocks of numbers to representatives in the design/drafting groups within each Division/Section/Center.

An engineer requests numbers for documents from his or her local design/drafting groups.

ELECTRICAL REFERENCES

Drafting Standards for Schematics

Graphic symbols
for electrical and electronic diagrams
ANSI Y32.2-1975

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IEEE 315A-1986
for electrical wiring and layout diagrams
ANSI Y32.9
Drafting Standards for Mechanical Drawings

Dimensioning and tolerancing
ANSI Y14.5M-1982

FACILITIES ENGINEERING SERVICES SECTION REFERENCES

FESS Engineering Policy, Procedures and Standards

http://fess.fnal.gov/engineering/eng_proced.html

Policy Manual

http://fess.fnal.gov/engineering/PolicyManual.pdf

A/E Consultant Handbook

http://fess.fnal.gov/enginee ring/AEConsultantHandbook.pdf

Procedure Manual

http://fess.fnal.gov/engineering/FESSProcedureManual.pdf

GIS Standards

http://fess.fnal.gov/engineering/GISStandardsManual.pdf

CAD Standards Manual

http://fess.fnal.gov/engineering/CADStandardManual.pdf

MECHANICAL REFERENCES

IDEAS CAD Standards

http://www-cad/ideas/index.html

PPD Design and Drafting Standards

\\blue1\CAD\tce-config\Drafting Standards\PPD_DesDrft_Standards_021802.doc

ASME Y14.100-2004 Drafting Standards

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http://www.asme.org/

GENIUM Modern Drafting Practices and Standards Manual

\\fermi-cadsrv-1\ADMSTDM\Drafting Manual\TOC.pdf

Engineering Release and Engineering Change Order Processing Specifications

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Department Data Flow Documents

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\\blue1\CAD\tce-config\Value Stream Mapping\Visio-PPD Top Current 20080402.pdf

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Appendix D: Chapter 5 Examples

MTA C-Magnet Pulser (2007)

The following is an example of design review results from two reviews of the same project.

Results of MTA C-Magnet Pulser Design Review 1.
5/14/07

1. Write a better specification for power supply.
2. Do thermal calculations for maximum expected current and rep rate.
3. Find out how long the beam will be passing through the magnet.
4. Ask Carol for original magnet specification.
5. Draw a better block diagram for system.
6. Included # of cables, # of caps, etc.
7. Write a SAR (Safety Analysis Report).
8. Restate some items in the LOTO.
   "Use proper PPE"
   "Verify shorting wires are intact"
   Fix 120VAC portion of LOTO.
9. Make a list of control chassis modifications including the differences from George's MBEX system.
10. Sit down and discuss the Rep Rate Limiter requirements with Radiation Safety and Craig.
11. Build trigger intercept box to replace firing card method of pulse limiting.

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Results of MTA C-Magnet Pulser Design Review 2.
8/29/08

1. Do a heat run.
2. Make an estimate of power lost per pulse.
3. Add a ground fault detector (CT?).
4. Add monitor points for load voltage (voltage divider).
5. Attempt to measure long term stability.
6. Add mitigation ideas to SAR.
7. Cover up exposed 120VAC on Ross Relays.
8. Make some small changes to LOTO
   -120VAC is plug and cord
9. Lable 120VAC inside rack. Move control power supplies to rear of rack if possible.

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Appendix E: Chapter 6 Examples

VTS 2&3 Cryostats (2010)

The following is an example of technical requirements specifications for procurement. It includes the requirements, interfaces, design documentation, a list of references, and a list of reference drawings.

FERMILAB TD/T&I Department	**VTS 2&3 Cryostats** **Technical Requirements Specification**	**Doc. No. TID-N-248** **Rev. No. 1.1** **Date: 18-Jan-10** **Page** 1 **of** 14

FERMILAB
Technical Division
Test and Instrumentation Department

VTS 2&3 Cryostats

Technical Requirements Specification

Prepared by: *[signed copy in T&I Dept. Files]* Date: 1/20/10 Cosmore Sylvester, VTS 2&3 Project Engineer	**Organization** TD/T&I	**Extension** 4765
Reviewed by: *[signed copy in T&I Dept. Files]* Date: 1/20/10 Joe Ozelis, VCTF Area Leader	**Organization** TD/T&I	**Extension** 4319
Reviewed by: *[signed copy in T&I Dept. Files]* Date: 1/20/10 Roger Rabehl, VCTF Cryogenic Engineer	**Organization** TD/T&I	**Extension** 8855
Reviewed by: *[signed copy in T&I Dept. Files]* Date: 1/20/10 Barry Norris, Process Operations Group Leader	**Organization** TD/T&I	**Extension** 3672
Approved by: *[signed copy in T&I Dept. Files]* Date: 1/20/10 Camille Ginsburg, VTS 2&3 Project Manager	**Organization** TD/SRF	**Extension** 3901
Approved by: *[signed copy in T&I Dept. Files]* Date: 1/20/10 Ruben Carcagno, IB1 Test Area Upgrades Project Manager	**Organization** TD/T&I	**Extension** 3915

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Revision History

Revision	Date	Section No.	Revision Description
1.0	11/13/09	All	Initial Release
1.1	1/18/10	As noted in Committee response	Include comments from the Final Design Review Committee

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FERMILAB TD/T&I Department	VTS 2&3 Cryostats Technical Requirements Specification	Doc. No. TID-N-248 Rev. No. 1.1 Date: 18-Jan-10 Page 3 of 14

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FERMILAB TD/T&I Department	VTS 2&3 Cryostats Technical Requirements Specification	Doc. No. TID-N-248 Rev. No. 1.1 Date: 18-Jan-10 Page 4 of 14

1. SCOPE

The VTS-2 and VTS-3 Cryostat Technical Specification outlines the requirements for the design of up to two cryostat assemblies which are to be fabricated and delivered to Fermilab for use at the Vertical Cavity Test Facility (VCTF) located in Industrial Building 1 (IB1). Each assembly includes:

1.1. Vacuum-insulated ASME Code stamped stainless steel pressure vessel suitable for 2.0K helium service
1.2. Process Piping
1.3. Vacuum Vessel manufactured from stainless steel
1.4. Multilayer super-insulation (MLI)
1.5. Liquid Nitrogen cooled thermal shield assembly and piping
1.6. Internal and External Magnetic shields
1.7. Shipping Restraint
1.8. Control Valves
1.9. Top plate assembly, including internal radiation shield, LN2 Shield, baffles, and cavity support plate
1.10. Instrumentation (liquid level sensors, Cernox® RTDs, warm up heater, Platinum RTDs).

2. DEFINITIONS

2.1. In this specification the VTS2&3 Cryostat shall be referred to as the *DEVICE*.
2.2. *BUYER* refers to Fermilab
2.3. *SELLER* refers to designer/fabricator/supplier

3. APPLICABLE DOCUMENTS

The following documents shall be applied to the design, fabrication, assembly, and tests of the *DEVICE*.

3.1. Fermilab Environmental, Safety, and Health Manuals.
 3.1.1. Vacuum Vessel FESHM 5033
 3.1.2. Pressure Vessel FESHM 5031
 3.1.3. Process Piping – ANSI B31.3

3.2. Fermilab supplied Reference Drawings listed in Appendix 1, the Functional Requirements Specification [1], and Technical Requirements Specification (this document) for the *DEVICE*.

3.3. Industry and Society Documents
 3.3.1. Latest revision of ASME Boiler Pressure Vessel (BPV) Code that is available at the initiation of the vessel design
 3.3.2. Latest available revision of ANSI Process Piping, B31.3 Code that is available at the initiation of the vessel design
 3.3.3. Compressed Gas Association (CGA) Pressure Relief Device Standards

4. MATERIALS

4.1. All materials and components specified in the design of the *DEVICE* shall be new and suitable for the use for which they are intended.

4.2. Materials known to become brittle at cryogenic temperatures shall not be used for components that may see temperatures lower than -150°C during normal or accidental conditions.

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4.3. Materials to be used for pressure vessel components shall meet all requirements of Section VIII Division 1, of the ASME BPV Code.

4.4. Any material used in pressure piping components of the *DEVICE* shall conform to ASME/ANSI B31.3 material requirements for appropriate fluid service category and operating temperature range.

4.5. The material used for construction of the helium pressure vessel, top plates, valves, and for the vacuum vessel, must be either ANSI 304 or ANSI 316 stainless steel, unless otherwise noted on the Fermilab supplied drawings.

4.6. Any fittings, bends, miters, laps and branch connections of the *DEVICE* shall conform to ASME/ANSI B31.3 requirements for appropriate fluid service category.

4.7. Any flanges or blanks installed on the *DEVICE* shall conform to ASME/ANSI B31.3 requirements for appropriate fluid service category.

4.8. The external surfaces of the helium vessel, LN2 shield, and piping in the vacuum space shall be thermally isolated from each other by wrapping with alternate layers of aluminized Mylar and Reemay® polyester fabric or other suitable spacing material approved by *BUYER*. Use a 1 inch wide silver adhesive tape such as 3M Scotch Brand part number 850 or equivalent, to secure the above materials.

4.9. The base material for the reflectors must be coated with Aluminum (Al), on both sides, to a minimum thickness of 140 Å each side. Physical and mechanical properties as specified for the base material (polyester film) shall remain unchanged after the application of the coating. Reference Fermilab drawing number 0102-MA-294072, and specification 1620-ES-106605 for polyester and aluminized Mylar material properties.

4.10. Magnetic materials are not permitted in the assembly. To ensure that the area inside the vessel where cavities will be supported during testing is free from magnetic fields, the magnetic shielding must be designed and installed such that the residual magnetic field inside the cryostat starting at a depth of 42.69 inches from the top plate and continuing for the remainder of the lower section of the cryostat must be ≤ 10 mG at 2K, regardless of radial position within the magnetic shield volume.

5. REQUIREMENTS

5.1. General

5.1.1. The *DEVICE* shall be designed to support the test of Superconducting RF (SRF) Cavities of the type and configuration specified in the Functional Requirements Specification [1].

5.1.2. The *DEVICE* design shall be based on the existing and operational VTS-1 design, modified according to the specifications in this document. Appendix 1 provides a list of the "as-built" VTS-1 drawings, which are referenced in this document.

5.1.3. The *DEVICE* will be transported while in a horizontal position and will be installed upright. *SELLER* must make provisions in the design to ensure that no damage to the *DEVICE* occurs due to handling during transportation and installation.

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5.1.4. The main modifications to the design of the *DEVICE* with respect to the VTS-1 design are:

5.1.4.1. Testing aperture inner diameter increased from 24 inches to 34 inches.

5.1.4.2. Helium vessel length is increased for ease of liquid level control and for additional physical margin during tests with two (2) sets of vertically stacked 9-cell ILC style SRF cavities.

5.1.4.3. Increased trace tubing coverage on the LN2 shield to create a more uniform temperature profile around the LN2 shield.

5.1.4.4. Eliminated the JT Heat Exchanger.

5.1.4.5. Relocated the relief line from the top plate to a dedicated line on the cryostat vacuum flange to assure the integrity of the pressure relief system without the need for LOTO control.

5.1.4.6. Provide a method for inter-dewar LHe transfer as a way to reduce IB1 LHe inventory demands when operating multiple VTS.

5.1.4.7. Eliminated Phase separator and 5K thermal shield.

5.2. Dimensional Envelope

5.2.1. The outside diameter of the Vacuum vessel, plus external magnetic shield assembly must be ≤ 58 inches. Referring to drawing number 1670-ME-441631 for VTS-1, the length of the vacuum vessel must be increased by 18.562 inches. This produces an overall required length from the top flange to the crown of the dished head of 211.375 inches.

5.2.2. The installed *DEVICE* will be suspended from the Vacuum vessel flange in a vertical shaft located in the IB1 Test Facility at Fermilab. The concrete shaft diameter is 60 inches and the depth is 240 inches. Refer to sheet #2 of Fermilab drawing 10-1-198 for shaft construction details.

5.2.3. The *SELLER* must provide the design for the LN2 shield and piping which is located in the space between the helium vessel OD and the ID of the Vacuum vessel.

5.2.4. To accommodate the existing external radiation shielding lid, the height of protrusions (valve actuators, vacuum relief, vacuum valves, piping, etc.) from the vessel's cover plate must be limited to ≤ 26 inches, and all protrusions must lie within the circle described by the outside diameter of the vacuum vessel.

5.3. Helium Vessel

5.3.1. The internal maximum allowable working pressure (MAWP) is 65 psig surrounded by vacuum. This results in a differential pressure through the vessel shell of 80 psid.

5.3.2. The relief port connection to the helium vessel is 2-1/2 NPS schedule 40 stainless steel. *SELLER* must design the connection of this pipe to the shell of the helium vessel to be BPV Code compliant.

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5.3.3. The pumping line port connection to the helium vessel is 3 NPS schedule 40 stainless steel. *SELLER* must design the connection of this pipe to the shell of the helium vessel to be BPV Code compliant.

5.3.4. Referring to drawing number 1670-ME-441635 for VTS-1, the length of the new helium vessel must be increased by 15.5 inches. This produces an overall required depth from the top flange to the crown of the stainless steel dished head of 191.35 inches.

5.3.5. The helium vessel outside diameter is 36.50 inches. The required clear aperture of the helium vessel (inside the internal magnetic shield support tube) must be 34 inches.

5.3.6. The helium vessel must be designed to withstand a minimum pressure of 15 psid external, in addition to the specified requirements for internal pressure.

5.3.7. At least 30 layers of MLI are required on the helium vessel for the purpose of reducing heat flux in a loss-of-vacuum accident. Materials used for the MLI blanket are specified in section 4.8.

5.3.8. In addition to loads due to the internal pressure, the helium vessel flange will experience additional static loads which are transmitted via the top plate. This load must be accommodated in the vessel design. The estimated maximum load suspended from the helium vessel top plate is 5000 pounds.

5.4. Vacuum Vessel

5.4.1. The vacuum vessel shall be designed to ensure that the ASME Code allowable stresses for the material are not exceeded and to ensure that the vessel is stable (resistant to buckling).

5.4.2. The vacuum vessel shall be designed and built to comply with Fermilab Safety requirements. Fermilab's vacuum vessel standard FESHM 5033 specifies design to ASME code rules and ASME BPV Code allowable stresses. (An ASME Code stamp is not required but it is preferred).

5.4.3. The external pressure for buckling failure predicted by Finite Element Analysis (FEA), when used for shapes not specifically covered in the BPV Code, shall not be less than 3.5 times the MAWP.

5.4.4. In operation, the vacuum vessel will experience a maximum external pressure of 15 psid. The vessel must be designed for a minimum external MAWP of 15 psid. The design internal MAWP shall be 15 psig.

5.4.5. The weight of the entire assembly (helium vessel, top plate and instrumentation, LHe, cavities, internal radiation and magnetic shields, external magnetic shields, LN2 shield, MLI, internal piping, valves, actuators, etc.) will be supported by the top flange of the vacuum vessel. The flange must be designed to carry this load without exceeding the ASME BPV Code allowable stress for the flange material.

5.4.6. The suspended *DEVICE* will be supported by leveling mounts similar to Reid Tool Supply P/N TLE-35SS which are installed in the flange. Provisions must be made in the vacuum

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vessel flange for accepting up to six (6) leveling mounts equally spaced on the bolt circle diameter of the flange.

5.4.7. A penetration in the bottom head as shown on VTS-1 drawing number 1670-MD-441630 for a removable shipping restraint is acceptable.

5.4.8. *SELLER* must provide support for mounting the external magnetic shield assembly on the outside of the vacuum vessel. Shield support and the external shield assembly must be limited to a maximum diameter of 58 inches.

5.5. Thermal Shield

5.5.1. The helium vessel and helium piping are to be thermally shielded with a LN2-cooled shield made of copper. Trace piping which will contain LN2 should be thermally attached to the shield via soldering.

5.5.2. The 80K shield assembly must be covered with a minimum of 60 layers of MLI, yielding a total blanket thickness at least 1.0 inch.

5.5.3. The LN2 thermal shield tubing must be designed for a maximum allowable working pressure of 150 psig. All fittings used in this assembly must satisfy ANSI B31.3 Process piping standard for temperature and fluid service category.

5.6. Top Plate

5.6.1. The top plate assembly, which includes the top plate, pipe stubs and associated flanges, and is a major component of the *DEVICE,* must be designed to be compliant with the ASME BPV Code. Details regarding the size, number, and relative location of the penetrations required for instrumentation and vacuum connections from the LHe bath to room temperature connections are shown on drawing number 1670-MD-418344 Rev A. Drawing number 1670-MMD-418343 Rev A provides details of the weldment. These are offered as Preliminary Drawings that show the preferred layout of the penetrations and the *SELLER* must verify Code compliance of the final design.

5.6.2. The top plate must be designed for an internal maximum allowable working pressure (MAWP) of 65 psig.

5.6.3. In addition to load due to the internal pressure, the top plate will experience additional static loads due to vacuum and gravity loads. These loads must be accommodated in the design of the top plate. The estimated gravity load suspended from top plate is 4800 pounds.

5.6.4. In addition to the internal pressure and gravity loads, the top plate must be designed to withstand a minimum external pressure of 15 psid. This 15 psid load will be present at the same time as the gravity loads.

5.6.5. Each top plate must be U-stamped and registered with the National Board.

5.7. Pumping Line

5.7.1. The section of the pumping line that is housed in the *DEVICE* shall be sized to allow for operation at 2.0K with a maximum pressure drop of ΔP of 0.08 torr.

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5.7.2. The pumping line must fit in the space envelope between the helium vessel and LN2 shield assembly.

5.7.3. The centerline of the 3 NPS schedule 40 stainless steel pumping line port must be located 26.81 inches from the top surface of the helium vessel flange.

5.7.4. Position the top fill valve approximately 90 degrees relative to the pumping line inlet.

5.7.5. The vacuum jacket at the room temperature connection to the pumping line is 5 NPS schedule 10 stainless steel.

5.7.6. At least 30 layers of MLI are required on the pumping line piping.

5.8. Internal Tubing

5.8.1. The piping and valve scheme for VTS-1 is shown on drawing 1670-ME-441633. This scheme could be adopted for VTS2&3 after it is modified to reflect the elimination of the phase separator and the 5K shield which are in VTS-1.

5.8.2. Piping outside the geometric scope of the BPV Code shall be designed in accordance with the most recent version of the ASME B31.3 Process Piping Code.

5.8.3. Helium circuit piping in the vacuum space is to be of a non-magnetic, weldable 300 series stainless steel, with all joints in the insulating vacuum space manufactured by welding. Tubing and piping layouts must be designed to minimize thermal stresses on the connected components.

5.8.4. The piping material for the liquid nitrogen circuits must be a non-magnetic weldable stainless steel.

5.8.5. Penetrations on the helium vessel for tube or pipe connections are to be manufactured as suggested on Fermilab supplied reference drawing number 1670-ME-441635. *SELLER* has the responsibility to ensure that all installed penetrations are compliant with the ASME BPV Code.

5.8.6. The instrumentation tubing must have at least 36 inches of length from the low-temperature end to a LN2-cooled intercept, and another 36 inches of length from the LN2-cooled intercept to the 300K anchor.

5.9. Helium Control Valves

5.9.1. Two (2) low-temperature helium control valves are included in this assembly (item 4 in drawing 1670-ME-441634 for VTS-1). All valves used for this assembly must have a proven track record of reliable operation in similar use. Fermilab will provide the performance specification for these control valves.

5.9.2. Valve actuators shall be of pneumatic type with 4-20 mA controls interface. The valve plus actuator must fit in the height constraint given in section 5.2.4.

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5.9.3. The two control valves shall be installed as shown on drawing (1670-ME-441633 for VTS-1), with the bottom port at the helium vessel pressure and the side port at the helium supply pressure.

5.9.4. Valve assemblies must be manufactured from materials similar to those in the CV8 series (Angle pattern, P/N CV8-086-CWTR1E-CB) from CPC-Cryolab. The required port size for these valves is ¾ inch diameter tube.

5.10. Operating Parameters

5.10.1. The operating parameters of the *DEVICE* are presented in Table 1.

Table 1: Operating parameters of the *DEVICE*

Helium bath temperature	1.6K to 4.5K
Helium bath pressure at 2K	0.44 psia (23 Torr)
Helium supply flow rate	10 – 20 grams/sec.
Helium Supply Pressure	22 psia
Nitrogen Supply flow rate	3 grams/sec.
Nitrogen Supply pressure	45 – 50 psig
4K Helium bath pressure	18 psia (~1000 Torr)
LN2 Supply temperature	92K – 93K

5.11. Heat Leak Budget

5.11.1. The maximum *DEVICE* static heat leak budget is:

5.11.1.1. 120 Watts to 90K (LN2-cooled shield)
5.11.1.2. 10 Watts to 2.0/4.5K
5.11.1.3. 3.9 Watts for cryogenic control valves

5.12. Pressure Drop

5.12.1. Estimates regarding acceptable piping pressure drops in the various helium and nitrogen circuits will be provided to the *BUYER* after the final pipe routings has been determined. The pumping line pressure drop is given in section 5.7.

5.13. Instrumentation

5.13.1. Temperature Sensors

5.13.1.1. Cernox® and platinum RTD's (PT-100) from Lakeshore Cryotronics will be provided by Fermilab for installation in the piping assembly as shown on Fermilab drawing number 1670-MD-441708.

5.13.1.2. All temperature sensors shall be wired and measured using a 4-wire technique.

5.13.1.3. Sensors for measuring and monitoring the in-dewar conditions (temperature, liquid level, etc.) must be designed to be permanently housed inside the cryostat without interference with the day-to-day use of the *DEVICE*. Proposed designs for this

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feature must be approved by *BUYER* before it is adopted to ensure that the design does not interfere with the intended use of the *DEVICE*.

5.13.2. Pressure Sensing Lines

5.13.2.1. Pressure sensing lines shall be welded to sleeves to preserve the tubing cross section.

6. INTERFACES

6.1. Cryogenic Flow Schematic

The cryogenic flow schematic for the IB1 distribution system and for VTS2&3 is shown on drawings 1670-ME-460043 and 1670-ME-418338 (VTS-2 Simplified Flow Schematic).

6.2. Process Connections

The process connections to the cryostat assembly will be made as shown on the interface drawing 1670-MD-418339 Rev D. The location of the penetrations shown on this drawing must be maintained in order to ensure alignment with existing infrastructure.

6.3. Inter-dewar transfer

6.3.1. At the conclusion of testing in VTS-2&3 cryostats, the cold cryostat is isolated from the vacuum pumps. Warm helium gas is introduced into the pumping line, adding gas on top of the liquid bath and raising the pressure to above atmospheric. The warm cryostat to be cooled is connected to its helium return. The bottom fill valves (e.g., VTS-2 LCV-2930) of both cryostats and the intermediate isolation valves are opened. A continued supply of warm helium gas to the cold cryostat will push liquid helium from the bottom of the cold cryostat to the bottom of the warm cryostat. Refer to VTS 2 and VTS3 P&ID drawing number 1670-ME-428350 for details.

7. DESIGN DOCUMENTATION

7.1. All documents shall be submitted in English, using SI or “English” units and suitable for reproduction.

7.2. All mechanical and electrical drawings used to fabricate and test the cryostat assembly, shall become the property of Fermilab and must be delivered to Fermilab as part of the final documentation package.

7.3. The *SELLER* must provide complete sets of 2-D and 3-D CAD drawings in PDF format for the *DEVICE*. Drawings must be equivalent in scope and level of detail as the VTS-1 drawings provided in this specification for reference (Appendix 1).

7.4. The *SELLER* must provide a Design Report, including Design calculations (ASME code calculations, model and results of any FEA done in support of design, pressure drop calculations, or heat load calculations).

7.5. Results from the flow and pressure drop tests must be provided.

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7.6. A written summary of the results from room temperature tests conducted on the RTDs must be provided.

7.7. Results of the leak checking of components and the final leak check must be provided.

8. REFERENCES

[1] VTS 2&3 Functional Requirements Specification, TD-09-023, October 21, 2009

[2] Memorandum of Understanding between US Universities & Accelerator Laboratories and Indian Universities & Accelerator Laboratories concerning Collaboration on R&D for Various Accelerator Physics and High Energy Physics Projects, January 9, 2006

[3] ADDENDUM to [2] – Addendum III: "Fermilab and Indian Accelerator Laboratories Collaboration on High Intensity Proton Accelerator and SRF Infrastructure Development", February 10, 2009

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FERMILAB TD/T&I Department	VTS 2&3 Cryostats **Technical Requirements Specification**	**Doc. No. TID-N-248** **Rev. No. 1.1** **Date: 18-Jan-10** **Page** 13 **of** 14

9. APPENDIX 1: List of Reference Drawings

Drawing number	Rev	Description (lines 2 and 3 from drawing title block)
1670.000-MD-442932	A	Vertical Cryostat- Radiation Shield- Stainless Steel Disc
1670.000-MA-442933		Vertical Cryostat - Support Rod Boss- Radiation Shield
1670.000-MA-442934	A	Vertical Cryostat - Lug- Radiation Shield Cradle
1670.000-MB-442935	A	Vertical Cryostat - Radiation Shield- Polyethylene Disc
1670.000-MD-442936	B	Vertical Cryostat - Radiation Shield- Tie-down Plate
1670.000-MA-442937		Vertical Cryostat - Radiation Shield- Tie-down Rod
1670.000-MC-442938		Vertical Cryostat - Lead Shield- Basket Weldment
1670.000-MC-442939	A	Vertical Cryostat - Radiation Shield- stainless steel-polyethylene-lead
1670.000-MA-442940		Vertical Cryostat - Spider-Lead Shield Basket-type 1
1670.000-MA-442941		Vertical Cryostat - Spider-Lead Shield Basket-type 2
1670.000-MC-457193		Vertical Cryostat - Liner-II Weldment- Magnetic Shield
1670.000-MC-457194		Vertical Cryostat - Liner-II Tube Segment-Magnetic Shield
1670.000-MD-457195		Vertical Cryostat - liner flange-ii magnetic shield
1670.000-MC-457196		Vertical Cryostat - Ring-Magnetic Shield Liner-II tooling
1670.000-MB-457506		Vertical Cryostat - Modified Reducing CF-flange
1670.000-MA-457507		Vertical Cryostat - Modified CF-flange - Cavity Vacuum
1670.000-MD-457508	A	Vertical Cryostat - Cavity Vacuum Line- spool 2
1670.000-MB-457509		Vertical Cryostat – Flex Hose- Cavity Vacuum spool 2
1670.000-MC-457510	A	Vertical Cryostat - Cavity Vacuum Line- spool 3
1670.000-MD-441630	A	Vertical Cryostat - Main Assembly
1670.000-MD-441631		Vertical Cryostat - Vacuum Vessel Weldment
1670.000-ME-441632		Vertical Cryostat – 80K Shield- Shield Assembly
1670.000-ME-441633	A	Vertical Cryostat - Piping Details
1670.000-ME-441634	A	Vertical Cryostat - Vacuum Vessel Top plate- Weld details
1670.000-ME-441635	A	Vertical Cryostat - Helium Vessel- Weldment
1670.000-MD-441636	A	Vertical Cryostat - Helium Vessel- Top Flange
1670.000-MC-441637		Vertical Cryostat – 80K Shield Top Plate Assembly
1670.000-MC-441638		Vertical Cryostat – 80K Shield Top Plate
1670.000-MD-441639		Vertical Cryostat - Vacuum Vessel Top Flange Weldment
1670.000-MC-441640		Vertical Cryostat - Vacuum Vessel- Top Flange
1670.000-MB-441641		Vertical Cryostat - Shipping Support Nozzle
1670.000-MC-442199		Vertical Cryostat - Support Ring- Magnetic Shield
1670.000-MD-442339	A	Vertical Cryostat - Helium Vessel- Top Plate Weldment
1670.000-MC-442340		Vertical Cryostat - Rohacell Baffle- type-1
1670.000-MC-442341		Vertical Cryostat - Rohacell Baffle- type-2
1670.000-MC-442342		Vertical Cryostat - G-10 Baffle- type-1
1670.000-MC-442343		Vertical Cryostat- G-10 Baffle- type-2
1670.000-MB-457812		Vertical Cryostat – Radiation Shield-Polyethylene Disc type 2

This document is uncontrolled when printed. The current version is maintained on the T&I website.

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Drawing number	Rev	Description (lines 2 and 3 from drawing title block)
1670.000-ME-458228		Vertical Cryostat - Top Plate Insert Assembly
1670.000-MD-441708		Vertical Cryostat – Temperature Sensor Feed-through Details
1670.000-ME-304864		Stand 4 Feed Can – Piping Spool Details
0102-MA-294072		SSC Dipole magnet – MLI Blanket Spacer Material – Reemay® Superbond Polyester
1670.000-MD-460043		Cryogenic Infrastructure – Midway Kinney Pump P&ID
1670.000-MD-418338		VTS 2 - Simplified Flow Schematic
1670.000-MD-418339	D	Vertical Cryostat – VTS 2 - Preliminary Top Flange Interface
1670.000-ME-418350		VTS 2 and VTS 3 - P&ID
1670.000-MD-418343	A	VTS2 Top Plate - Weldment
1670.000-MD-418344	A	VTS2 Top Plate – Machining Details
10-1-198		IB1 Vertical Test Shafts 2 and 3 – Sections and Details, Sheet 3

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SMTF Type a/c Capacitor Specification (2004)

The following is an example of specifications for procurement. It includes separate mechanical and electrical specifications, along with a list of documents that should be included in the bid.

SMTF Type a/c Capacitor Specification

Fermi National Accelerator Laboratory
P.O. Box 500
Batavia IL 60510

SPECIFICATION # 9230-ES-438002

November 5, 2004

Prepared by:________________________. __________.
Howie Pfeffer, AD/EE Sup. Eng. (630) 840–4425 Date

Reviewed by:________________________. __________.
Chris Jensen, AD/EE Support Engineer Date

Approved by:________________________. __________.
Dan Wolff, AD/EE Support Department Head Date

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1. INTRODUCTION

This specification is for a modulating capacitor bank. This bank will be used to generate an AC voltage and current. The bank will have a 100% voltage reversal with immediate recharge, a period of approximately 6 ms and a repetition rate of 10 pulses per second. The capacitors will be bussed in parallel to form a 2000 μF bank. The capacitor bank will pass a 1600 A_{peak} current pulse in addition to its resonant discharge through a 330 μH inductor. The bank is labeled "bouncer" cap. C2 in Figure 1. The bank will additionally have occasional crowbar discharges where the bank is completely discharged in approximately 300 μs.

2. SCOPE

The vendor shall supply capacitors to satisfy the conditions of this specification. The vendor should insure that the individual capacitors comply with the National Electric Code and supply Material Safety Data Sheets on any required materials. Fermilab will bus the capacitors together to form a capacitor bank. The capacitors should not have internal discharge resistors.

3. ELECTRICAL SPECIFICATIONS

3.1 TOTAL BANK CAPACITANCE — 2000 μF ± 5%

The capacitor bank shall consist of no more than 16 capacitors. The capacitors shall only be combined in parallel.

3.2 OPERATING VOLTAGE

1.5 kV_{peak} AC Nominal
2.0 kV_{peak} AC Maximum

The capacitor shall be designed to be corona free in operation to 3 kV_{peak}.

3.3 DISCHARGE CURRENT (OPERATING)

3600 A_{peak} Nominal
560 A_{rms} Nominal
630 A_{rms} Maximum

Figure 2 shows nominal operating current and voltage waveforms.

3.4 PEAK DISCHARGE CURRENT (FAULT) — 13 kA_{peak} for the entire bank

If the crowbar SCR is fired to discharge the capacitor bank, the discharge current for the bank will be a 13 kA_{peak} pulse with a ~300 μs decay time constant.

This fault discharge will occur at a rate of:

1 per minute maximum
1000 per year maximum
10 000 per lifetime

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3.5 OPERATING LIFETIME (for the entire bank) — $4.5\ 10^9$ Nominal Cycles or 135,000 Hours Continuous

The capacitor shall be designed to operate for at least this lifetime with 90 % survivability under operation at the nominal conditions described in paragraphs 3.2 through 3.5.

3.6 DISSIPATION FACTOR — ≤ 0.3 % at ~120 Hz and 25 C)

3.7 EQUIVALENT SERIES INDUCTANCE — < 3 μH for entire bank

3.8 EQUIVALENT SERIES RESISTANCE — < 1.5 mΩ for entire bank at 167 Hz

3.9 LEAKAGE CURRENT (INSULATION RESISTANCE — < 20 μA per capacitor at 25 C and 2 kV > 100 MΩ per capacitor)

3.10 DIELECTRIC SYSTEM — Polypropylene and Dielectric Fluid or Paper/Polypropylene and Dielectric Fluid

If the volume of the dielectric fluid is more than 3 gallons per case, the use of less flammable liquids (ignition temperature > 300 C) for the dielectric fluid is requested. (National Electric Code, Article 460, Section 460-2(a))

4. MECHANICAL SPECIFICATIONS

4.1 STYLE

The capacitor shall have two bushings. Either terminal of the capacitor shall be able to operate at 2 kV with respect to the case and hold off 3 kV with respect to the case.

The capacitor shall have flanges for securing the capacitor in place and for providing a means for grounding the case. The flanges should be plated and not painted.

4.2 WEIGHT

The weight of each individual capacitor should be kept under approximately 100 pounds so that they may be easily handled in an enclosed space.

4.3 NAMEPLATE

A nameplate shall be permanently attached to each capacitor and display the following:
Capacitance
Maximum Working Voltage (2 kV_{peak})
Type of Dielectric Fluid
Type of Service (AC)
Serial Number or Date of Manufacture
Manufacturer's Name and Model Number

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5. ENVIRONMENTAL CONDITIONS

The capacitor shall meet all requirements of this specification when operating under the following environmental conditions:

AMBIENT TEMPERATURE	: 0 to 50 C
BAROMETRIC PRESSURE	: 28 to 31 inches of mercury
RELATIVE HUMIDITY	: 20 to 90%

6. BID SUBMITTALS

The following information shall be submitted with the bid:

Outline drawing of the capacitor
Estimated weight of the capacitor
Voltage stress on the dielectric
Estimated corona inception voltage
Dielectric system
Termination construction type

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SMTF Type a/c Capacitor Specification # 9230-ES-438002 November 5, 2004 5

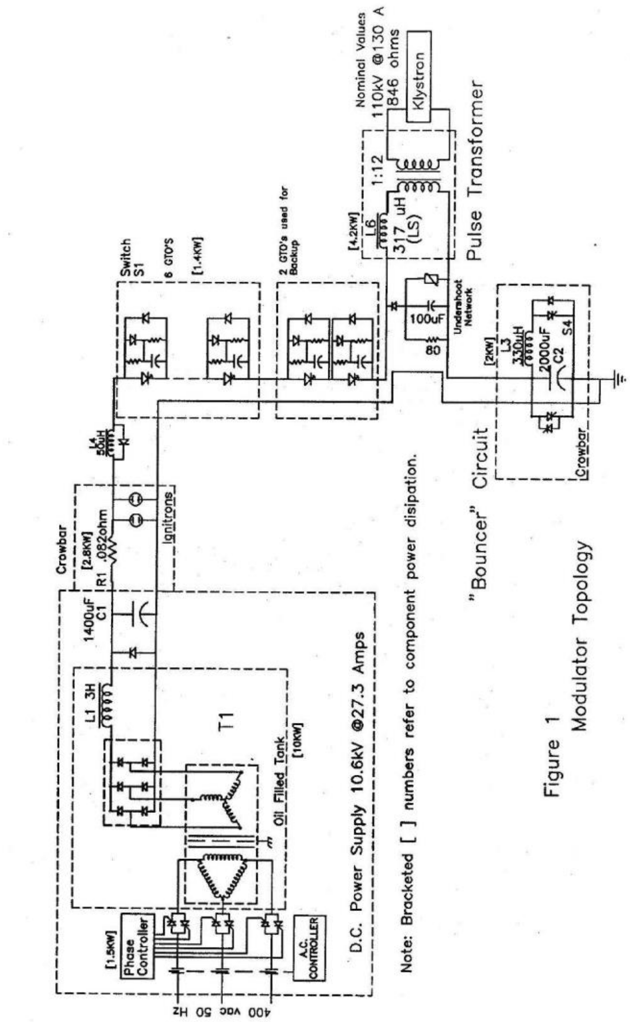

Figure 1
Modulator Topology

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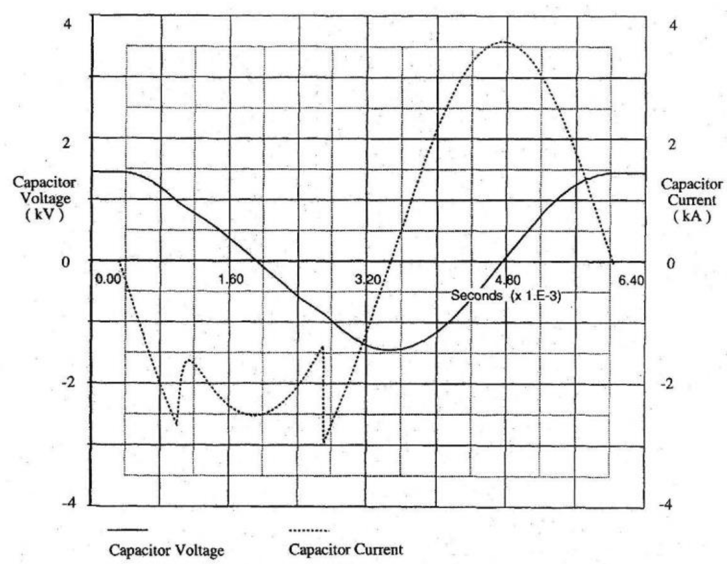

Figure 2, Capacitor Voltage and Current

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PBar Lithium Lens Silicon Controlled Rectifiers (2006)

The following is an example of specifications for procurement. It includes the specifications for the equipment and a list of potential bidders with their contact information.

Fermilab

PBAR LITHIUM LENS SILICON CONTROLLED RECTIFIERS

Specification #8000-ES-288333

Originators: D. Wolff/H. Pfeffer ___________________________DATE: 7/24/06

1. It (avg)	1kA min.
2. dI/dT (repetitive)	400A/µs min.
3. Itsm (10 ms sine) Vrm </= 10v, Tj = 125 ºC	17kA min.
4. VRRM, VDRM	2100 Volts min.
5. QRR – Tj = 125C dI/dt = 60A/µs, It = 1kA, Vr=50V	450 µC max.
6. I^2t (10 ms sine)	1.4E6 A^2t min
7. Gate trigger voltage, Vgt	4 V max.
8. Gate trigger current, Igt	350 ma max
7. Pole face size	47 mm +/- 2mm

D. Wolff/H. Pfeffer
Phone #630-840-4052/630-840-4425
Fax #630-840-2677
wolff@fnal.gov/pfeffer@fnal.gov

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Fermilab

BIDDERS LIST

ABB Semiconductors
575 Epsilon DR
Pittsburg PA, 15238
Phone #412-967-5858
Fax #412-967-5868

Wescode Semiconductor
320 Cherry Ave.
Long Beach, CA 90807
Phone #562-595-6971
Fax #562-595-8182

Powerex Inc
170 Pavilion Lane
Youngwood, PA 15697
Phone #724-925-7272

Eupec Inc.
Richardson Electronics
40W023 Keslinger RD
LaFox, IL 60147-0393
Phone #630-208-2200
Fax #630-208-2550

POSEICO
Contact: Darrick Schiebe
C&H Technology Inc.
6121 Baker Road
Phone 800-274-4284
952-933-6190
Fax 952-933-6223
Email darrick@chtechnology.com

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HINS Text Cryostat Cryogenic Distribution System (2007)

The following is an example of questionnaire sent out to potential bidders. It is used to evaluate their capabilities.

	CRYOGENICS	Doc. No.1650-ES-381345TQ Rev. No. 0 Date: February 27, 2007 Page 1 of 9

Technical Questionnaire

for

HINS Test Cryostat

Cryogenic Distribution System

Author(s):	Arkadiy Klebaner	Date:

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CRYOGENICS

Doc. No.1650-ES-381345TQ
Rev. No. 0
Date: February 27, 2007
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	CRYOGENICS	Doc. No.1650-ES-381345TQ Rev. No. 0 Date: February 27, 2007 Page 3 of 9

1. INTRODUCTION

This Technical Questionnaire will be used for technical evaluation of the HINS Test Cryostat Cryogenic Distribution System (CDS) proposal.

2. UPSTREAM BAYONET BOX (UBB)

2.1. Vacuum vessel

2.1.1. Dimensions without support [mm]:

2.1.1.1. Height:

2.1.1.2. Diameter:

2.1.2. Total weight [kg]:

2.1.3. Dimensions with support [mm]:

2.1.3.1. Height:

2.1.3.2. Diameter:

2.1.4. Briefly describe vacuum vessel. (Does the vessel consist of an all welded single piece design or multiple flanged sections).

2.1.5. Briefly describe a procedure for dismounting the vacuum vessel including necessary tools and equipment.

2.2. Cryogenic valves

2.2.1. List cryogenic control and check valves, including type, size, Cv and dimensions of the inlet and outlet pipes.

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2.2.2. Brief description of seals

2.2.3. Manufacturer of the valves:

2.2.4. Manufacturer of the actuator:

2.2.5. For pneumatic actuators list:

2.2.5.1. Required compressed air consumption [m3/hr]:

2.2.5.2. Required compressed air supply pressure [kPa]:

2.2.6. Briefly describe connection between bayonets and control valves:

3. TRANSFER LINE

3.1. Briefly describe support method and spiders for cryogenic lines:

3.2. How is the thermal contraction compensation achieved?

3.2.1. Are any bellows to be used (circle one): YES/NO

3.2.1.1. If YES, what type of bellows

3.2.1.2. If YES, bellows manufacturer:

3.3. Are there special elements (e.g. flexible hoses) that will be installed on the internal lines?

3.4. Expected heat leak [W]

80 K lines:

4.5 K lines:

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	CRYOGENICS	Doc. No.1650-ES-381345TQ Rev. No. 0 Date: February 27, 2007 Page 5 of 9

3.5. Include brief description of radiation shield.

3.6. How will the radiation shield be fixed to the support plate of the UBB?

4. DOWNSTREAM BAYONET BOX (DBB)

4.1. Vacuum vessel

4.1.1. Dimensions without support [mm]:

4.1.1.1. Height:

4.1.1.2. Diameter:

4.1.2. Total weight [kg]:

4.1.3. Dimensions with support [mm]:

4.1.3.1. Height:

4.1.3.2. Diameter:

4.1.4. Briefly describe vacuum vessel. (Does the vessel consist of an all welded single piece design or multiple flanged sections).

4.1.5. Briefly describe a procedure for dismounting the vacuum vessel including necessary tools and equipment.

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4.2. Cryogenic valves

4.2.1. List cryogenic control and check valves, including type, size, Cv and dimensions of the inlet and outlet pipes.

4.2.2. Brief description of seals

4.2.3. Manufacturer of the valves:

4.2.4. Manufacturer of the actuator:

4.2.5. For pneumatic actuators list:

4.2.5.1. Required compressed air consumption [m3/hr]:

4.2.5.2. Required compressed air supply pressure [kPa]:

4.2.6. Briefly describe connection between bayonets and control valves:

5. THERMAL INSULATION

5.1. Type of multi-layer insulation (MLI):

5.1.1. Aluminized foil

- Material:
- Film thickness:
- Embossed ? (circle one) YES/NO
- If YES, what is the diameter and spacing of dimples?

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- Perforated ?(circle one) YES/NO
- If YES, What is diameter and spacing of perforated holes:
- Single or two-sided coating:
- Thickness of the reflective coating:
- Manufacturer

5.1.2. Spacer

- Material:
- Type:
- Thickness of one layer:
- Number of spacers per one reflective foil:
- Manufacturer

5.2. What is the performance of the chosen MLI?

5.3. Briefly describe MLI application technique.

6. INSTRUMENTATION

6.1. Briefly describe the installation method for temperature sensors (including mounting and wiring technique; provide a sketch)

6.2. Briefly describe the installation method for pressure sensing lines (provide a sketch).

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	CRYOGENICS	Doc. No.1650-ES-381345TQ Rev. No. 0 Date: February 27, 2007 Page 8 of 9

7. TESTS

7.1. Briefly describe test program and test methods (use separate sheets as needed).

7.2. How will the flexible pieces be secured during the pressure test? (include sketches)

7.3. Briefly describe the shipping fixture (include sketches).

7.4. Will the UBB be shipped with internal shipping supports, which will need to be removed during installation?

7.5. Will the DBB be shipped with internal shipping supports, which will need to be removed during installation?

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7.6. How many pieces of the CDS will be delivered to FNAL:

8. OTHER

8.1. Describe how you will address ASME B31.3 or PED 97/23 Code compliance requirements

8.2. List any features in your offer which do not comply with the requirements of the **1650-ES-381345** specification:

8.3. A complete list of essential spare parts (if any) not included in the proposal for two years operation:

8.4. A complete list of deliverables provided by the *SELLER*:

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HINS Test Cryostat Cryogenic Distribution System (2009)

The following is an example of a complex technical specification document for procurement. It includes general requirements along with requirements for interfacing, construction, design, quality control and shipping.

Technical Specification
for
HINS Test Cryostat
Cryogenic Distribution System

1650 – ES – 381345

Revision 0

Author(s):	Arkadiy L. Klebaner	Date:
Reviewed by:	Jay C. Theilacker	Date:
Cryostat Interface:	Thomas H. Nicol	Date:
General layout:	Robert C. Webber	Date:
Approved by:	Giorgio Apollinari	Date:

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HINS CRYOGENICS 1650-ES-381345 Revision 0

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1. INTRODUCTION

Fermi National Accelerator Laboratory (FNAL) is in the process of building a research and development facility for test prototypes of the Single, Double and Triple spokes cavities with associated magnets built for the FNAL High Intensity Neutrino Source (HINS) and Project X. The facility is located at the Meson Detector Building (MDB) and will house a test system centered around the HINS Test Cryostat (TC).

The HINS TC will be used for Spoke cavities R&D studies, including Q versus accelerating gradient measurements, low power performance studies, optimization of a power coupler positioning, etc. The cryostat is sized to house a single dressed Spoke cavity with a focusing magnet. The dressed cavity will be cooled to 4.5 K by two-phase helium during testing. The TC consists of a vacuum vessel which houses an 80K thermal shield and a mechanical support system holding the helium vessel and a focusing magnet. The cryostat has a port for the vacuum line that pumps on the Spoke cavity. The cryostat is welded to a cradle, which is rigidly anchored to the floor. Cryogenic services are supplied to the TC from MDB cryogenic system via the HINS TC Cryogenic Distribution System (CDS).

The purpose of this document is to provide a performance specification for the HINS TC CDS, which includes Upstream Bayonet Box (UBB), Downstream Bayonet Box (DBB) and Transfer Line that connects the UBB and the DBB.

The company offering the *DEVICE* must have produced a similar device to that being tendered.

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2. DEFINITIONS

In this specification the CDS shall be referred to as the *DEVICE*, major elements from which the *DEVICE* is comprised shall be referred as *COMPONENTS*, the fabricator of the equipment shall be referred to as the *SELLER* and Fermi National Accelerator Laboratory shall be referred to as the *BUYER.*

3. DESCRIPTION OF WORK

3.1. The *SELLER* shall furnish all facilities, equipment, special tooling, consumables, and material, except where explicitly excluded in this specification, and perform all work and services necessary to engineer, design, fabricate, assemble, test and deliver to the *BUYER'S* site *COMPONENTS* of a fully functional *DEVICE*, in strict accordance with this specification and the appropriate drawings and parts list.

3.2. The *SELLER* shall provide a written step-by-step instruction for *COMPONENTS* assembly into a fully functional *DEVICE.*

3.3. The *SELLER* shall provide documentation as specified in **Section 12** of this specification.

3.4. All mechanical and electrical drawings used to fabricate the *DEVICE,* it *COMPONENTS* and shipping fixture shall become the property of the *BUYER.*

3.5. All special tooling shall become the property of the *BUYER.*

4. DRAWINGS, CODES AND DOCUMENTS

4.1. **Section 15** of this specification lists drawings and documents provided by the *BUYER.*

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4.2. Final *DEVICE* drawings shall be generated by the *SELLER* based on this specification and attachments hereto.

4.3. In the event of conflict between drawings, models and written specification, the written specification shall be the governing document.

4.4. In the event of incompleteness or error in *BUYER*-supplied drawings or models, the *SELLER* shall notify the *BUYER* to obtain design directives.

4.5. If the *SELLER* deems it necessary to observe additional governing codes and regulations, the *BUYER* shall be notified of this immediately.

4.6. The following list of codes, drawings and standards is to be applied to the design, fabrication, assembly and tests of the *DEVICE*:

- Cryogenic flow schematic, Fermilab drawing 4906.320 – LC – 458106
- HINS Transfer line, Fermilab drawing 5520.000 – ME – 458368
- Fermi bayonet detail, Fermilab drawing 1650 – MD – 257379
- West end expansion joint, Fermilab drawing 5520.000 – ME – 439944
- American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) or European Union (EU) Pressure Equipment Directive (PED) 97/23/CE latest Issue. The latest revision of Code shall be applied to the *DEVICE* at the time of the *DEVICE's* fabrication
- American National Standards Institute (ANSI) ASME Code for Process Piping, B31.3 2004 edition or EU PED 97/23/CE latest Issue. The latest revision of Codes shall be applied to a given *DEVICE* at the time of the *DEVICE's* fabrication
- Standards of the Expansion Joint Manufacturers Association (EJMA), eighth edition 2003
- Compressed Gas Association (CGA) Pressure Relief Device Standards

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4.7. In the event that contradictions in this specification or related documents and/or valid governing codes are detected, the *BUYER* shall be informed immediately and the problem is to be resolved in writing.

5. MATERIALS

5.1. All materials and components used in construction of the *DEVICE* shall be new and suitable for the use for which they are intended.

5.2. Materials known to become brittle at cryogenic temperature shall not be used for components that may become cold during normal or accidental conditions.

5.3. Any materials used in pressure containing piping components of the *DEVICE* shall conform to ASME/ANSI B31.3 or PED 97/23/CE ANNEX I material requirements for appropriate fluid service/category.

5.4. Except where explicitly defined by this specification, austenitic stainless steels shall be used for all components of the *DEVICE* that are part of the vacuum jacket.

5.5. Any fittings, bends, miters, laps and branch connections of the *DEVICE* shall conform to ASME/ANSI B31.3 and/or PED 97/23/CE ANNEX I requirements for appropriate fluid service category.

5.6. Any flanges and blanks of the *DEVICE* shall conform to ASME/ANSI B31.3 and/or PED 97/23/CE ANNEX I requirements for appropriate fluid service category.

5.7. Two-sided aluminized mylar film shall be used for multilayer superinsulation (MLI).

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5.8. Any material used for construction of the *DEVICE* shall be capable of withstanding a cumulative radiation levels up to 5 MGray over 20 years.

6. REQUIREMENTS

6.1. General

6.1.1. This Technical Specification defines performance requirements of a fully operational *DEVICE*.

6.1.2. The cryogenic flow schematic for the *DEVICE* is shown on the *BUYER'S* drawing 4906.320 – LC – 458106.

6.1.3. The *DEVICE* shall be designed and fabricated to allow for a minimal work and testing during assembly and installation of the *DEVICE* at the *BUYER'S* site.

6.1.4. All piping shall be designed and fabricated in accordance with the ANSI Process Piping, B31.3 code or EN 13480 harmonized standard.

6.2. Operational lifetime

The lifetime of the HINS TC is expected to be 20 years with a yearly operating time of 6,000 hrs for the Cryogenic Distribution System. The *DEVICE* will be located inside of the radiation cave, therefore the *DEVICE* shall withstand expected radiation environment. Expected cumulative radiation levels are listed in paragraph 5.8 of this specification.

6.3. Steady state operation

The *DEVICE* is supplied cryogens from a 3-circuit transfer line. The circuits include a Single phase helium supply (Line A), a two-phase helium return (Line B) and an 80 K LN_2 supply (Line C).

6.4. Transient operation

The *DEVICE* shall be designed to be independent of cooldown/warm-up rates and sequences. Each cryogenic circuit of the *DEVICE* shall be capable of being

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cooled-down or warmed-up independently at different rates. The *DEVICE* should be capable of undergoing at least 500 thermal cycles during the lifetime.

6.5. Operating and design pressures

The *DEVICE* operating and design pressures are presented in the Table 1.

Table 1 Operating and design pressures

Cryogenic Line	Circuit description	Operating pressure	Design pressure
[-]	[-]	[kPa]	[kPa]
A	Single phase helium supply	225	548
B	Two phase helium return	112	548
C	Liquid nitrogen supply	239	548

6.6. Operating temperatures

The *DEVICE* operating temperatures are presented in Table 2.

Table 2 Operating temperatures

Cryogenic Line	Circuit description	Operating temperature
[-]	[-]	[K]
A	Single phase helium supply	4.5
B	Two phase helium return	4.5
C	Liquid nitrogen supply	78.0

6.7. Heat leak budget

The total heat leak to the *DEVICE* should not exceed:

- 15 W at 4.5 K
- 150 W at 80K

6.8. Pressure drop requirements

6.8.1. With the exception of cryogenic control valves, the minimum hydraulic diameter of any component for each appropriate cryogenic circuit of the

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DEVICE shall not be less than listed on the *BUYER's* drawing # 4906.320 – LC – 458106.

6.9. Vacuum jacket

6.9.1. There shall be no condensation of water on the vacuum jacket of the *DEVICE* under normal operation. The maximum temperature difference between the *DEVICE* and ambient temperature in the HINS cave shall not exceed 10 degree Celsius.

6.10. Joints, flanges, blanks, and gaskets

6.10.1. All permanent joints shall be welded.

6.10.2. All ports used to connect vacuum equipment shall be fitted with KF-40 flanges.

6.10.3. O-ring gaskets are permitted only on warm connections operating at above atmospheric pressure.

6.10.4. The use of vacuum grease is not permitted.

6.11. Instrumentation

6.11.1. Temperature measurements

6.11.1.1. LakeShore Cryotronics® Cernox® and PT-100 temperature sensors shall be used in the *DEVICE*.

6.11.1.2. The *BUYER* will supply all required temperature sensors and wires.

6.11.1.3. Each Cernox® sensor will have a unique number and associated calibration curve. This unique number shall be clearly marked on the exterior of the feedthru.

6.11.1.4. For Crenox® thermometers, each measuring point shall have two sensors – one primary, one secondary. Both sensors shall be connected to the feedthru connector. The feedthru shall be clearly labeled showing each sensor's unique identification number. The feedthru shall have a

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pressure rating of equal or higher value than a cryogenic circuit it will be used in.

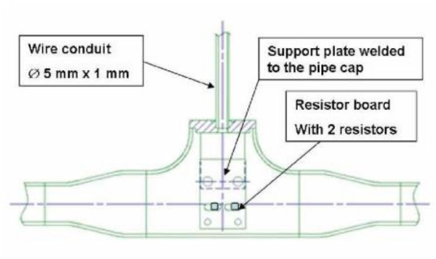

Figure 1 Cold end cryogenic thermometer example

6.11.1.5. Adequate slack of leads shall be left at the connector for proper termination.

6.11.1.6. All temperature sensors shall be wired using a 4 wire technique. The *BUYER* will supply all required wiring diagrams.

6.11.1.7. Internal mounting in a flow path of the temperature sensors is required for all measuring points. Surface mounting of thermometers is not allowed.

6.11.1.8. Figure 1 illustrates a typical design for the cold end. The *SELLER* may propose an alternative design for sensors installation.

6.11.1.9. For the design illustrated on Figure 1, a resistor board is mounted in the ½" IPS (DN 15) pipe tee. Resistor wires are threaded inside a ∅¼" (5 mm) tube - conduit.

6.11.1.10. Adequate strain relief for leads for all temperature sensors shall be applied.

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6.11.1.11. To minimize conduction heat load via the conduit, the length of the tube should be at least three feet (~ one meter) long. All conduits shall be thermally intercepted and properly taper wrapped with MLI.

6.11.1.12. The *SELLER* shall provide all mating electrical connectors.

6.11.1.13. To prevent damage to thermometers due to inductive currents, all electrical leads shall be shorted prior to welding on nearby components.

6.11.2. Pressure measurements

6.11.2.1. Pressure sensing lines shall be welded to the sleeves to preserve the tubing cross section. A sample mounting technique of a pressure tap is illustrated in Figure 2.

6.11.2.2. Stainless steel capillary tubing ∅1/8" x 0.035"wall (∅ 3 x 1 mm) shall be used for pressure sensing lines. Maximum allowable inner diameter of capillary tubing used in the *DEVICE* shall not exceed 0.12" (3 mm).

6.11.2.3. To minimize conduction heat load via the pressure sensing lines, the length of the tube should be at least three feet (~one meter) long.

6.11.2.4. There shall be no contact between pressure sensing lines and any component of the *DEVICE*.

6.11.2.5. Pressure sensing lines shall be spiraled upwards.

6.11.2.6. The external pressure sensing lines shall be at least one and half foot (~0.5 meter) long and terminated with Swagelok® fittings for appropriate service. All fittings shall be capped.

6.11.2.7. Use of thermometer's conduit as a pressure sensing line is allowed.

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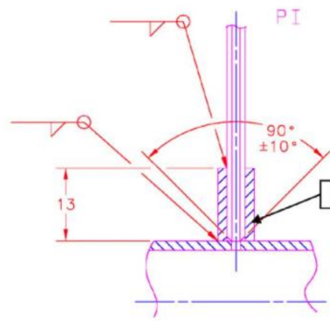

Figure 2 A typical pressure sensing line connection

6.12. Leak tightness

Maximum integral leak rates at maximum pressure differential occurring during operation shall not exceed the values given in Table 3.

Table 3 Maximum acceptable vacuum leak rates

Maximum acceptable integral leak rates, [Pa*m^{3}*s^{-1}]		
	Room temperature	Cryogenic temperature
Cryogenic circuits to insulating vacuum	1*10^{-10}	1*10^{-9}
Atmosphere to insulating vacuum	1*10^{-10}	1*10^{-9}
Cryogenic circuits to atmosphere	1*10^{-10}	1*10^{-9}

6.13. Vacuum space

The vacuum insulation space shall be designed for continuous sealed vacuum operation. During normal operation the insulating vacuum shall be maintained without active continuous mechanical pumping. The integral helium leak rate shall not exceed 1x 10^{-10} (Pa*m^{3}/sec).

6.14. Vacuum load

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The *DEVICE* will experience vacuum load forces. The *DEVICE* design shall take into account vacuum load forces, weight forces and all dynamic forces that may occur in case of an accidental loss of insulating vacuum.

6.15. Components

The *DEVICE* will consist of the following components:

- Upstream Bayonet Box
- Downstream Bayonet Box
- Connecting Transfer Line

Dimensional constraints for each component and space availability in the test cave are presented in the following listed mechanical drawings:

- HINS Transfer line, Fermilab drawing 5520.000 – ME – 458368
- Fermi bayonet detail, Fermilab drawing 1650 – MD – 257379
- West end expansion joint, Fermilab drawing 5520.000 – ME – 439944

6.16. Upstream Bayonet Box

The Upstream Bayonet Box (UBB) contains the following components:

- Vacuum vessel
- Three cryogenic bayonets (MV-210-N, MV-211-H and MV-212-H)
- Two cryogenic control valves (PVC1 and PVC2)
- 80 K thermal radiation shield
- Four cryogenic check valves (CV-211-H, CV-212-H, CV-213-H and CV-214-H)
- Cryogenic process piping
- Process instrumentation
- Internal piping support system
- Expansion joints and anchors for all cryogenic lines

6.16.1. Vacuum vessel

6.16.1.1. The vacuum vessel shall be designed to withstand a minimum of 101325 Pa differential pressure. The vessel shall be designed to ensure

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that allowable stresses are not exceeded, and to ensure that the vessel is resistant to buckling.

6.16.1.2. Welding shall be done in a manner equivalent to a standard welding procedure specified and qualified under the rules of the ASME BPV Code Section IX or appropriate EN harmonized standards, including but not limited to EN287, EN 288, EN 1708-1, etc

6.16.1.3. The vacuum vessel shall be equipped with a relief valve. The *BUYER* will supply a vacuum relief valve to be used on the *DEVICE*.

6.16.1.4. The top plate of the vacuum vessel shall be designed to withstand a minimum of 101325 Pa differential pressure. The top plate shall be designed to ensure that allowable stresses are not exceeded and to ensure that the end plate is resistant to buckling.

6.16.1.5. All openings in the top plate shall be adequately reinforced in a manner consistent with the rules of the ASME BPVC or EN 13445 harmonized standard.

6.16.1.6. Due to the large vacuum vessel diameter, the top plate will experience significant vacuum load forces. The top plate design shall take into account vacuum load forces, weight forces and all dynamic forces that may occur in case of an accidental loss of insulating vacuum. The top plate thickness shall be designed to withstand the vacuum load without visible deflection.

6.16.1.7. The UBB vacuum vessel shall be equipped with three supporting legs. Supporting legs design should allow for leveling and vertical position adjustment of the UBB for up to 2" (~50 mm) during its installation.

6.16.1.8. UBB weight loads and forces during accidental conditions will be transferred to the floor via the UBB vacuum vessel supporting legs. Design of the supporting legs shall include all possible loading conditions.

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6.16.1.9. The UBB shall be equipped with lifting lugs, which will be used during transportation and installation.

6.16.2. Connection to the supply transfer line

6.16.2.1. The supply transfer line (STL) to UBB will carry cryogens from the MDB refrigerator. The STL contains three cryogenic pipes sharing common vacuum. A cross section of the STL is presented on the *BUYER's* drawing # 5520.000-ME-439944. The STL line sizes and materials are presented in Table 4.

Table 4 Supply transfer line piping

Cryogenic line	Circuit description	Nominal pipe size		Sch	Wall thickness	Material
[-]	[-]	[DN]	NPS	[-]	[mm]	[-]
A	Single phase helium supply	20	3/4	10	2	ASTM312 TP304L
B	Two phase helium return	20	3/4	10	2	ASTM312 TP304L
C	Liquid nitrogen supply	30	1	10	3	ASTM312 TP304L

6.16.2.2. The connection snout on the UBB shall be designed to match the STL. It shall include three cryogenic pipes to match appropriate circuits of the STL, surrounded by a copper shield. The copper shield shall be thermally connected to Line C (80 K Thermal shield).

6.16.2.3. The snout shall be designed to allow for welded connection to the STL. The snout shall be positioned on the side of the UBB. The snout location, relative to the UBB center, is shown on the *BUYER's* drawing 5520.000 – ME – 458368.

6.16.2.4. The snout shall have a vacuum barrier to isolate the STL vacuum space from the UBB vacuum space. It shall contain a KF40 vacuum pump out port, closed with a blank-off flange and sealed with an o-ring.

6.16.3. Cryogenic bayonets

6.16.3.1. Only FERMI design cryogenic bayonets shall be used for UBB.

6.16.3.2. The design of FERMI style bayonets is presented on "1 ½" FEMALE BAYONET ASSEMBLY", Fermilab drawing 1650 – MD – 257379.

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6.16.3.3. The *BUYER* will supply all required FERMI style bayonets for installation into the UBB.

6.16.3.4. Bayonet tubes (item 5 on the Fermi drawing 1650-MD-257379) are made of 1.5"OD (38 mm) by 0.035" (0.9mm) wall stainless steel tubing.

6.16.3.5. The non-perpendicularity of a Bayonet tube to a top plate shall be equal or less than 0.010" (0.25 mm).

6.16.3.6. Under no loading conditions any Bayonet tube should experience a deflection more than 0.010" (0.25 mm) from its neutral state.

6.16.4. Cryogenic control valves

6.16.4.1. WEKA AG cryogenic control valves are preferred valves to be used in the *DEVICE*.

6.16.4.2. Austenitic stainless steel shall be used for cryogenic valves. Any materials used to complete a pressure boundary shall conform to ASME/ANSI B31.3 or PED 97/23/EC material requirements for appropriate fluid service category.

6.16.4.3. Welding procedures and welders used for valve manufacturing shall conform to ASME BPVC Division IX or EN288 and EN287.

6.16.4.4. Valves shall be of the extended spindle type with co-axial control stem. They shall be metal-bellows sealed and backed up by an additional safety back-up seal with leak test port.

6.16.4.5. Valves shall be designed for 10,000 fully open/close cycles at nominal pressure.

6.16.4.6. All valves shall be pressure tested with Helium in accordance with ASME BPVC or PED 97/23/EC.

6.16.4.7. The valve housing shall be welded to the internal pipework such that the connection welding process does not deform the valve body and does not deteriorate the valve seal.

6.16.4.8. The welded connection to the *DEVICE* vacuum jacket should be done via a short bellows to allow for the correction of small

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misalignment errors and stem/bonnet thermal contraction. All bellows should be protected with squirm protectors. The design and manufacturing of the bellows shall be in accordance with EJMA eighth edition standard. In case bellows use is not practical, other methods to allow for the correction of small misalignment errors and stem/bonnet thermal contraction shall be used.

6.16.4.9. Under steady state operating conditions, PVC1 and PVC2 valves will operate in an open position.

6.16.4.10. The single phase supply control valve (PVC1) shall be 50:1 equal percentage valve equipped with a bullet of Cv = 0.5 (Kv = 0.43). The single phase supply valve design shall allow for changing of the seat seal, bullet, or both with different sizes or profiles.

6.16.4.11. The two phase return control valve (PVC2) shall be 50:1 equal percentage valve equipped with a bullet of Cv = 4.0 (Kv = 3.45). The two phase return valve design shall allow for changing of the seat seal, bullet, or both with different sizes or profiles.

6.16.4.12. All valve seats must be hardened to prevent degradation of its surface under influence of possible contamination in the helium.

6.16.4.13. All control valves, when closed, shall be leak tight across the seal and seat including at cryogenic temperatures. Leaks rates measured at room or cryogenic temperatures and maximum working pressure shall not exceed the following values:

- individual leak across seat $1*10^{-5}$ [Pa*m^3/s]
- individual leak rate to atmosphere $1*10^{-9}$ [Pa*m^3/s]
- individual leak rate to vacuum $1*10^{-9}$ [Pa*m^3/s]

6.16.4.14. To minimize the heat inleak by conduction to the low-temperature valve body, a heat intercept to the thermal shield at approximately 80 K shall be used.

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6.16.4.15. Provisions shall be made for stem replacement under cryogenic conditions at slightly higher than atmospheric pressure.

6.16.4.16. Actuators for the control valves shall be equipped with electro-pneumatic positioner with digital pneumatic control and 4 to 20 mA analog feedback signal. The output pressure or valve position shall be displayed.

6.16.5. The 80 K thermal radiation shield

6.16.5.1. The 80 K shield shall be supported from the end plate. The fixed part shall serve as a thermal screen and structural support for internal cryogenic process pipes.

6.16.5.2. The 80 K shield shall have adequate size openings for helium process pipes to assure that no unforeseen thermal short occurred at any point.

6.16.5.3. Cryogenic lines A and B shall be surrounded by the 80 K thermal radiation shield.

6.16.5.4. The shield shall be thermally connected to the C line. Amount and frequency of thermal intercepts shall be sufficient to provide uniform temperature across the shield. The maximum temperature gradient across the shield shall not exceed 30 K.

6.16.6. Cryogenic check valves

6.16.6.1. WEKA AG cryogenic check valves are preferred check valves to be used in the *DEVICE*.

6.16.6.2. Cryogenic check valves shall be of in-line pattern with butt weld ends and seal welded to the outside.

6.16.6.3. All check valve shall be positioned vertically with a flow exiting from the top of the check valve.

6.16.6.4. All helium check valves bodies shall be at approximately 20 K during the *DEVICE* steady state operation, as defined in paragraphs 6.3 and 6.6 of this specification.

6.16.7. Cryogenic process piping

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The cryogenic process piping shall be designed to interface to the existing West end expansion joint (5520.000-ME-439944). The piping shall be equipped with expansion joints to allow for contraction of appropriate cryogenic circuits.

6.16.8. Internal piping support system

6.16.8.1. The internal support system of the cryogenic circuits shall be designed to minimize heat leak. It shall be made of low thermal conductivity materials and components. The thermal conduction path shall be as long as practical. Heat intercepts at higher temperatures shall be used extensively. Thermal losses due to abnormal contact of components are unacceptable.

6.16.8.2. The internal support system of the cryogenic circuits shall be designed to prevent any excessive vibration of cryogenic lines for all operating flow rates.

6.16.8.3. Industry acceptable expansion joints shall be used to compensate for thermal contraction/expansion of the UBB cryogenic lines. Each element that connects to cryogenic circuits shall be supported by internal supports.

6.16.8.4. The internal support system shall provide adequate spacing and positioning to avoid abnormal contact of components and to enable movement inside the vacuum space with minimum friction.

6.16.8.5. There shall be no significant distortion or deterioration of superinsulation due to differential movement of cryogenic circuits.

6.17. Downstream Bayonet Box

The Downstream Bayonet Box (DBB) contains the following components:

- Vacuum vessel
- Three cryogenic bayonets (MV-220-N, MV-221-H and MV-222-H)
- Three cryogenic control valves (PVS1, PVS2 and PVST)
- 80 K thermal radiation shield

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- Five cryogenic check valves (CV-220-N, CV-221-H, CV-222-H, CV-223-H and CV-224-H)
- Cryogenic process piping
- Process instrumentation
- Internal piping support system
- Expansion joints and anchors for all cryogenic lines

6.17.1. Vacuum vessel

6.17.1.1. The vacuum vessel shall be designed to withstand a minimum of 101325 Pa differential pressure. The vessel shall be designed to ensure that allowable stresses are not exceeded, and to ensure that the vessel is resistant to buckling.

6.17.1.2. Welding shall be done in a manner equivalent to a standard welding procedure specified and qualified under the rules of the ASME BPV Code Section IX or appropriate EN harmonized standards, including but not limited to EN287, EN 288, EN 1708-1, etc.

6.17.1.3. The vacuum vessel shall be equipped with a relief valve. The *BUYER* will supply a vacuum relief valve to be used on the *DEVICE*.

6.17.1.4. The top plate of the vacuum vessel shall be designed to withstand a minimum of 101325 Pa differential pressure. The top plate shall be designed to ensure that allowable stresses are not exceeded and to ensure that the end plate is resistant to buckling.

6.17.1.5. All openings in the top plate shall be adequately reinforced in a manner consistent with the rules of the ASME BPV Code or EN 13445 harmonized standard.

6.17.1.6. Due to the large vacuum vessel diameter, the top plate will experience significant vacuum load forces. The top plate design shall take into account vacuum load forces, weight forces and all dynamic forces that may occur in case of an accidental loss of insulating

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vacuum. The top plate thickness shall be designed to withstand the vacuum load without visible deflection.

6.17.1.7. The DBB vacuum vessel shall be equipped with three supporting legs. Supporting legs design should allow for leveling and vertical position adjustment of the DBB for up to 2" (~50 mm) during its installation.

6.17.1.8. DBB weight loads and forces during accidental conditions will be transferred to the floor via the DBB vacuum vessel supporting legs. Design of the supporting legs shall include all possible loading conditions.

6.17.1.9. The DBB shall be equipped with lifting lugs, which will be used during transportation and installation.

6.17.2. Cryogenic bayonets

6.17.2.1. Only FERMI design cryogenic bayonets shall be used for UBB.

6.17.2.2. The design of FERMI style bayonets is presented on "1 ½" FEMALE BAYONET ASSEMBLY", Fermilab drawing 1650 – MD – 257379.

6.17.2.3. The *BUYER* will supply all required FERMI style bayonets for installation into the UBB.

6.17.2.4. Bayonet tubes (item 5 on the Fermi drawing 1650-MD-257379) are made of 1.5"OD (38 mm) by 0.035" (0.9mm) wall stainless steel tubing.

6.17.2.5. The non perpendicularity of a Bayonet tube to a top plate shall be equal or less than 0.005" (0.13 mm).

6.17.2.6. Under no loading conditions any Bayonet tube should experience a deflection more than 0.010" (0.25 mm) from its neutral state.

6.17.3. Cryogenic control valves

6.17.3.1. WEKA AG cryogenic valves are preferred valves to be used in the *DEVICE*.

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6.17.3.2. Austenitic stainless steel shall be used for cryogenic valves. Any materials used to complete a pressure boundary shall conform to ASME/ANSI B31.3 or PED 97/23/EC material requirements for appropriate fluid service category.

6.17.3.3. Welding procedures and welders used for valve manufacturing shall conform to ASME BPVC Division IX or EN288 and EN287.

6.17.3.4. Valves shall be of the extended spindle type with co-axial control stem. They shall be metal-bellows sealed and backed up by an additional safety back-up seal with leak test port.

6.17.3.5. Valves shall be designed for 10,000 fully open/close cycles at nominal pressure.

6.17.3.6. All valves shall be pressure tested with Helium in accordance with ASME BPVC or PED 97/23/EC.

6.17.3.7. The valve housing shall be welded to the internal pipework such that the connection welding process does not deform the valve body and does not deteriorate the valve seal.

6.17.3.8. The welded connection to the *DEVICE* vacuum jacket should be done via a short bellows to allow for the correction of small misalignment errors and stem/bonnet thermal contraction. All bellows should be protected with squirm protectors. The design and manufacturing of the bellows shall be in accordance with EJMA eighth edition standard. In case bellows use is not practical, other methods to allow for the correction of small misalignment errors and stem/bonnet thermal contraction shall be used.

6.17.3.9. Under steady state operating conditions, PVS1 will be used to control liquid level in spoke cavity.

6.17.3.10. Under steady state operating conditions, PVS2 valves will operate in an open position.

6.17.3.11. Under steady state operating conditions, PVST will be used to maintain thermal stability of the CDS transfer line

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6.17.3.12. The single phase supply control valve (PVS1) shall be 50:1 equal percentage valve equipped with a bullet of Cv = 0.12 (Kv = 0.10). The single phase supply valve design shall allow for changing of the seat seal, bullet, or both, with different sizes or profiles.

6.17.3.13. The two phase return control valve (PVS2) shall be 50:1 equal percentage valve equipped with a bullet of Cv = 4.0 (Kv = 3.45). The single phase supply valve design shall allow for changing of the seat seal, bullet, or both, with different sizes or profiles.

6.17.3.14. The transfer line J-T valve (PVST) shall be 50:1 equal percentage valve equipped with a bullet of Cv = 0.10 (Kv = 0.09). The transfer line valve design shall allow for changing of the seat seal, bullet, or both, with different sizes or profiles.

6.17.3.15. All valve seats must be hardened to prevent degradation of its surface under influence of possible contamination in the helium.

6.17.3.16. All control valves, when closed, shall be leak tight across the seal and seat including at cryogenic temperatures. Leaks rates measured at room or cryogenic temperatures and maximum working pressure shall not exceed the following values:

- individual leak across seat $1*10^{-5}$ [Pa*m^3/s]
- individual leak rate to atmosphere $1*10^{-9}$ [Pa*m^3/s]
- individual leak rate to vacuum $1*10^{-9}$ [Pa*m^3/s]

6.17.3.17. To minimize the heat inleak by conduction to the low-temperature valve body, a heat intercept to the thermal shield at approximately 80 K shall be used.

6.17.3.18. Provisions shall be made for stem replacement under cryogenic conditions at slightly higher than atmospheric pressure.

6.17.3.19. Actuators for the control valves shall be equipped with electro-pneumatic positioner with digital pneumatic control and 4 to 20 mA

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analog feedback signal. The output pressure or valve position shall be displayed.

6.17.4. The 80 K thermal radiation shield

6.17.4.1. The 80 K shield shall be supported from the end plate. The fixed part shall serve as a thermal screen and structural support for internal cryogenic process pipes.

6.17.4.2. The 80 K shield shall have adequate size openings for helium process pipes to assure that no unforeseen thermal short occurred at any point.

6.17.4.3. Cryogenic lines A and B shall be surrounded by the 80 K thermal radiation shield.

6.17.4.4. The shield shall be thermally connected to the C line. Amount and frequency of thermal intercepts shall be sufficient to provide uniform temperature across the shield. The maximum temperature gradient across the shield shall not exceed 30 K.

6.17.5. Cryogenic check valves

6.17.5.1. WEKA AG cryogenic check valves are preferred check valves to be used in the *DEVICE*.

6.17.5.2. Cryogenic check valves shall be of in-line pattern with butt weld ends and seal welded to the outside.

6.17.5.3. All check valve shall be positioned vertically with a flow exiting from the top of the check valve.

6.17.5.4. All helium check valves bodies shall be at approximately 20 K during the *DEVICE* steady state operation, as defined in paragraph 6.4 of this specification.

6.17.6. Internal piping support system

6.17.6.1. The internal support system of the cryogenic circuits shall be designed to minimize heat leak. It shall be made of low thermal conductivity materials and components. The thermal conduction path shall be as long as practical. Heat intercepts at higher temperatures

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shall be used extensively. Thermal losses due to abnormal contact of components are unacceptable.

6.17.6.2. The internal support system of the cryogenic circuits shall be designed to prevent any excessive vibration of cryogenic lines for all operating flow rates.

6.17.6.3. Industry acceptable expansion joints shall be used to compensate for thermal contraction/expansion of the DBB cryogenic lines. Each element that connects to cryogenic circuits shall be supported by internal supports.

6.17.6.4. The internal support system shall provide adequate spacing and positioning to avoid abnormal contact of components and to enable movement inside the vacuum space with minimum friction.

6.17.6.5. There shall be no significant distortion or deterioration of superinsulation due to differential movement of cryogenic circuits.

6.18. Transfer Line

6.18.1. The transfer line shall be designed to connect the UBB and the DBB. The transfer line houses three (3) cryogenic process pipes.

6.18.2. The transfer line outer dimensions and layout are presented on HINS Transfer line, Fermilab drawing 5520.000 – ME – 458368

6.18.3. The transfer line shall allow for:

- Single phase helium supply (line A)
- Two phase helium return (line B)
- LN_2 supply (line C)

The information on suggested the transfer line nominal pipe sizes and materials is presented in Table 5.

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Table 5 Device transfer line cryogenic circuits

Cryogenic line	Circuit description	Nominal pipe size		Sch	Wall thicknes s	Material
[-]	[-]	[DN]	NPS	[-]	[mm]	[-]
A	Single phase helium supply	16	1/2	10	1	ASTM312 TP304L
B	Two phase helium return	16	1/2	10	1	ASTM312 TP304L
C	Liquid nitrogen supply	16	1/2	10	1	ASTM312 TP304L

7. INTERFACE REQUIREMENTS

7.1. Cryogenic Flow Schematic

The cryogenic flow schematics for the MDB cryogenic distribution system and the HINS test cryostat are shown on the drawings 4906.320 – LC – 458106.

7.2. MDB Cryogenic system

The Meson Detector Building (MDB) provides the primary development and testing forum for major superconducting radio-frequency (SRF) based projects in high energy physics, most notably the International Linear Collider (ILC), Fermilab High Intensity Neutrino Source, as well as compliments the existing and planned SRF facilities at other laboratories for nuclear physics, materials, and life sciences.

The ILCTA MDB cryogenic system consists of Fermilab Cryogenic Test Facility cryogenic plant and Meson tunnel cryogenic transfer line. CTF, formerly the Meson Central Cryogenics (MCC), is located on the west side of the Meson beamline, about 1,500 feet south-west of the MDB. The CTF houses three (3) Tevatron satellite refrigerators capable of producing a total of 1.8 kW at 4.5K. CTF is connected to the ILCTA MDB test area via cryogenic transfer line.

7.3. HINS TC

The HINS test cryostat will be connected to the bayonet can in the test cryostat cave via individual flexible transfer lines. These transfer lines will be removable

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at the bayonet can end and permanently installed in the test cryostat. There will be three connecting lines – helium supply, helium return, and LN_2 shield supply. The LN_2 return will be vented through and external line which is not part of this procurement. All control valves associated with these three lines will be part of the bayonet can assembly. The anticipated total heat loads associated with the test cryostat, superconducting cavity, and power coupler are 1.5 watts to 4.5 K and 5 watts to 80 K. There is an additional requirement to supply 10 liters/hour GHe lead flow for current leads connected to the focusing magnet. This lead flow will be extracted from the helium supply.

8. CONSTRUCTION, FABRICATION AND ASSEMBLY

8.1. Cryogenic insulation

8.1.1. To shield elements at cryogenic temperatures from radiant heat emitted by adjacent higher temperature surfaces, all internal surfaces shall be thermally isolated from each other by wrapping with alternate layers of two-sided aluminized mylar and spacer.

8.1.2. Whenever practical, forty five (45) layers of aluminized mylar/spacer pairs shall cover all surfaces of the *DEVICE*.

8.1.3. Wherever practical, spiral half overlapped wrapping of aluminized mylar/spacer paired material is preferred.

8.1.4. Where spiral wrapping is inappropriate, blankets of no more than five layers of superinsulation interspersed with five layers of spacer may be applied.

8.1.5. Additional five (5) layered pair-blankets will be used to reach the total number of layers required. The edges of blankets shall be symmetrically located so as to reduce the number of edges in any one region.

8.1.6. At corners, penetrations and other joints: edges of aluminized mylar (whether individual or in blankets) shall be interleaved.

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8.1.7. For all external penetrations, superinsulation shall be tapered from single layers at room temperature to the maximum number of layers at cold end.

8.1.8. No edge of an inner layer of aluminized mylar shall touch any layer more than five (5) layers farther out in the wrapping. No other forms of thermal shorts in the insulation shall be permitted.

8.1.9. Wherever application of required number of layers of aluminized mylar/spacer will not fit between two surfaces, the number of acceptable layers should be determined by mutual agreement of the *BUYER* and *SELLER*.

8.1.10. Application techniques shall follow the procedures and principles above to minimize heat transfer through gaps, exposed edges and shorts.

8.1.11. Burnt or singed insulation materials are not acceptable.

8.1.12. Fiberglass or other shielding shall be used by the *SELLER* to prevent damage to materials during welding or other operations. No such materials shall be left in the assembly except with the written permission of the *BUYER*.

8.1.13. Insulation materials shall not plug or block any pump out port or vacuum relief port. The ends of these items are the only exposed material which can be seen from the inside of the assembly when insulation is completed.

8.2. Labeling

8.2.1. All instruments and valves shall be identified in accordance with the cryogenic flow schematic presented on the *BUYER's* drawing #4906.320-LC-458106.

8.2.2. All components, electrical terminals, cables and wires shall be labeled with suitable permanent identification labels. .

8.3. Welding

8.3.1. All weld joint preparation and welding techniques shall be done in accordance with Section Chapter V ASME/ANSI B31.3 code or EN 1708-1.

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8.3.2. The *SELLER* shall conduct the tests required to qualify Welding Procedure Specification (WPS) as required by Chapter V ASME/ANSI B31.3 code or EN 288.

8.3.3. The *SELLER* shall conduct the tests required to qualify Welders as required by Chapter V ASME/ANSI B31.3 code or EN 287.

8.3.4. The *SELLER* shall maintain records in accordance with paragraph UW-48 Section VIII Division I ASME BPVC or PED 97/23/EC of all welders and welding operators working on the *DEVICE* and the welds made by each so that all the data will be available for the *BUYER*.

8.3.5. All welding shall be done by the Gas Tungsten Arc Weld (GTAW) process, using welding quality argon gas for the inert shield.

8.3.6. All welds shall be internally purged with welding quality argon gas during the time of welding and post welding treatment.

8.3.7. Welds that show evidence of a lack of purge will be deemed unacceptable.

8.3.8. All welding shall be done in such a manner that the weld surface is smooth and free of irregularities.

8.3.9. No visible metal chips or foreign material may be detectable inside any component of the *DEVICE*.

8.3.10. All external surfaces in the weld area shall be cleaned of heat tint, slag, and other deposits.

8.3.11. No mechanical process shall be used to achieve the smooth appearance.

8.3.12. No production work shall be done until both the WPS and welders or welding operators have been qualified in accordance with the Chapter V ANSI ASME B31.3 or EN 287.

8.4. Tube and pipe bending

8.4.1. Bending shall be done in accordance with good machine shop practices.

8.4.2. All bends shall be free of kinks, cuts, and abrasions.

8.4.3. Conduits shall remain circular after bending to within 90% of original minimal diameter.

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8.4.4. Vendor may substitute tube bends for fittings where desirable.

8.5. Cleaning

8.5.1. Each component and subassembly shall be thoroughly cleaned at every stage of all scale, spatter, flux, foreign materials, etc.

8.5.2. Cleaning agents shall be suitable for the materials of construction, and shall be neutralized if necessary.

8.5.3. Weld spatter shall be removed by wire brushing using stainless steel brushes.

8.5.4. Each assembly shall be cleaned to provide an inner surface of all pipes and tubes free of grease, flux, moisture, dirt, and other foreign materials by vapor degreasing or suitable wash. Surfaces shall be visibly inspected and wiped down with a white cloth. In order to be considered free of contamination, no discoloration shall appear on the white cloth.

8.5.5. After cleaning, each section shall be blown dry with clean dry air until no moisture remains.

9. DESIGN VERIFICATION AND APPROVALS

9.1. Mandatory design approval

The following items are subject to written approval by the *BUYER* within thirty (30) business days and prior to the onset of the *DEVICE* or its *COMPONENTS* fabrication:

9.1.1. Materials to be used for the *DEVICE* fabrication that contain plastic.

9.1.2. Design and material choice of the *DEVICE* internal support system.

9.1.3. Design and material choice of the process piping anchors.

9.1.4. Engineering calculations, design, material choice and expansion/contraction compensation methods to be used in the *DEVICE*.

9.1.5. Design of the UBB and DBB bayonet tubes to internal piping connections.

9.1.6. Type and make of the cryogenic valves and actuators to be used in the *DEVICE*.

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9.1.7. Type and make of cryogenic check valves to be used in the *DEVICE*.

9.1.8. Type of instrumentation feedthru to be used in the *DEVICE*.

9.1.9. Type and design of expansion joints to be used in the *DEVICE*.

9.1.10. Type of instrumentation connectors to be used in the *DEVICE*.

9.1.11. Design for temperature sensors installation. Amount and frequency of the 80K thermal intercepts.

9.1.12. Final drawings of the *DEVICE* including parts and subassemblies.

9.1.13. Welding Procedure Specifications, prior to any welding being done on the *DEVICE* or its subassemblies.

9.1.14. Welder's Qualification Records prior to any welding being done on the *DEVICE* or its subassemblies.

9.1.15. Any deviation from requirements listed in the paragraph 6.10.1, e.g. high or low temperature brazing or soldering.

9.1.16. Quality Assurance Plan (QAP).

9.1.17. Leak test procedures.

9.1.18. Design of the shipping fixtures and packaging of the *DEVICE* for shipment to *BUYER'S* site.

9.1.19. Documentation format other than listed in paragraph 12.15 of this specification shall be transmitted from the *BUYER* to the *SELLER* in writing prior to the *DEVICE* packaging and shipping.

9.1.20. The shipping crate design prior to its fabrication. Any load testing performed by the *SELLER* to verify the crate design shall be witnessed by the *BUYER* representative.

10. QUALITY CONTROL AND TESTS

10.1. Quality assurance

10.1.1. The *DEVICE* is to be designed and manufactured in accordance with generally applied quality standards and techniques.

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10.1.2. The *SELLER* shall prepare and implement the QAP covering design, procurement, fabrication, testing and inspection of the *DEVICE* and its *COMPONENTS* including subassemblies.

10.1.3. The QAP shall include major milestones of the project.

10.1.4. The *BUYER* reserves the right to have its technical or procurement representatives witness any or all manufacturing stages, tests and inspections under the QAP program to demonstrate compliance with this specification.

10.2. Modifications management

10.2.1. Both the *BUYER* and the *SELLER* have the right to inform the other party of requests for modifications. Each recommended modification shall be clearly identified (by a unique number) to be used in all subsequent correspondence.

10.2.2. All modifications that affect the *DEVICE* performance or interface requirements or other contractual content shall be documented and approved in writing without delay with respective notice to the *BUYER*. For each such modification, the following information shall be provided:

- Reason for modification
- Assessment of technical feasibility, where deemed necessary
- Assessment of the effect on other elements of the contract
- Affect on the extent of work involved, documentation and drawings
- Affect on the project schedule
- Affect on the overall project cost
- Other affected factors (reliability, safety, maintenance)
- Any other additional documentation

10.3. Inspection, examination and tests

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10.3.1. The *SELLER* shall conduct all tests, inspections and examinations required by design and/or construction codes that are listed in the paragraph 4.6 of this specification.

10.3.2. The *SELLER* shall perform all examinations required by ANSI B31.3 or PED 97/23/EC, including materials tests and non-destructive examinations.

10.3.3. The *SELLER* shall conduct leak tests of *COMPONENTS* or their subassemblies as deemed necessary to assure leak tightness. No leaks should be detected on the most sensitive scale of the leak detector (minimum sensitivity 1 x 10^{-10} $Pa*m^3*s^{-1}$) during the leak testing.

10.3.4. The *SELLER* shall conduct a final leak test of *COMPONENTS* prior to shipment to the *BUYER* site. No leaks should be detected on the most sensitive scale of the leak detector (minimum sensitivity 1 x 10^{-10} $Pa*m^3*s^{-1}$) during the leak testing.

10.3.4.1. All leak tests should be made in accordance with written procedure prepared by *SELLER*. The procedures must include, but not limited to, the following:

- Description of the sub-assembly or component;
- Test equipment specification;
- Name and qualification of the person(s) performing the test.

10.3.4.2. Any test failure which is correctable by simple rewelding or rebrazing may be undertaken without further direct contact with the *BUYER*. Any unacceptable leaks which are repaired, shall be fully documented and described by written notice to the *BUYER* upon delivery of *COMPONENTS*.

10.3.5. The *SELLER* shall perform pressure tests required by design and/or construction codes that are listed in paragraph 4.6.

10.3.5.1. All piping circuits shall be pneumatically pressure tested with dry inert gas in accordance with paragraph 345.5 of the ANSI B31.3 piping code or requirements of the PED 97/23/EC.

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10.3.6. The *SELLER* shall perform general electrical continuity tests

10.3.6.1. All wiring, thermometers and electrical connections shall be tested for electrical continuity and signal impedance.

10.3.6.2. All actuators and valves shall be tested and actuated.

10.4. Acceptance tests

10.4.1. Within 24 weeks of receipt of the *COMPONENTS*, the *BUYER* or his designated tester shall conduct leak tests at Fermilab. Measured helium leaks greater than 1×10^{-10} $Pa*m^3*s^{-1}$ shall be defined as a failure of the equipment to pass the test.

10.4.2. Within 24 weeks of receipt of *COMPONENTS*, the *BUYER* or his designated tester shall conduct pressure tests at Fermilab. A leak detected at any pressure level reading during the tests or visible deformation of any tested component shall be defined as a failure of the equipment to pass the test.

10.4.3. Within 24 weeks of receipt of *COMPONENTS*, the *BUYER* or his designated tester shall conduct electrical tests at Fermilab. In case *COMPONENTS* fail electrical continuity tests or any of the valves fail to be actuated, the *SELLER* shall conduct repairs at the *SELLER'S* expense.

11. SHIPPING

11.1. The *COMPONENTS* shall be shipped by air and/or truck. No train or ocean freight transportation is permitted.

11.2. All openings shall be sealed against the penetration of moisture, dirt or air.

11.3. All circuits shall be pressurized to 0.13 MPa with dry nitrogen.

11.4. The *SELLER* shall support any internal piping that is not fully restrained by means of added removable supports installed through *COMPONENTS* end flanges. The added restraints shall be easily removed after shipping is complete. The additional supports shall not be welded to the internal piping.

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11.5. The *BUYER* will provide four RD298 Shocklog Tri-axial Recorders made by Lamerholm Fleming Ltd. for shock and vibration monitoring during transport of the crate. Two units are to be mounted on the UBB and DBB inside the shipping crate for redundancy. A second pair of redundant accelerometer systems shall be located on the exterior of the shipping crates such that they are protected from damage during handling of the crate.

11.6. All items shall be crated or boxed as to be readily handled with a fork-lift truck or shall have suitable lifting attachments for use with an overhead crane.

11.7. Crate shall be clearly marked indicating the items of content, the contract number, the gross weight and presence of the shock recorders.

11.8. During handling and transport, the shipping crate and enclosed *COMPONENTS* will be subject to both shock and vibratory accelerations.

11.9. A maximum vertical shock acceleration transmitted to *COMPONENTS* shall not exceed |5.0|g.

11.10. A maximum horizontal shock acceleration transmitted to *COMPONENTS* shall not exceed |2.0| g.

11.11. The specified limits are the net maximum allowable accelerations measured on *COMPONENTS* during transport. The shipping crate must isolate *COMPONENTS* from the actual external shipping accelerations which could be considerably higher.

11.12. The *SELLER* shall design the shock and vibration isolation system such that a fully loaded crate has a primary (first) mode of oscillation >5 Hz and <10 Hz. Additionally, the crate must be designed to undergo a free drop from a height of 0.15 m without transmitting more than the vertical shock limit of 5.0 g's to the *DEVICE*.

11.13. *COMPONENTS* shall be supported uniformly across its bottom surface within the crate. The jack mounting points must not be used to support the *COMPONENTS* within the crate.

11.14. In addition to providing the shock and vibration isolation, the following features shall be incorporated in the design of the shipping crate:

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a) Full enclosure on all sides of *COMPONENTS*
b) Sufficient interior restraint to prevent *COMPONENTS* from shifting within the crate
c) *COMPONENTS* are to be supported only on the exterior surfaces
d) Appropriate and clearly marked exterior features to allow tie down during transport and lifting by means of both a crane and a forklift
e) Design of crate and lifting fixture (if used) shall be sized to allow lifting with a crane having a maximum hook height of 17 ft (~5.2 m)
f) Provision for repeated access to *COMPONENTS* without significant damage occurring to the crate
g) Protection from prolonged exposure to the weather without corrosion or other damage occurring to *COMPONENTS*
h) Clear and obvious labels in English and native language of origin indicating the presence of fragile contents, as well as shock and vibration recording instruments
i) Labels warning against tipping the crate from its normal position or stacking any items on top of it
j) Extra interior space and restraints for any miscellaneous hardware (mounting jacks, etc.)
k) Any welds used in the construction of the shipping crate must conform to American Welding Society (AWS) code as determined by an AWS certified weld inspector

12. DOCUMENTATION REQUIREMENTS

12.1. The *SELLER* shall provide copies of mill certification reports for all materials supplied by the *SELLER*. The mill certificates shall include both physical and chemical properties of the materials. For commercial items such as weld rods, electrodes, and fasteners, certificates of compliance shall be supplied in lieu of mill certification reports

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12.2. The *SELLER* shall furnish copies of the WPS utilized in welding operation on the *DEVICE*.

12.3. The *SELLER* shall furnish copies of Welders' Qualification Records for each welder utilized in welding operation on the *DEVICE*.

12.4. The *SELLER* shall furnish copies of Welding Records as defined in paragraph 8.3.4 of this specification for welding operation on the *DEVICE*.

12.5. The *SELLER* shall furnish all engineering and design information, including structural calculations for the UBB and the DBB vacuum vessels.

12.6. The *SELLER* shall furnish all engineering and design information, including structural calculations for any component that falls within the scope of ANSI B31.3 or PED 97/23/EC.

12.7. The *SELLER* shall furnish a general layout drawing of the *DEVICE* showing main dimensions and weights.

12.8. The *SELLER* shall furnish the *DEVICE'S* Process and Instrumentation Diagram showing all components, connections, pipe sizes and schedules, valves, sensors, transmitters and instruments.

12.9. The *SELLER* shall furnish an active components list with information, which includes but is not limited to, component temperature and pressure ratings, manufacturing origin, etc.

12.10. The *SELLER* shall furnish a complete set of the *DEVICE* assembly and parts drawings and associated parts lists.

12.11. The *SELLER* shall furnish specifications, manuals, welding specification, welders qualification records, pressure and leak tests results for purchased components used in the *DEVICE*.

12.12. The *SELLER* shall furnish final wiring diagrams, terminal lists and placement for all electrical components and instrumentation.

12.13. The *SELLER* shall furnish quality control reports, including but not limited to leak check test reports with name and qualification of the person(s) performing tests.

12.14. The *SELLER* shall furnish documents in the English language.

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12.15. All drawings shall be supplied in Data Exchange Format (DXF). Any electronically generated documents shall be supplied in MS Office 2003 format. Documents with hand written entries shall be submitted in the Portable Document Format (PDF) format.

13. PROJECT MILESTONES

As a part of the proposal, the BUYER shall submit a list of milestones including estimated completion time relative to the start of the contract. The list shall include but is not limited to the following milestones:

- Start of contract
- Kick-off meeting
- Handing over the *BUYER* drawings to the contractor
- Review of project management documents
- Review of quality management documents
- Review of detailed schedule
- Review of the detailed design and complete production documents
- Start of manufacture
- Testing the *COMPONENTS* at the *SELLER'S* premises
- Delivery of the *COMPONENTS* to the *BUYER*

14. PROJECT MANAGEMENT

The *SELLER* shall coordinate and control all project-specific activities and corresponding resources and shall ensure realization of the standards of this technical specification and successful fulfillment of the contract.

A Project Management (PM) plan shall be prepared for the execution of the project. This plan shall define the obligations of the entire PM for both the *SELLER* and the major

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subcontractors. The personnel assigned to the tasks must have certified qualifications and respective competence.

During the execution of the contract, the *SELLER* shall verify the effectiveness of the PM plan and improve it as necessary. The *SELLER* is obligated to immediately carry out all corrective measures.

The PM plan shall be submitted to the *BUYER* within fifteen work days prior to the Review of Project Management Documents milestone. It shall include, but is not limited to, the following items:

14.1. Project organization

The responsible project management must be documented by:

- Appointment by name of the project leader, specification of his duties. The project leader is the sole contact for all issues concerning the contract. If another person is responsible for business issues, then this person must also be named.

14.2. Project plan

14.2.1. Work Breakdown Structure based on the work processes for manufacture of the *DEVICE* (production tasks) including project management duties (supporting tasks).

14.2.2. Organizational structure of the project created for execution of the contract, the integration of this project in the company, the organizational integration of subcontractors and their contractual basis.

14.2.3. Definition of the essential elements of project control, such as periodic meetings of the project management, regular meetings with the *BUYER* and subcontractors, as well as periodic meetings with higher committees of the *SELLER*, etc.

14.2.4. The *SELLER* shall submit to the *BUYER* a detailed schedule of all essential work at the Review of Detailed Schedule milestone. This plan must include the work of both the *SELLER* and the subcontractors. The time

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resolution of this plan must cover at least two weeks. It is to be prepared in MS Project and shall be submitted to the *BUYER* both in printed and digital form. The schedule is to be based on mutually agreed upon Project Milestones.

14.2.5. The *SELLER* shall update the schedule on a monthly basis during the course of the contract; in special cases, the *BUYER* can also request updates at shorter intervals. The schedule shall also indicate what percentage of a task has already been performed.

14.2.6. In case of events affecting the schedule, the *SELLER* shall take suitable measures to ensure that the schedule is maintained. This expressly includes the assignment of additional personnel (overtime and shift work) and additional equipment at the contractor's expense.

14.3. Project control

The following tasks shall be performed regularly during execution of the project:

14.3.1. Progress report: The *SELLER* is obligated to make regular reports to the *BUYER*. The reports shall be prepared monthly and shall be submitted to the customer no later than the third work day of a given month. In special individual cases, especially in the case of technical problems and delays in schedule, the *BUYER* may also request shorter reporting intervals. The reports must give clear information on all individual tasks according to the schedule.

14.3.2. Independent of the schedule reports, all events that may have an affect on the schedule shall be reported to the *BUYER*. In case of serious problems that endanger the achievement of contractually agreed milestones, the *BUYER* shall be informed immediately in writing.

14.3.3. The *SELLER* agrees to grant *BUYER* or his representatives unrestricted and free access for observation or inspection of all processes relevant to the execution of the contract on the *SELLER'S* and subcontractors' premises.

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14.4. Project meetings

14.4.1. The *SELLER* shall plan and prepare a series of project meetings, whereby the agenda, the participants, the location and means are to be determined in co-ordination with the *BUYER*. There shall be provision for teleconferences.

14.4.2. The *BUYER* and the *SELLER* have the right to request special meetings as needed.

14.4.3. Unless otherwise arranged, the *SELLER* must prepare all minutes of the meetings with the *BUYER* within five work days.

15. ITEMS SUPPLIED BY FERMILAB

The following list of items shall be supplied by the *BUYER*:

a) Cryogenic flow schematic, Fermilab drawing 4906.320 – LC – 458106
b) HINS Transfer line, Fermilab drawing 5520.000 – ME – 458368
c) Fermi bayonet detail, Fermilab drawing 1650 – MD – 257379
d) West end expansion joint, Fermilab drawing 5520.000 – ME – 439944
e) Five (5) FERMI bayonet tubing including bayonet seal couplings
f) Five (5) 1-1/2" Bayonet valves assemblies
g) Five (5) Chevron seal assemblies
h) Five (5) Vacuum coupling caps
i) Two (2) Vacuum relief valves
j) Temperature sensors and associated wiring diagrams
k) Wire to be used for the temperature sensors
l) Technical Questionnaire

16. DOCUMENTS TO BE INCLUDED IN THE PROPOSAL

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The following items are required to be included in the proposal:

A. A complete list of deliverables
B. The *DEVICE* assembly instructions and procedures on *BUYER'S* site by the *BUYER*
C. A complete list of proposed cryogenic control valves, indicating sizes, ranges, types and manufacturers
D. A complete list of proposed safety and check valves indicating sizes, ranges, types and manufacturers
E. Description of MLI to be used in the *DEVICE*
F. A sketch showing layout of main components of the *DEVICE* with estimated dimensions and weights
G. Estimated time schedule showing main activities of this project and the critical path
H. QAP proposal
I. Completed Technical Questionnaire

All documents shall be submitted in English, using SI units and suitable for reproduction.

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VTS II Cryostat (2010)

The following is an example of a complex technical specification document for procurement. It includes drawings, materials, loads, documentation, shipping, and acceptance tests requirements.

FERMILAB TD/T&I Department	Procurement Specification VTS II Cryostat Fermilab Specification Number: 5500-ES-371085	Doc. No. TID-N-259 Rev. None Date: 02/08/2010 Page 1 of 18

FERMILAB
Technical Division
Test and Instrumentation Department

Procurement Specification
VTS II Cryostat
Fermilab Specification Number: 5500-ES-371085

Prepared by: *[Signed copy in T&I Dept. Files]* Date: 02/08/10 Cosmore Sylvester, VTS2&VTS3 Project Engineer	**Organization** TD/T&I	**Extension** x4765
Reviewed by: *[Signed copy in T&I Dept. Files]* Date: 02/08/10 Joe Ozelis, VCTF Area Leader	**Organization** TD/T&I	**Extension** x4319
Approved by: *[Signed copy in T&I Dept. Files]* Date: 02/08/10 Ruben Carcagno, IB1 Test Area Upgrades Project Manager	**Organization** TD/T&I	**Extension** x3915

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FERMILAB TD/T&I Department	**Procurement Specification** **VTS II Cryostat** **Fermilab Specification Number: 5500-ES-371085**	**Doc. No. TID-N-259** **Rev. None** **Date: 02/08/2010** **Page 2 of 18**

Revision History

Revision	ER/ECO	Date	Description	Originated By	Approved By
None	ER #9693	02-Feb-10	Original Issue	Cosmore Sylvester	Ruben Carcagno

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1. Introduction

This specification provides the requirements for a cryostat assembly which is to be fabricated and delivered to Fermilab for use at the Vertical Cavity Test Facility (VCTF) located in Industrial Building 1 (IB1). This assembly includes a vacuum-insulated and ASME Boiler and Pressure Vessel (BPV) code stamped pressure vessel to be operated with helium at 2.0K, a liquid nitrogen cooled shield, a vacuum vessel, a top plate, cryogenic valves, a liquid helium bayonet connection, a liquid nitrogen bayonet

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connection, vacuum vessel isolation valve, and process instrumentation. A total of two (2) ASME BPV code certified and stamped top plates are required for the cryostat.

2. Scope

The vendor shall furnish all facilities, equipment, special tooling, consumables, and material, except where explicitly excluded in this specification, and perform all work and services necessary to design, fabricate, assemble, test, and deliver to Fermilab's site a fully functional ASME BPV Code stamped cryostat, in strict accordance with this specification, the relevant codes, industry standards, and supplied drawings. Fabrication drawings for the Code certified components (helium vessel, top plate, piping, and the vacuum vessel) shall be generated by the vendor based on this specification and supplied to Fermilab as part of the documentation provided. The vendor shall provide additional documentation as specified in section 13 of this specification. The deliverables are:

- Cryostat
- Two Top plates
- Vendor generated Drawings
- Vendor Design Report including calculations
- Shipping Restraint
- Documentation

3. Definitions

3.1. In this specification the VTS II cryostat and top plates shall be referred to as the *DEVICE*. *BUYER* refers to Fermilab, and the *SELLER* refers to the designer/fabricator/supplier of the *DEVICE*.

4. Drawings and Codes

4.1. The following codes, standards, and drawings are to be used for the design, fabrication, assembly and test of the helium vessel assembly, vacuum vessel assembly, process piping, and the top plate.

4.1.1. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code (latest version available at the time of fabrication).

4.1.2. ANSI/ASME Process Piping, B31.3

4.1.3. ASME Y14.5M-1994 Dimensioning and Tolerancing Code

4.1.4. Simplified Flow Schematic – Fermilab drawing number 1670.000-ME-418338 Rev. D

4.1.5. Cryogenic Interface - Fermilab drawing number 1670.000-ME-460923

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4.1.6. Top Plate Layout - Fermilab drawing number 1670.000-MD-460931 and 1670.000-MD-460932

5. Conflict Resolution

5.1. In the event of conflict between the *BUYER* supplied drawings and the written specification, the *SELLER* shall notify the *BUYER* to obtain further written guidance.

5.2. In the event of incompleteness or error in the *BUYER* supplied drawings, the *SELLER* shall notify the *BUYER* to obtain written construction directives.

6. Materials

6.1. The vendor shall ensure that the materials used for pressure vessel components meet all the requirements of Section VIII, Division 1 of the ASME BPV code. Copies of material certifications must be provided to *BUYER*.

6.2. Any materials used for pressure piping components shall conform to ASME/ANSI B31.3 requirements for appropriate service category and operating temperature range.

6.3. Material known to become brittle at cryogenic temperature shall not be used for components that may see temperatures lower than -150°C during normal or accidental operating conditions.

6.4. Except where explicitly otherwise defined by this specification, austenitic stainless steels (ANSI 304 or 316) shall be used for all components of the cryostat that are part of the top plate, helium vessel, or vacuum vessel.

6.5. Except where explicitly otherwise defined by this specification, OFE copper shall be used for components that are part of the nitrogen cooled shield.

6.6. Any fittings, bends, miters, or branch connections shall conform to ASME/ANSI B31.3 requirements for appropriate fluid service category and operating temperature range.

6.7. All pipe fittings shall be stamped with its working pressure "WP" in accordance with ANSI B16.9 specification.

6.8. Any flanges or blank-offs shall conform to ASME/ANSI B31.3 requirements for appropriate fluid service category and operating temperature range.

6.9. All internal vessel and piping surfaces shall be thermally isolated from each other by wrapping with alternate layers of aluminized Mylar and Reemay®.

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Use Scotch brand 850 PAU adhesive tape or similar to secure the above materials.

6.10. A minimum of thirty (30) layers of aluminized Mylar/Reemay® pairs shall cover all surfaces of the LHe vessel, and the internal helium piping. A minimum of sixty (60) layers are required on the LN2 cooled copper shield.

6.11. Wherever practical, a spiral half overlapped wrapping of aluminized Mylar/Reemay® paired material is preferred on piping. Where spiral wrapping is not practical blankets of no more than five layers of aluminized Mylar, interspersed with five layers of Reemay® may be applied. Additional five layered pair-blankets shall be used to reach the total number of layers required. The edges of multi layer insulation (MLI) blankets shall be symmetrically located so as to reduce the number of edges in any one region.

6.12. Whenever possible, edges of aluminized Mylar (whether individual or in blankets) shall be interleaved.

6.13. For all external piping penetrations, the MLI shall be tapered from a single layer at room temperature to the maximum number of layers required at the cold end as shown in drawing number 1670.000-MD-460996. The taper should be formed in such a manner that the bottom layer is of shortest extent, with upper layers being progressively longer.

6.14. No edge of an inner layer of aluminized Mylar shall touch any layer more than five (5) layers farther out in the wrapping. No other forms of thermal shorts in the insulation shall be permitted.

6.15. Wherever application of the above number of layers of aluminized Mylar/Reemay® will not fit between two surfaces, the number of acceptable layers will be determined by mutual agreement of the *BUYER* and the *SELLER*.

6.16. Application techniques shall follow the procedures and principles above to minimize heat transfer through gaps, exposed edges and shorts.

6.17. Burnt or singed insulation materials are not acceptable.

6.18. Fiberglass or other shielding shall be provided by the *SELLER* to prevent damage to insulation materials during welding or other operations. No such materials shall be left in the assembly except with the written permission of the *BUYER*.

6.19. Insulation materials shall not plug or block any pump out port or vacuum relief port.

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7. Helium Vessel

7.1. The simplified cryogenic flow schematic for the *DEVICE* is shown on drawing number 1670.000-MD-418338 Rev. D. A simplified mechanical assembly showing how the device is configured during operation is shown in Figure 1.0.

7.2. All components that fall within the scope of the ASME BPV code section VIII, division 1 shall be designed, fabricated, and tested in accordance with the ASME BPV code.

7.3. Following the completion of the design and prior to the start of fabrication a mandatory design review shall be scheduled by the *SELLER*. The *BUYER'S* approval of the design shall be obtained by the *SELLER* prior to the start of fabrication.

7.4. All piping shall be designed, fabricated and tested in accordance with the ASME/ANSI Process Piping B31.3 code.

7.5. All welding shall conform to the requirements of the ASME BPV Code, Section IX.

7.6. All welding shall be done by the Argon shield, fusion arc weld process. In addition to the above requirements, all welds shall be internally purged with 100% Argon during the time of welding.

7.7. The *SELLER* shall conduct helium leak tests of the helium vessel to assure leak tightness. No leaks should be detected on the most sensitive scale of the leak detector (with a minimum sensitivity 1 x 10^{-9} std. cc/sec) during the helium leak testing.

7.8. All joints in the helium circuit shall be soap and bubble checked for leakage at 80 psid, followed by a helium leak check using a leak detector with a minimum sensitivity of 1 x 10^{-9} std. cc/sec of helium.

7.9. Subsequent to the initial leak check all helium and nitrogen circuits shall be cold shocked with LN2 until equilibrium temperature of ~ 90 K is reached. Following the cold shock, a helium leak check using a leak detector with a minimum sensitivity of 1 x 10^{-9} std. cc/sec of helium will be performed, with a confirmation of no leaks.

7.10. At least 30 layers of MLI are required on the internal tubing.

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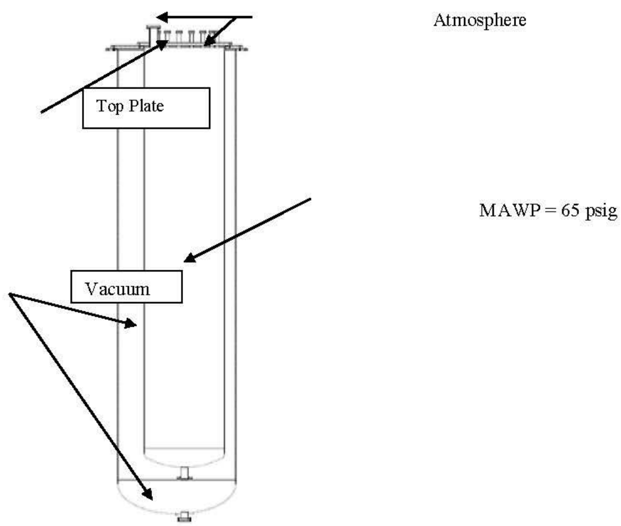

Figure 1.0 Cryostat in-use configuration

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8. Thermal Shield

8.1. The helium vessel and helium piping are to be thermally shielded with an LN2-cooled shield made of copper. Copper trace tubing (alloy 122) which will contain LN2 should be thermally attached to the shield via soldering.

8.2. Vendor modifications to this design are subject to *BUYER'S* written approval before the start of manufacturing.

8.3. The tubing material for the liquid nitrogen circuits not directly in contact with the copper shield must be ANSI 304 or 316 stainless steel.

8.4. All piping shall be designed, fabricated and tested in accordance with the ASME/ANSI Process Piping B31.3 code.

8.5. The LN2 shield must be covered with 60 layers or more of MLI, yielding a minimum total blanket thickness at least 1.0 inch.

8.6. The thermal shield tubing design must withstand a minimum pressure of 115 psid.

8.7. All joints shall be soap and bubble checked for leakage at 115 psid, followed by a helium leak check using a leak detector with a minimum sensitivity of 1 x 10^{-9} std. cc/sec of helium.

8.8. Subsequent to the initial leak check all helium and nitrogen circuits shall be cold shocked with LN2 until equilibrium temperature of ~ 90 K is reached. Following the cold shock, a helium leak check using a leak detector with a minimum sensitivity of 1 x 10^{-9} std. cc/sec of helium will be performed, with a confirmation of no leaks.

9. Cryogenic design and operating parameters

9.1. The design parameters for the *DEVICE* are given in Table 1.0. The operating pressure ranges between 0.1 psia and 19.0 psia.

Item	MAWP	Design Temperature
Helium Vessel	65 psig (surrounded by vacuum)	1.5K
Helium Piping	65 psig (surrounded by vacuum)	1.5K
LN2 Piping	100 psig (surrounded by vacuum)	90K
Vacuum Vessel	15 psid	300K

Table 1.0

9.2. Transient Operation

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The *DEVICE* shall be designed to allow for operation that is independent of the cooldown/warm up rates and sequence for the various cryogenic circuits. Each cryogenic circuit shall be capable of being cooled-down or warmed up independently at different rates.

9.3. Steady State Operation
The *DEVICE* is intended for the testing of superconducting RF cavities. During steady-state operations, the *DEVICE* provides a LHe bath at temperatures between 4.5K and 1.5K. Temperatures below 4.5K are attained by pumping on the He bath. The design of the *DEVICE* incorporates features that, coupled with proper fabrication techniques, minimize static heat loads to acceptable levels.

The cryostat design has provisions for filling the Helium Vessel with LHe to a desired level and for cooling this LHe volume to temperatures down to 1.5K by pumping on the LHe volume. After testing is complete, the remaining volume of LHe is warmed to 4.5K and vaporized, with the boiloff GHe returned to the cryoplant.

9.4. Heat Leak
The total heat leak for the *DEVICE* shall not exceed

- 120 W to 90K surface
- 10 W to 4.5K/2.0K (includes 4 watts for Cryogenic Control Valves)

SELLER shall verify the thermal design of the *DEVICE*. If changes or modifications are made to the VTS II design that have the potential to increase these heat leaks, the *SELLER* shall perform and provide to *BUYER* the heat leak calculations for such design modifications. The *BUYER* shall review and approve all such calculations and design modifications prior to implementation.

9.5. Pressure Drop
With the exception of the cryogenic control valves, the minimum hydraulic diameter of any component for any cryogenic circuit shall not be less than listed on *BUYER* supplied drawing. Pressure sensing lines which are connected to larger diameter piping or shells shall be welded to sleeves to preserve the tubing cross section. An example is shown in Figure **2**.

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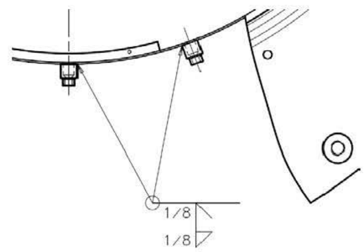

Figure 2 – Provision for instrumentation tube to vessel wall welds

9.5.1. As a check that the piping in the final assembly is free of obstructions, the following flow tests shall be performed by the *SELLER*. The following estimated pressure drops are determined with a 5 psig inlet pressure. Pressure drop may be scaled with flow squared in order to match vendor's instrumentation. See 1670.000-ME-418338 and 1670.000-ME-418351 for line definitions referenced in the following paragraphs.

9.5.2. ΔP1--LN2 shield (Nozzle I and C). A pressure drop of less than 3 psid shall be seen when measured with a flow of 4 SCFM air or nitrogen.

9.5.3. ΔP2--LHe supply line/bottom fill valve (Nozzle D of 1670-ME-418338 Rev. D; LCV-2930 of drawing 1670-ME-418351). A pressure drop of less than 1 psid shall be seen when measured with a flow of 4 SCFM air or nitrogen, with the valve fully opened.

9.5.4. ΔP3--LHe supply line/JT valve (Nozzle J of 1670-ME-418338 Rev. D; LCV-2920 of drawing 1670-ME-418351). A pressure drop of less than 5 psid shall be seen when measured with a flow of 4 SCFM air or nitrogen, with the valve fully opened.

9.5.5. ΔP5—GHe warm-up line (through Nozzles E on 1670-ME-418338 Rev. D). A pressure drop of less than 5 psid shall be seen when measured with a flow of 4 SCFM air or nitrogen.

9.5.6. ΔP6—Pump-out line for o-ring grooves (Nozzle A on 1670-ME-418338 Rev. D). A pressure drop of less than 3 psid shall be seen when measured with a flow of 2 SCFM air or nitrogen.

9.6. Instrumentation
Cernox® sensors from Lakeshore Cryotronics and platinum RTD's (PT-100) shall be installed in the process piping as shown on drawing number 1670.000-ME-460933. A minimum of six (6) inches of slack shall be provided on the leads to allow for connector removal and rewiring. Instrumentation which is for use in monitoring test

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conditions inside the *DEVICE* (liquid level sensors, heaters, RTD's) shall be installed by the *BUYER* after receipt of the *DEVICE*.

9.6.1. Each sensor (RTD) will have a unique serial number. This number shall be clearly marked and accessible on the lead wire bundles for each sensor at the room temperature end of each 4-wire bundle.

9.6.2. All temperature sensors shall be wired and measured using a 4-wire technique. *SELLER* will supply the wiring diagrams and measurement procedure.

9.6.3. Internal mounting of the temperature sensor (inside the pipe/tube) is preferred for all measuring points.

9.6.4. The *SELLER* is required to internally mount the thermometers in the flow path as shown on drawing 1670.000-ME-460920. Electrical instrumentation connectors will be supplied by *BUYER* and will be installed after receipt of the *DEVICE*. *SELLER* to provide blank-off plates manufactured per *BUYER* supplied drawing number 1670.000-MB-481078.

9.6.5. The electrical leads of each RTD shall be shorted prior to welding on nearby components to prevent damage to RTD's due to inductive currents.

9.6.6. In order to minimize conduction heat load via the pressure sensing lines and via the leads of the internally mounted RTDs, the length of the tube from the 80K surface to the 300K region should be at least 36 inches.

10. Vacuum Vessel

10.1. The vacuum vessel of the *DEVICE* must provide and maintain continuous sealed vacuum during operation without active mechanical pumping.

10.2. The vacuum vessel will experience a maximum external working pressure of 15 psid. The design internal MAWP is 15 psig.

10.3. The vacuum vessel shall be designed to ensure that the ASME Code allowable stresses for the material are not exceeded and to ensure that the vessel is stable (resistant to buckling) while subjected to a maximum external pressure of 15 psid. A Code stamp for this vessel is not required; however Code rules shall be applied to the design.

10.4. All welds on the vacuum vessel shall conform to the requirements in the ASME BPV code.

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10.5. The *SELLER* shall conduct helium leak tests to assure leak tightness. No leaks should be detected on the most sensitive scale of the leak detector (with a minimum sensitivity 1 x 10^{-9} torr-liter/sec of helium) during the helium leak testing.

10.6. All helium leak tests should be made in accordance with a written procedure prepared by *SELLER* and approved by the *BUYER*. The procedures must include, but are not limited to, the following information:

10.6.1. Description of the sub assembly or component

10.6.2. Specification for the equipment used for the leak test

10.7. Any test failure during the leak test which is correctable by simple re-welding or re-soldering may be undertaken without further direct contact with the *BUYER*. All leaks which fall within the leak tightness requirements or any unacceptable leaks which are repaired shall be fully documented and described in the written documents provided to the *BUYER* upon delivery of the *DEVICE*.

11. Loads

11.1. Some components of the *DEVICE* will experience loads due to vacuum, weight of test objects, and pressure. As an example, the weight of the entire assembly will be supported by the vacuum vessel top flange (drawing number 1670.000-ME-460929). This flange must be designed to carry this maximum static load of 30,000 pounds without exceeding the ASME BPV Code allowable stress for the flange material.

11.2. The top plate shall be designed to support a minimum of 4800 pounds which is the estimated weight of the insert assembly (baffles, vacuum instrumentation, cavities, internal radiation shields, cavity pumping line, variable couplers, etc.). In addition the top plate will experience loads due to atmospheric pressure on the top surface while the helium vessel is under vacuum, and will experience internal pressures up to the MAWP of the helium vessel. The design of the top plate must take into account all these static and dynamic loads.

11.3. The helium vessel shall be designed and manufactured to be ASME BPV Code compliant. The design of this vessel shall be capable of safe operation with an internal MAWP of 65 psig with full vacuum on the outer surfaces. The weight of the liquid helium contents is 800 lbs and the weight of the internal magnetic shield assembly is 516 lbs.

11.4. The *DEVICE* shall be designed and constructed in such a way as to allow it to be placed in a horizontal position for shipping and/or installation purposes

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without experiencing any degradation or component failure. The *SELLER* is responsible for the design and implementation of supports required to accommodate loads experienced during shipping and handling.

11.5. Provisions to accommodate the thermal contraction in the process piping must be included in the process piping design. In particular, the lateral deflection on the bayonet assemblies due to thermally induced loads shall be limited to between 0.005 inch and 0.010 inch. Use the *BUYER* supplied male bayonets to demonstrate that they can be freely inserted and removed following final assembly of the female bayonets.

12. BUYER Supplied Materials

The *BUYER* will provide the *SELLER* with the following items:

- Vacuum vessel isolation valve (Leybold part number: 215377)
- Parallel Plate relief assembly (1670.000-MB-106391)
- Cernox® RTDs mounted on circuit boards and lead wires connected. RTDs will be mounted on circuit boards in pairs and lead wires attached. Refer to 1670.000-MD-418338 Rev. D for the number of RTD's required.
- Liquid helium female bayonet assembly (1670.000-MD-257376-1)
- LN2 bayonet female assembly (1670.000-MD-257376-2)
- Cryogenic valves for top and bottom LHe supply (CPC-Cryolab Angle pattern, P/N CV8-086-CWTR1E-CB). If the *SELLER* wishes to provide these valves, *BUYER* will provide valve specifications and requirements to the *SELLER* upon request. The *BUYER* must approve in writing any substitution of the *BUYER* supplied valves by the *SELLER*.
- Liquid helium male bayonet assembly
- LN2 bayonet male assembly

13. Documentation

13.1. All mechanical and electrical drawings used to fabricate the cryostat assembly, the shipping fixture, and the design calculations for the DEVICE shall become the property of the *BUYER* and its domestic and international collaborators. These documents must be delivered to Fermilab as part of the final documentation package which must be provided as PDF files.

13.2. All special tooling developed for manufacturing this device shall become the property of the *BUYER* and its domestic and international collaborators.

13.3. *SELLER* generated "as built" drawings are to be delivered to *BUYER* in standard "English customary units".

13.4. The *SELLER* shall provide a copy of component test forms for each component tested. Test forms for the component or *DEVICE* shall be updated at the time of each test performed by the *SELLER* and must remain available for inspection by the *BUYER*.

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13.5. The *SELLER* must provide the *BUYER* with the ASME U1-A Manufacturer's data report for the helium vessel assembly, and for each top plate.

13.6. Copies of manuals, operating instructions, specifications, or drawings for any manufacturer supplied items must be supplied by the *SELLER* at the time of delivery of the *DEVICE* as PDF files.

13.7. Digital pictures which capture fabrication and assembly details at the witness and hold points must be provided to *BUYER*.

13.8. The *SELLER* shall provide to *BUYER* copies of material certifications and material test results required for Code compliance.

13.9. The *SELLER* shall provide to *BUYER* certificates of compliance for welding rods, electrodes, and other commercial items.

13.10. The *SELLER* shall provide to *BUYER* piping weld inspection results as specified in ASME B31.3.

13.11. The *SELLER* shall provide to *BUYER* a copy of the Manufacturer's Records of Welder or Welding Operators Qualification Tests as required by the provisions of the rules of Article III of the ASME BPVC, Section IX.

13.12. The *SELLER* shall provide to *BUYER* copies of all vacuum vessel design calculations and analyses specified in section 10.

13.13. The *SELLER* shall provide to *BUYER* pressure test certificates for all Coded pressure vessels.

13.14. The *SELLER* shall provide to *BUYER* pressure test certificates for all B31.3 piping.

13.15. The *SELLER* shall provide to *BUYER* mass spectrometer test certificates for all subassemblies and each completed purifier assembly.

13.16. The *SELLER* shall provide to *BUYER* copies of completed electrical test forms.

14. Witness and Hold Points

14.1. The *BUYER* and its domestic and international collaborators reserve the right to conduct a visit to the *SELLER* to assess that vendor's QA program prior to the start of fabrication. The *BUYER* also reserves the right to make on-site inspections of the *SELLER'S* facility at any time during fabrication of the *DEVICE* with particular interest at the following manufacturing stages:

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14.2. Design Review
14.3. Vessels construction, tube routing, valve installation, etc. to ensure proper construction and positioning before welding and before the application of MLI
14.4. After welding of liquid helium vessel to gage the final minimum inside diameter
14.5. Pressure Test
14.6. Installation of instrumentation (such as thermometry) in tubing and/or in vessel
14.7. Application of the first layer of MLI on vessels, tubing, thermal shields, valves, etc., and to observe the procedure for adding subsequent layers of MLI
14.8. Installation of the thermal shield
14.9. Assembly of the thermal shield tubing
14.10. Application of MLI on the thermal shield assembly
14.11. Assembly of the helium vessel and thermal shield into the vacuum vessel.
14.12. Flow test
14.13. Final assembly
14.14. The *SELLER* shall notify the *BUYER* at least 10 working days in advance of the day/time that these procedures/tests are planned so that Fermilab personnel will have sufficient time to schedule a visit to witness these tests if so desired.

15. Progress Reports

15.1. As part of the RFP process, *SELLER* must provide a detailed schedule with milestones to *BUYER*. After contract award, this schedule shall be used to monitor progress and must be updated by *SELLER* monthly. Bi-weekly teleconference meetings must be scheduled by *SELLER* to allow for the discussion of technical details and fabrication progress with the *BUYER'S* technical team. In addition, the *SELLER* must provide to *BUYER* a written monthly progress report in a mutually agreed upon format which must include the following:

15.2. Current month's activities.

15.3. Status of previous action items.

15.4. Identify items which may not be in full compliance with the specification or require major repair or revision to be brought into compliance must be reported.

15.5. The activities planned for the following month.

15.6. Project progress against the project schedule. Schedule updates or variations must be discussed along with corrective action that may be proposed by either party.

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15.7. Status of material procurements.

15.8. Other problems that may adversely affect the scheduled performance of the *DEVICE*.

15.9. *SELLER* will provide minutes of reviews and meetings:
- Meeting minutes must be provided within 5 days following the meeting.
- Action items lists must be provided within 3 days following the meeting where applicable.

15.10. *SELLER* must inform *BUYER* of any design changes which are deemed necessary after the design review, and secure BUYER'S approval before implementation.

16. Shipping

16.1. The *DEVICE* shall be crated in such a manner as to prevent damage from twisting, bending, or impact during shipment form *SELLER* to *BUYER*.

16.2. *SELLER* shall design the shipping restraint to facilitate transportation of the *DEVICE* in a horizontal position without damage to the *DEVICE*.

16.3. All items to be shipped shall be so crated or boxed as to be readily handled with a fork-lift truck or shall have suitable lifting attachments for use with an overhead crane. *SELLER* shall clearly identify sling/lift points and the center of gravity of the unit.

16.4. Shipping crates shall be clearly marked indicating the items of content, the Purchase Order number, and the gross weight.

16.5. *SELLER* shall provide the "as built" weight of the *DEVICE*.

17. Acceptance Tests

Upon receipt, the following incoming inspection tests will be performed immediately
- Visual inspection to check for defects in welds and for misalignment of welded sections
- Check operation of top and bottom fill valves
- Preliminary Helium leak check of the assembly
- Continuity and resistance measurement of the RTDs
- Final Helium leak check after removal of shipping restraint

18. Appendix (*BUYER* Supplied Drawings)

18.1. Table 2.0 lists all the *BUYER* supplied drawings.

Drawing Number	Rev	Description

This document is uncontrolled when printed. The current version is maintained on the T&I website.

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Drawing Number	Rev	Description
1670.000-ME-418338	D	SIMPLIFIED FLOW SCHEMATIC
1670.000-ME-418351		VTS-2 P&ID
1670.000-ME-460917		VERTICAL CRYOSTAT MAIN ASSEMBLY
1670.000-MD-460918		VACUUM VESSEL WELDMENT VTS-2
1670.000-ME-460919		80K SHIELD ASSEMBLY VTS-2
1670.000-ME-460920		PIPING DETAILS VTS-2
1670.000-ME-460921		WELD DETAILS HE VESSEL TOP FLG
1670.000-ME-460922		HELIUM VESSEL WELDMENT VTS-2
1670.000-ME-460923		HELIUM VESSEL-TOP FLANGE VTS-2
1670.000-MC-460924		NOZZLE HE VESSEL SHELL TO FLANGE
1670.000-MC-460925		SUPPORT RING- MAG. SHIELD VTS-2
1670.000-MC-460926		80K SHIELD TOP PLATE ASSY VTS-2
1670.000-MC-460927		80K SHIELD TOP PLATE VTS-2
1670.000-MB-460928		SHIPPING SUPPORT SLEEVE VTS-2
1670.000-MD-460929		VAC VESSEL TOP FLG WELDMENT VTS2
1670.000-MC-460930		80K SHIELD BOTTOM PLATE VTS-2
1670.000-MD-460931		HE VESSEL-TOP PL. WELDMENT VTS-2
1670.000-MD-460932		TOP PLATE HE VESSEL VTS-2
1670.000-MD-460933		TEMP. SENSOR FEEDTHRU VTS-2
1670.000-MB-460934		BLANK-OFF INSTRUMENT PORT VTS-2
1670.000-MB-460935		INSTRUMENTATION FEEDTHRU BOSS
1670.000-MB-460936		SENSOR CLOSURE PLATE- 1/4" TUBE
1670.000-MD-460937		PRESSURE-THERMOMETRY ASSY VTS-2
1670.000-MC-460938		PRESSURE-THERMOMETRY BLOCK VTS-2
1670.000-MB-460939		TRANSDUCER BLOCK MTG BRKT VTS-2
1670.000-MB-460940		BLANK-OFF CRYO-PORT 3/4 TUBE
1670.000-MB-460941		BLANK-OFF VAC BREAK VTS-2 TYPE 1
1670.000-MB-460942		BLANK-OFF VAC BREAK VTS-2 TYPE 2
1670.000-MB-460943		BLANK-OFF GHE VENT-PORT VTS-2
1670.000-MA-441720	A	THREADED ROD - THERMAL STAND-OFF
1670.000-MB-441698		REMOVABLE PIN WELDMENT
1620-C-96774		FLAT REFLECTOR- SUPERINSULATION
1670.000-MA-294072		REEMAY SPUNBOUND POLYESTER (RSP)
1670.000-MB-441641		SHIPPING SUPPORT NOZZLE
1670.000-MC-441644		SHIPPING SUPPORT-SHIELD EXTENSION
1670.000-MD-257376-1		1-1/2" FEMALE BAYONET ASSEMBLY(He)
1670.000-MD-257376-2		1-1/2" FEMALE BAYONET ASSEMBLY(N2)
1670.000-MB-441645		PUMP-OUT PORT WELDMENT
1670.000-MB-441646		PUMP-OUT PORT STAND-OFF
1670.000-MA-441647		PUMP-OUT PORT TUBE
1670.000-MB-106391		VACUUM RELIEF VALVE
1670.000-MB-106395	A	VACUUM RELIEF VALVE BASE PLATE
1670.000-MA-441651		BLANK-OFF CRYO PORT TYPE 1
1670.000-MB-304902	A	19-PIN CONNECTOR ADAPTER
1670.000-MD-460996		MLI INSULATION METHODS
1670.000-MB-460997		BLANK OFF – CRYO INSTR. PORT
1670.000-MB-481078		BLANK OFF – 19 PIN CONNECTOR
1670.000-MC-481079		LN2 INLET COIL – VTS2

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Procurement Bid Evaluation Criteria

The following is an example of procurement bid evaluation spreadsheet. This was used to rank bids from qualified vendors.

Factor	Weight value
A.1. Delivery Schedule and Production Facility	**10**
A.2. Design, Fabrication Method and Approach	**20**
A.3. Management and Quality Assurance	**10**
B.2. Price including BUY AMERICA ACT fee (12% SmallB, or 6% BigB)	**60**
TOTAL	100

The following adjective ratings are to be used to establish a common range of scores among the evaluators for proposals at similar levels of excellence, or lack thereof.

Adjective Rating	% of Points for Criteria	
Excellent	90	100
Very Good	75	89
Satisfactory	60	74
Marginal	40	59
Unsatisfactory	0	39

Definitions are as follows:

Excellent:
Exceeds required qualifications and performance capabilities; highest probability of success; no significant weakness.

Very Good:
Above average qualifications or performance capabilities; high probability of success; few significant weaknesses.

Satisfactory:
Meets required standards; good probability of success; weaknesses can be readily corrected.

Marginal:
Does not appreciably meet requirements; weaknesses may be correctable to satisfactory degree; low probability of success

Unsatisfactory:
Fails to meet minimum requirements; needs a major revision to the proposal to make it acceptable.

A.Klebaner 1/6/2009

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PROJECT NAME
RFP No. 0000000
BID EVALUATION CRITERIA

Evaluator Name(s): Engineer A, Engineer B, Engineer C and Procurement Specialist
Date:

Evaluation Factors	US Company A Small Business	Foreign Company B	Foreign Company C	Comments
A. Technical Evaluation				
A.1. Delivery Schedule and Production Facility				
Production capacity (machines, space and equipment)	100	80	50	Based on visits to Company A, Company B and Company C
Quality of machines and test instruments	90	80	90	Based on visits to Company A, Company B and Company C
Key technical staff (fabrication engineers, welders, technicians)	90	70	75	Based on vendor's visits and comm with eng and tech staff
Proposed delivery schedule	100	90	45	Based on the project schedule requirements
Potential to avoid schedule conflict	60	70	100	Based on previous experience
Schedule credibility	50	40	50	Based on submitted scheduled
Adjective Overall Rating (excellent to unsatisfactory)	Very Good	Satisfactory	Satisfactory	
Average %Points (see range for each adjective rating)	82	72	68	
Weight Value (out of 100 total scoring points)	10	10	10	
Scoring points	**8.2**	**7.2**	**6.8**	
A.2. Design, Fabrication Method and Approach				
Understanding requirements	100	100	90	Based on review of the RFPs
Completeness of Technical Questionnary	85	0	90	Based on submitted Technical Questionnary
Technical Approach to meeting Specification	85	80	85	Based on review fo the RFPs
Mechanical and technical integration of components	85	80	85	Based on provided info on T_ connections
Specific design solution(s) (contraction/expansion, etc)	85	35	50	Based on specific design solutions for instrumentation
Vendors choice	75	45	75	Based on review fo the RFPs
Gen Inspection plan/test procedures	60	60	80	Based on review fo the RFPs
Tasks to be subcontracted and quality of subcontractors	60	60	60	Based on review fo the RFPs
Crating and shipping plan	75	75	60	Based on review fo the RFPs
Adjective Overall Rating (excellent to unsatisfactory)	Very Good	Marginal	Satisfactory	
Average %Points (see range for each adjective rating)	79	59	73	
Weight Value (out of 100 total scoring points)	20	20	20	
Scoring points	**15.8**	**11.9**	**14.6**	
A.3. Management and Quality Assurance				
Quality Assurance Plan	100	100	100	Based on review fo the RFPs
Welding, cleaning, vacuum leak check procedures	100	100	100	
Proj manager assigned to the project and % effort dedicated to CDS	70	70	90	
Quality of key welding personnel	100	100	100	
Change control procedures and implementation style	70	70	70	
Site proximity and ease of oversight	40	40	100	
Adjective Overall Rating (excellent to unsatisfactory)	Very Good	Very Good	Excellent	
Average %Points (see range for each adjective rating)	80	80	93	
Weight Value (out of 100 total scoring points)	10	10	10	
Scoring points	**8.00**	**8.00**	**9.33**	
Total Technical Score (max 40 points)	**32**	**27**	**31**	

B.DeCraff./A.Klebaner/T.Nicol 9:01 AM 1/6/2009

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PROJECT NAME
RFP No. 0000000
BID EVALUATION CRITERIA

Evaluator Name(s): Engineer A, Engineer B, Engineer C and Procurement Specialist
Date:

Evaluation Factors	US Company A Small Business	Foreign Company B	Foreign Company C	Comments
B. Price Evaluation				
B.1 Price quote	$100,000	$90,000	$100,000	
B.2 Price incl BUY AMERICA ACT fee (12% SmallB, or 6% BigB)	$100,000	$100,800	$112,000	
Adjective Overall Rating (excellent to unsatisfactory)	Excellent	Excellent	Very Good	
%Points (see range for each adjective rating)	100	99	89	
Weight Value (out of 100 total scoring points)	60	60	60	
Total Price score (max 60 points)	60	60	54	
Total Technical and Price Score (max 100 points)	92	87	84	
Resulting rank	1	2	3	

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Appendix F: Chapter 8 Examples

Tevatron Dipole Kautzky Valve Replacement Procedure (2002)

The following is an example of written procedures, which would be included in release to operations documentation. It includes a list of required material and a list of responsibilities for the procedure.

ADDP-CR-2301
REV. 2

ACCELERATOR DIVISION DEPARTMENTAL PROCEDURE

CRYOGENIC SYSTEMS

ADDP - CR - 2301

TEVATRON DIPOLE KAUTZKY VALVE

REPLACEMENT PROCEDURE

PREPARED BY ______________________ DATE __________
D. Ostrowski
Senior Technician

REVISED BY ______________________ DATE __________
D. Ostrowski
Senior Technician

APPROVED BY ______________________ DATE __________
J. C. Theilacker
AD/Cryogenic Department Head

REVISION NO. 2 REVISION ISSUE DATE 3/19/02

CONTROLLED COPY NO. _______

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ADDP-CR-2301
REV. 2

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1.0 PURPOSE AND SCOPE

The purpose of this procedure is to define the steps taken to replace a cold Tevatron dipole single-phase helium Kautzky valve.

2.0 PRECAUTIONS

Cold helium gas could cause severe burns if it comes in contact with the skin. A large release of Helium gas in a small area could cause a localized ODH condition.

3.0 TOOLS AND MATERIALS

1	Flashlight (confirm that it works)
2	9/16" Open end wrenches
1	1/2" Open end wrench
1	7/16" Open end wrench
2	New Kautzky valves
4	O-rings #2-226 (used on inlet and outlet flange)
2	O-rings #2-133 (used on Kautzky caps)
2	O-rings #2-137 (Alternate type used on Kautzky caps)
4	Marmon clamps
4	1/4" S.S. Swagelock plugs
4	1/4" Swagelock caps
3	Face shields
3	pr Cryo gloves
1	3/8" Ratchet
1	3/8" Extension 4" long with 7/16" deep well socket
1	3/8" Torque wrench set for 80 inch pounds
1	Plunger assembly
2	Kautzky valve blank off flanges (male)
2	Kautzky valve Blank off flanges (female)
2	Turbo propane torches w/automatic ignition
1	Spare tank of propane
1	Blank off for double Kautzky change (wedge)
4	Danger tags and locks for LOTO
1	Bottle of Snoop
1	Portable light source
1	50' extension cord
1	Portable Kautzky Control Pressure Station

All personnel involved will wear long-sleeved shirts, long pants, leather safety shoes (no tennis shoes), face shields, cryo gloves, and an oxygen monitor when cryogens are present.

All personnel involved shall read the entire procedure before proceeding.

4.0 RESPONSIBILITIES

Person A Leads the team.
Person B Assists.
Person C Observes and assists where neeeded.

Experience level advancement:

C - least experienced
A - most experienced

Reference ADDP-CR-9200 for personnel requirements and qualifications.

5.0 PREREQUISITES/INITIAL CONDITIONS

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5.1 For a helium Kautzky valve change, have Cryogenic Coordinator dump any liquid helium inventory and warm up affected string to at least 20K.

6.0 REFRIGERATOR BUILDING SETUP

6.1 If Kautzky manifold is hard lined, first valve in the Helium Kautzky cylinders at the Kautzky supply pressure manifold in the service building and valve out the hard line. Make certain there is at least the equivalent of a full cylinder. Then "Crash" the building by closing EV-101-H located in the box on the front of the refrigerator building.

6.2 Shut off wet and dry engines (if they aren't already off). Put both in LOCAL and push the emergency stop button to OFF. Turn off the cold compressor and place it in LOCAL.

6.3 Close EVQH, EVLH and EVJT. Leave in LOCAL.

6.4 Open EVBY, EVUC, and EVDC. Leave in LOCAL.

6.5 Building pressure (on PI-4 gauge) should go down to about 0 psig. Single-phase pressure should go down to <3 psig (on single phase gauge on valve box appendage).

6.6 Install lock and "Danger Do Not Operate" tags on the EV-101 "Crash" button box. Close the I/O crate door and place lock and "Danger Do Not Operate" tag on locking hinge to isolate valve actuators.

7.0 TEVATRON DIPOLE SINGLE PHASE KAUTZKY VALVE REPLACEMENT

7.1 Connect the Kautzky valve control pressure line to the Kautzky valve change fixture. Purge the two Kautzky valve supply pressure lines for about 15 seconds, then connect one line from the change fixture to the old kautzky (still on the magnet) and the other from the change fixture to the new Kautzky valve. Open both supply valves on the change fixture to close both Kautzky valves.

7.2 Put on face shields and cryogenic gloves (if cryogens are present).

7.3 Warm defective valve as much as possible. Avoid damaging platinum resistor on suction flex line, wires, and O-rings.

7.4 ***Person A*** Removes the magnet to Kautzky valve Marmon clamp while ***Person B*** holds the old valve on the magnet, pressing hard to prevent cold helium gas from escaping.

7.5 ***Person A*** Drops the clamp and grabs the new Kautzky valve, checks that the poppet is closed and gets into position to insert the valve. Caution: Do not be in front of port!

Person B Gets into a position to remove old valve so as not to block ***Person A***'s way. Caution: Do not be in front of port!

7.6 When everyone is ready,

Person A Gives a signal and

Person B Remove the old valve, (which is still pressurized and attached to the flex hose) and

Person A Immediately installs the new Kautzky valve to the magnet pushing it hard against the magnet to keep cold helium gas from escaping and freezing the O-ring.

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	Person C	If problem occurs at this point (such as the O-ring stays on the magnet causing leakage and frosting through the new Kautzky valve) insert the plunger into the magnet port immediately after ***Person A*** has removed the new valve.
7.7	***Person B***	Caps the magnet side of old Kautzky valve and attaches a Marmon clamp. (There may be about 5 lbs. of force from suction pressure if the valve is stuck open.) If the Kautzky valve actuator bellows has a severe leak, close valve on Control Pressure Station to old valve to prevent the supply cylinder from going empty and opening all the Kautzky valves in the string.
7.8	***Person B***	Installs a Marmon clamp on new Kautzky valve to magnet flanges and torques it to 80 in-lbs.
7.9	***Person A***	Holds the suction header flex hose with both hands and slightly pushing towards the Kautzky valve while
	Person B	Holds the Kautzky valve with one hand pushing slightly towards ***Person A*** and removes the clamp with his free hand.
7.10	***Person A&B***	position themselves as close as possible to the new Kautzky valve on the magnet. On ***Person A's*** signal ***Person B*** removes the old Kautzky valve from the flex hose and ***Person A*** immediately installs it on the new Kautzky valve. Be prepared for a very noisy and strong rush of gas from the flex hose when the Kautzky valve is removed.
	Person B	Install a Marmon clamp on new Kautzky valve to flex hose flanges and torques it to 80 in-lbs.
7.11	***Person B***	Reinstalls the control pressure line to the new Kautzky valve. Make certain to use a backup wrench on the fitting to avoid breaking the solder joint on the Kautzky valve fitting.

7.12 Snoop control pressure connection and flanges and fix any leaks.

8.0 REFRIGERATOR BUILDING RETURN

8.1 Check everything you bring out of the tunnel including yourself for radiation and tag as appropriate per Fermilab Radiological Control Manual, Chapter 3.

8.2 Remove locks and "Danger" tags. "Uncrash" building by opening EV-101. Wait till pressure equalizes and then return actuator valves in refrigerator building to REMOTE and engines and cold compressor to REMOTE.

8.3 Call the Cryogenic Coordinator/Main Control Room and inform them that you are done and returning the refrigerator to their control.

9.0 EXTRA-DEPARTMENTAL DISTRIBUTION

None

10.0 RECORDS

10.1 Complete the Kautzky valve failure report (Attachment 1) and return it to the Department Head.

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REV. 2

PROCEDURE USAGE

KAUTZKY VALVE FAILURE REPORT

Date ____________

Time ____________

Tunnel Location ____________

Serial Numbers
old valve ____________

new valve ____________

Reason for Replacing

____

____

____

____

Names of tunnel access team

____

____

____

____

Form is to be turned in to the Department Head when completed. Records will be retained for one calendar year.

PAGE 1 OF 1 ATTACHMENT 1

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Equipment Specific Lockout/Tagout Procedure for the C-0 Shunt Power Supply at B4 (2003)

The following is an example of department procedures. It includes the list of steps for the procedure along with a checklist to ensure all steps are completed.

BDDP-EE-4923
Rev. 0

BEAMS DIVISION DEPARTMENTAL PROCEDURE

ELECTRICAL/ELECTRONIC SUPPORT DEPARTMENT

BDDP-EE-4923

EQUIPMENT SPECIFIC LOCKOUT/TAGOUT PROCEDURE

FOR THE C-0 SHUNT POWER SUPPLY AT B4

PREPARED BY_________________________________ DATE __________
Howie Pfeffer, Knowledgeable Employee

APPROVED BY_________________________________ DATE __________
Dan Wolff, Department Head

ISSUE DATE: 1/9

/03

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BDDP-EE-4923
Rev. 0

REVIEW AND CONCURRENCE RECORD

REVIEWED BY_________________________________ DATE ___________
Julius Lentz

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BDDP-EE-4923
Rev. 0

1.0 PURPOSE AND SCOPE

The purpose of this Beams Division Departmental Procedure (BDDP) is to outline and detail the conduct of LOCKOUT/TAGOUT (LOTO) for the maintenance of the C-0 SHUNT Power Supply. The Power Supply consists of a FET bank, a resistor bank and a 120 Amp bias supply. It is directly connected to the Tevatron Bus,which is a source of potential hazard.

2.0 AUTHORIZED PERSONNEL

A Beams Division employee is authorized to perform this LOTO procedure if he/she has the necessary knowledge and current training in electrical safety, has read and understands this LOTO procedure, possesses the requisite knowledge with respect to high power electronic equipment and the configuration of the horn load.

The EE Support Department Head maintains a list of department personnel authorized to perform this procedure. This list is accessible on the web via the department's home page under "LOTO Compliance".

In times of emergency the Department Head or the Power Supply Group Leader may authorize other employees to perform this procedure. They shall assure themselves that the employee has read this procedure and can safely perform the necessary activities.

3.0 THE NECESSITY OF WRITTEN LOTO PROCEDURE

Written LOTO procedures apply to the C-0 Shunt Power Supply because of the hazards associated with being connected to the main Tevatron Bus.

4.0 THE STEPS OF LOCKOUT/TAGOUT PRIOR TO MAINTAINANCE ACTIVITY

4.1 **Prepare:** The authorized employee shall understand the hazards involved and how to control them. **Safety Glasses shall be worn at all times while performing this procedure. The two-man rule shall apply at all times maintenance work is performed on this equipment**

4.2 **Notify:** The authorized employee should, as necessary, notify affected area personnel of the LOTO maintenance activity. Affected personnel include those who might normally use the equipment or would be affected by the unavailability of the equipment. It may be necessary to notify the Crew Chief in the Main Control Room (Ext. 3721), particularly if maintenance work is to be done to the water-cooling system.

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4.3 **Shutdown:**

4.3.1 Halt the Tevatron Ramp.

4.3.2 Turn OFF all Tevatron VCB's.

4.3.3 Get a Tev PS key from the crew chief and bring it to B4 service building.

4.4 **Isolate:** The authorized employee shall isolate the equipment from its energy sources

4.4.1 Isolate the 120 VAC power from the rack by doing the following:

4.4.1.1 Observe the lit 120VAC indicator bulb on the rack front panel.

4.4.1.2 LOTO the 120 VAC wall breaker #------

4.4.1.3 Verify that the 120 VAC has been isolated by observing that the indicator bulb is now OFF.

4.4.2 Use Tev PS key to open the back door of rack #-----

4.4.3 Open cover of knife switch enclosure.

4.4.4 Use TESTED voltmeter to assure there is no voltage on the knife switch terminals with respect to cabinet ground.

4.4.5 Open the knife switch.

4.4.6 Close and LOTO the knife switch enclosure door

The equipment is now locked out. Service or maintenance activity may now begin.

5.0 SHIFT AND PERSONNEL CHANGES

A lead authorized employee shall ensure that Lockout/Tagout procedures are followed when the C-0 Shunt Supply enclosure is locked out over a shift or personnel change. This same lead authorized employee shall ensure:

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Rev. 0

5.1 That no unauthorized lock and tag removals have taken place

5.2 An orderly exchange of locks and tags from off-going to on-coming employees

5.3 An orderly transfer of responsibility and information about the equipment status from the off-going to on-going shift.

6.0 THE FIVE STEPS FOR RETURN TO SERVICE

The authorized employee must perform the following steps prior to returning the equipment to service after maintenance activity.

6.1 **Check Equipment:** Check the equipment and the immediate area around it to ensure that nonessential items and tools are cleared and that the equipment is ready for safe operation.

• Check high current components and all high current connections for tightness and integrity.

6.2 **Check Work Area:** Check the work area to ensure that all employees are safely positioned or removed from the area as necessary and/or appropriate.

6.3 **Verify:**

1. Verify that you have a Tev PS key in your possession.
2. Open knife switch enclosure .
3. With TESTED voltmeter, verify that there is no voltage on knife switch inputs with respect to cabinet ground.
4. Close knife switch.
5. Close knife switch enclosure door. Do NOT padlock.

6.4 Remove Padlocks and Tags and Re-energize:

1. Close and lock all doors on the C-0 Shunt Supply enclosure.
2. Remove Lock from wall breaker #------- and energize the breaker.
3. Return Tev PS key to the MCR.

6.5 **Notify:** The authorized employee should, as necessary, notify affected area personnel of the completion of maintenance and LOTO activity. If the Crew Chief in the Main Control Room was notified prior to the activity, he/she should be notified of the completion of the activity.

This completes the requirements for returning the Power Supply to service.

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7.0 PROCEDURE TRAINING REQUIREMENTS

Authorized employees are required to have had LOTO training (Level 1 and Level 2), and have read and understood this LOTO procedure.

Electrical/Electronic Department Personnel using this procedure shall be trained on the job. After reviewing this document, the employee shall perform the steps accompanied by an employee with previous experience. The authorized employee shall then complete a "Beams Division Electrical/Electronic Department Procedures Review Form" and turn it in to the department secretary.

Personnel from other departments shall be trained according to the requirements of their department.

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Rev. 0

ATTACHMENT #1

LOTO Checklist for MiniBooNE Horn Power Supply at MI2

Shutdown:

________ If possible, lower the reference to zero.
________ Push the Emergency Off button.

Isolate:

________ Open the disconnect switch #DS-DHP-MI2A-3-CB4.
________ Turn and remove the key from the Kirk lock on the disconnect switch.

Verify:

________ Look into the disconnect window and verify that all 3 knife blades are open.

Relief of stored energy:

________ Open door #1 and inspect the position of the shorting relay

Relieve Stored Energy in Cells 1 and 2:
Test the RESISTOR stick (pulsating tone)
________ Using the RESISTOR stick touch the cap bank common side and then hot side
________ Do the same for the adjacent cell.
________ Test the hard ground stick (constant tone)
________ Using the hard ground stick, attach ground cables to the cap bank common side and then the hot side
________ Do the same for the adjacent cell.
________ Close the doors and lock them.

________ Open door #2 and inspect the position of the time delay shorting relay

Relieve Stored Energy in Cells 3 and 4
________ Using the RESISTOR stick touch the cap bank common side and then hot side
________ Do the same for the adjacent cell.
________ Using the RESISTOR stick, touch the common and the hot side of the Charging Supply Capacitor
________ Test the hard ground stick (constant tone)
________ Using the hard ground stick, attach ground cables to the cap bank common side and then the hot side
________ Do the same for the adjacent cell.
________ Using the hard ground stick, attach ground cables to the Charging Supply Capacitor common side and then the hot side
________ Close the doors and lock them.

1 ATTACHMENT 1

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Rev. 0

Proceed with Cells 16 through 5 using the same procedure as Cells 1 and 2
________ CHECK BACKUP SHORTING RELAY
________ Door 8, cells 15 and 16
________ Door 7, cells 13 and 14
________ Door 6, cells 11 and 12
________ Door 5, cells 9 and 10
Door 4, cells 7 and 8
________ Door 3, cells 5 and 6

________ Place the RESISTOR grounding stick back to the normal location.

________ Install the key in the lock box and apply personal LOTO lock

The equipment is now locked out. Service or maintenance activity may now begin.

2 ATTACHMENT 1

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BDDP-EE-4923
Rev. 0

ATTACHMENT #2

Return to Service LOTO Checklist for MiniBooNE Horn Power Supply at MI2

Check Equipment:

________ Check nonessential items and tools are cleared from the area
________ Check high current components and all high current connections
Remove and debris around high voltage conductors (horn and strip line)

Remove all grounds from capacitor banks and from the charging supply capacitor
________ Door 1, cells 1 and 2
________ Door 2, cells 3 and 4
________ CHARGING POWER SUPPLY CAPACITOR
________ Door 3, cells 5 and 6
________ Door 4, cells 7 and 8
________ Door 5, cells 9 and 10
________ Door 6, cells 11 and 12
________ Door 7, cells 13 and 14
________ Door 8, cells 15 and 16

________ Make sure the resistive grounding stick is stored in the normal location.

Check Work Area:

________ Check the work area to ensure that all employees are safely positioned or removed from the area as necessary and/or appropriate

Verify:

________ Verify that all controls are in the OFF position

Remove Padlocks and Tags and Re-energize:

________ Close and lock all doors on the capacitor bank enclosure and charging supply racks
________ Return the door key to the Kirk captured key assembly

Notify:

________ The authorized employee should, as necessary, notify affected area personnel of the completion of maintenance and LOTO activity. If the Crew Chief in the Main Control Room was notified prior to the activity, he/she should be notified of the completion of the activity.

This completes the requirements for returning the Power Supply to service.

1 ATTACHMENT 2

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Equipment Specific Lockout/Tagout Procedure PD Klystron Modular with Temporary PD Charging Supply Located at Meson Detector Building (2007)

The following is an example of department procedures. It includes the list of steps for the procedure along with sign-off sheets for reviewing the procedure.

ADDP-EE-9923
Rev. 1

ACCELERATOR DIVISION DEPARTMENTAL PROCEDURE

ELECTRICAL/ELECTRONIC SUPPORT DEPARTMENT

ADDP-EE-9923

EQUIPMENT SPECIFIC LOCKOUT/TAGOUT PROCEDURE

PD KLYSTRON MODULATOR

WITH TEMPORARY PD CHARGING SUPPLY

LOCATED AT MESON DETECTOR BUILDING

PREPARED BY_________________________ DATE __________
Howie Pfeffer, Knowledgeable Employee

APPROVED BY_________________________ DATE __________
Dan Wolff, Department Head

ISSUE DATE: 2/16/07
REVISED: 2/25/07

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ADDP-EE-9923
Rev. 1

REVIEW AND CONCURRENCE RECORD

REVIEWED BY_________________________________ DATE ___________
Chris Jensen

Revision History

Rev 1 – Changed from BD to AD, Shutdown steps 5.3.2 and 5.3.3 were modified, added Electrical Safety in Workplace to training requirements

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1.0 PURPOSE AND SCOPE

The purpose of this Accelerator Division Departmental Procedure (ADDP) is to outline and detail the conduct of LOCKOUT/TAGOUT (LOTO) for the maintenance of the PD Klystron Modulator located at Meson Detector Building. The modulator consists of three major elements; a charging source, a switch / capacitor bank enclosure and a pulse transformer. The charging source converts 480 VAC to 12 kVDC. The main capacitor bank contains up to 300 kJ of stored energy at maximum working voltage. The bouncer capacitor bank contains up to 9 kJ of stored energy at maximum working voltage. The switch connects the main capacitor bank to the pulse transformer which steps up the voltage to the 100 kV level required by the klystron.

2.0 PERFORMANCE OF MAINTENANCE ACTIVITIES

3.0 AUTHORIZED PERSONNEL

An Accelerator Division employee is authorized to perform this LOTO procedure if he/she has the necessary knowledge and current training in electrical safety, has read and understands this LOTO procedure, possesses the requisite knowledge with respect to high power electronic equipment and the klystron load. For further training see section 8.0 Procedure Training Requirements.

The EE Support Department Head maintains a list of department personnel authorized to perform this procedure. This list is accessible on the web via the department's home page under "LOTO Compliance".

In times of emergency the Department Head or the Power Supply Group Leader may authorize other employees to perform this procedure. They shall assure themselves that the employee has read this procedure and can safely perform the necessary activities.

4.0 THE NECESSITY OF WRITTEN LOTO PROCEDURE

Written LOTO procedures apply to the PD Modulator because of the hazardous stored energy in the system's capacitor banks (which must be discharged after the source of power is locked out) and because of multiple power sources (480 VAC in the charging supply and 120 VAC in both the modulator and charging supply).

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5.0 THE STEPS OF LOCKOUT/TAGOUT PRIOR TO MAINTAINANCE ACTIVITY

5.1 **PREPARE:** The authorized employee shall understand the hazards involved and how to control them. Proper personal protective equipment (PPE) shall be worn at all times while performing this procedure. The two-man rule shall apply at all times maintenance work is performed on this equipment.

5.2 **NOTIFY:** The authorized employee should, as necessary, notify affected area personnel of the LOTO maintenance activity. Affected personnel include those who might normally use the equipment or would be affected by the unavailability of the klystron.

5.3 **SHUTDOWN:**

5.3.1 Go to the PD-R2 rack for the modulator controls.

5.3.2 Place the "Pulse Inhibit" switch to "Off".

5.3.3 Issue an OFF command

5.4 **ISOLATE:** The authorized employee shall isolate the equipment from its energy sources

5.4.1 Observe that the 480 VAC indicator lights on the disconnect switch enclosure (#DHP MDB–8–1, ckt 20–22–24) are on. The lights should go off as you turn off the disconnect.

IF THESE LIGHTS DO NOT GO OFF OR WERE NOT ON BEFORE OPERATING THE DISCONNECT, STOP THE PROCEDURE AND CONSULT WITH EXPERTS

5.4.2 Observe that the three switches in the window of the disconnect switch enclosure are all open.

5.4.3 Unplug and LOTO the cord going to the charging supply rack from the welding outlet.

5.4.4 Remove the Kirk key from the key switch on the "PD Charging Supply" rack for use in 5.5

Note: All 120 V_{AC} wiring within the capacitor bank enclosure is guarded and protected by utility boxes, terminal strip covers, etc. No 480 V_{AC} power exists within the capacitor bank enclosure.

5.5 **RELIEVE STORED ENERGY:** The main capacitor bank and the bouncer capacitor bank.

5.5.1 Visually verify that both the main capacitor bank shorting relay (seen at top of window) and the bouncer capacitor bank shorting relay (seen at bottom of window) are closed. They can be seen through the viewing window next to the pulse transformer. A flashlight may be required.

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5.5.2 Verify that the high-voltage meter (on the hot stick) is functioning by measuring the 200 V test voltage mounted on door #1. The meter response time is several seconds.

5.5.3 Open door #1 with Kirk key

5.5.4 Visually verify that the main capacitor bank shorting relay makes a continuous path to the return bus from the main capacitor high voltage bus through the discharge resistor stack.

5.5.4 Visually verify that the bouncer capacitor bank shorting relay makes a continuous path to the return bus from the bouncer capacitor high voltage bus through the two discharge resistors.

5.5.5 Visually verify that the return bus is connected to the capacitor rack frame ground.

5.5.6 Open Door #2 with Kirk key

5.5.7 Observe that the high voltage bushings of each of the bouncer capacitors are connected to the bouncer capacitor high voltage bus.

5.5.8 Observe that the return bushings of each of the bouncer capacitors are connected to the return bus (located behind the bouncer capacitor high voltage bus).

5.5.9 Observe that the high voltage bushings of each of the main capacitors are connected to the main capacitor high voltage bus through the wire wound fault resistor.

5.5.10 Observe that the return bushings of each of the main capacitors are connected to the return bus (located behind the main capacitor high voltage bus).

5.5.11 Observe that the jumpers for both capacitor high voltage buses and return buses are connected to the corresponding bus behind the adjacent door.

REPEAT STEPS 5.5.7 through 5.5.11 for door #3 and door #4

5.5.12 Open Door #2 with Kirk key

5.5.13 Using the high voltage meter, measure the voltage on the main capacitor high voltage bus and on the bouncer capacitor high voltage bus to determine both are zero.

NOTE: Apply meter to broad surface of bus to avoid accidental bridging to ground.

IF THIS MEASUREMENT OR ANY OTHER MEASUREMENTS DO NOT SHOW ZERO VOLTAGE, STOP THE PROCEDURE AND CONSULT WITH EXPERTS.

5.5.14 Using the high voltage meter, observe that the voltage on the each of the main capacitor high voltage bushings is zero.

5.5.15 Using the high voltage meter, observe that the voltage on each of the bouncer capacitor high voltage bushings is zero.

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REPEAT STEPS 5.5.13 through 5.5.15 for door #3 and door #4

5.5.16 Using the high-voltage meter, observe that the voltage on the power supply filter capacitors is zero. (This step is unique to door # 4)

5.5.17 Verify that the high voltage meter still reads 200 VDC at the test voltage point on Door #1.

IF THIS MEASUREMENT DOES NOT SHOW 200 VDC THE METER MAY BE BROKEN. STOP THE PROCEDURE AND CONSULT WITH EXPERTS.

5.5.18 Open Door #2 with Kirk key

5.5.19 Using the ground stick, touch each of the main capacitor high voltage bushings.

5.5.20 Using the ground stick, touch each of the bouncer capacitor high voltage bushings.

5.5.21 While grounding the bouncer capacitor high voltage bus with the ground stick, ground it with the ground clip (smaller size).

5.5.22 While grounding the main capacitor high voltage bus with the ground stick, ground it with the ground clip (larger size).

REPEAT STEPS 5.5.19 through 5.5.22 for door #3 and door #4

5.5.23 Using the ground stick, touch the power supply filter capacitors.
(NOTE: This step is unique to Door 4)

5.5.24 Return the Kirk key to its original location

THE MODULATOR IS NOW LOCKED OUT. SERVICE OR MAINTENANCE ACTIVITY INSIDE THE MODULATOR MAY NOW BEGIN.

IF ACCESS TO THE INSIDE OF THE PULSE TRANSFORMER IS REQUIIRED THE FOLLOWING MUST BE DONE AFTER ABOVE STEPS.

5.5.25 Go to rack PD-R1 and turn off the supply labeled "Transformer Bias Supply"

5.5.26 Unplug the supply in the back of the rack (208V, 1 Ø) and LOTO it.

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ADDP-EE-9923
Rev. 1

THE PULSE TRANSFORMER BIAS SUPPLY IS NOW LOCKED OUT. SERVICE OR MAINTENANCE ACTIVITY INSIDE THE PULSE TRANSFORMER MAY NOW BEGIN.

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ADDP-EE-9923
Rev. 1

IF ACCESS TO THE KLYSTRON CATHODE OIL TANK, KLYSTRON HV CABLES OR PULSE TRANSFORMER OUTPUT SECTION IS REQUIRED THE FOLLOWING STEPS MUST BE DONE AFTER ABOVE STEPS

5.5.27 Go to rack PD-R1 and turn off the supply labeled "Klystron Heater Supply"

5.5.28 Unplug the supply in the back of the rack (120V, 1 Ø) and LOTO it.

THE KLYSTRON HEATER SUPPLY IS NOW LOCKED OUT. SERVICE OR MAINTENANCE ACTIVITY INSIDE THE PULSE TRANSFORMER OUTPUT SECTION AND KLYSTRON CATHODE OIL TANK MAY NOW BEGIN.

6.0 SHIFT AND PERSONNEL CHANGES

A lead authorized employee shall ensure that Lockout/Tagout procedures are followed when the capacitor bank enclosure is locked out over a shift or personnel change. This same lead authorized employee shall ensure:

6.1 That no unauthorized lock and tag removals have taken place.

6.2 An orderly exchange of locks and tags from off-going to on-coming employees.

6.3 An orderly transfer of responsibility and information about the equipment status from the off-going to on-going shift.

7.0 THE FIVE STEPS FOR RETURN TO SERVICE

The authorized employee must perform the following steps prior to returning the equipment to service after maintenance activity.

7.1 CHECK EQUIPMENT: Check the equipment and the immediate area around it to ensure that nonessential items and tools are cleared and that the equipment is ready for safe operation.

- Check high current components and all high current connections for tightness and integrity.
- Good housekeeping practices shall be followed to prevent compromising high voltage bus insulation. Any debris must be removed by the use of a vacuum cleaner, never by blowing or by the use of compressed air.
- Remove all (6) grounds from the capacitor banks before returning the equipment to service.

6

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- Make sure the high-voltage meter stick and ground sticks are in the normally stored location.

7.2 **CHECK WORK AREA:** Check the work area to ensure that all employees are safely positioned or removed from the area as necessary and/or appropriate.

7.3 **VERIFY:** Verify that all controls are in the OFF position.

7.4 **REMOVE PADLOCKS AND TAGES AND RE-ENERGIZE:** Close and lock all doors on the capacitor bank enclosure. Plug in the cord and close in the disconnect.

7.5 **NOTIFY:** The authorized employee should, as necessary, notify affected area personnel of the completion of maintenance and LOTO activity. If the Crew Chief in the Main Control Room was notified prior to the activity, he/she should be notified of the completion of the activity.

This completes the requirements for returning the Power Supply to service.

8.0 PROCEDURE TRAINING REQUIREMENTS

Authorized employees are required to have had Lockout/ Tagout Level 2 (FN000212/CR), Electrical Safety in the Workplace (FN000385/CR) and have read and understood this LOTO procedure.

Electrical/Electronic Department Personnel using this procedure shall be trained on the job. After reviewing this document, the employee shall perform the steps accompanied by an employee with previous experience. The authorized employee shall then complete an "Accelerator Division Electrical/Electronic Department Procedures Review Form" and turn it in to the department secretary.

Personnel from other departments shall be trained according to the requirements of their department.

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Appendix G: Chapter 9 Examples

Lessons Learned for the Unauthorized Use of Radioactive Water Source (2008)

The following is an example of a lessons learned that would be included in the final documentation. It includes a description of the event, causual analysis, preventative actions, and recommendations.

Lessons Learned
Unauthorized Use of Radioactive Water Source
November 4, 2008

Event

On October 6, 2008, two masonry contractors were constructing a cinder block wall underground in the NuMI Absorber area. The contractors mistakenly obtained water for mortar preparation and tool cleaning from a radioactive water cooling system (RAW) for the NuMI Decay Pipe with a tritium concentration of 62,200 pCi/ml.

During the pre-job planning meeting, the NuMI Shutdown Coordinator instructed the Construction Coordinator that the water needed for the masonry work was to be obtained from the domestic water source at ground level in the Minos Service Building. After the work started, the Construction Coordinator asked the Minos Building Manager whether it might be possible for the contractors to get their masonry water closer to the location of their work. The Minos Building Manager directed him to a spigot on the groundwater (GW) pipe at the bottom of the access shaft that could be used as a water source. Later in the day, the masonry contractors asked the Minos Building Manager if there was a spigot closer to their work location than the spigot at the bottom of the access shaft. The Minos Building Manager pointed out the GW pipe and told the contractors they should "follow the pipe" to locate a closer spigot to their work area. The contractors followed the pipe and found a spigot near the Decay Pipe RAW skid that they thought was a continuation of the GW cooling loop pipe, when in fact it was the return line for the Decay Pipe RAW system. The RAW system was labeled with a barrier rope extending across the access tunnel leading to the Decay Pipe RAW system. Attached to the barrier rope was a sign indicating "Radioactive Liquids, DO NOT WORK IN THIS AREA WITHOUT PRIOR RSO APPROVAL, For entry contact MCR 3721". However due to the enclosure design, there was an 18" gap at the end of the barrier rope on the east side of the enclosure where a person could pass. The gap existed simply because there was no place to attach the rope to the enclosure wall; instead, the rope was attached to a vertical pipe section, resulting in the 18"gap between the end of the rope and the wall. The gap was at the location where the contractors accessed the spigot on the RAW system. Fortunately the radiological exposure to the workers was minimal as a result of the incident.

Primary Cause:

The Construction Coordinator deviated from the planned work activities by permitting the use of a water source which was not in accordance with the direction given by the NuMI Shutdown Coordinator. When this change was made, the NuMI Shutdown Coordinator was not consulted.

Secondary Causes:

1. The Building Manager who was not part of the cinder block wall construction activities provided inadequate direction to the contractors.

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2. The Construction Coordinator was not consulted when the contractors changed the spigot from which they intended to take the water.
3. The Building Manager was unaware of the radiological hazards that could be encountered by inaccurately following the ground water pipe to locate a closer water source.
4. The requirement stated by the NuMI Shutdown Coordinator to use water for the job from the Minos Service Building was not specified in the Job Hazard Analysis
5. The Job Hazard Analysis was both prepared and approved by the Construction Coordinator

Actions/Conditions that May have Contributed to the Incident

Access to the work area was hindered. The workers needed to descend 350 feet from the Minos Service Building in a man-basket lowered down the Minos access shaft by a crane and then walk approximately 640 feet up a 15% slope in the NuMI tunnel with their supplies to get to the work area.

Corrective Actions:

1. The Job Hazard Analysis was amended for the remainder of the job to require that the water used for job be obtained from the Minos Service Building

Preventative Actions:

1. Spigot valves used by the contractors have been labeled and locked closed by the RSO.
2. The barrier rope separating the RAW system from the access tunnel will be extended to the wall during the next scheduled shutdown period.
3. This lessons-learned document was prepared for the incident.

Lessons Learned:

1. Work planning and communications are key factors to successful execution of work activities.
2. Field changes need to be communicated to all relevant stakeholders prior to being instituted.

Recommended Actions for Other Divisions/Sections/Centers:

Divisions/Sections should ensure that their personnel are performing effective hazard analyses for their work activities and following established work practices.

Contact: John Anderson, ext 4973, jea@fnal.gov

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MECAR System (1992)

The following is an example of a safety analysis report. This document, if required, would be included in the final documentation.

MECAR Project Safety Analysis Report

The MECAR system is a TTL level microprocessor system which is completely electrically isolated from the magnet excitation system, and as such, there are no safety hazards.

Bob Flora
October 9, 1992

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C-0 Shunt Supply (2003)

The following is an example of a safety analysis report, which would be included in the final documentation. It includes different safety hazards and hazard mitigations.

C-0 SHUNT SUPPLY SAFETY ANALYSIS REPORT

H. Pfeffer
1/6/03

INTRODUCTION

The C-0 Shunt Supply is a circuit that bypasses up to 300 Amps around the MI magnet string that will soon be installed in series with the Tevatron Bus at C-0. The current is bypassed by a bank of FET's in combination with a 45 mOhm resistor bank which takes most of the current. The FET's will conduct less than 100 Amps. There is an 8 Volt/ 120 Amp supply in series with the FET's to give them sufficient bias voltage when the Tev is at low currents. The bypassed current is measured with a precision DCCT, and regulated with an electronics crate similar to the Low Beta regulators. The Shunt circuit is housed within two attached 19" equipment racks.

SAFETY HAZARDS

The potential hazards in this circuit are the following:

1. VOLTAGE AND CURRENT FROM THE TEVATRON BUS

The shunt circuit is connected directly across magnets that are part of the Tevatron Bus. This bus carries currents of up to 4500 Amps and operates at voltages up to 1.5 kV.

2. CURRENT FROM THE BIAS SUPPLY

The FET bias supply is rated at 8Volt/120 Amps. Although its voltage is low, its current capacity poses a potential arcing hazard.

3. THE 120 VAC CONTROL POWER WIRING

The FET bias supply and some of the system electronics are powered by a 120 Vac, 30 amp circuit. Some of the 120 Volt terminals are exposed to incidental contact within the system racks.

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HAZARD MITIGATION

1. The Shunt equipment racks are locked and can only be accessed with a Tev Power Supply key. This assures that the Tev circuit is in bypass and the main power supply breakers are tripped OFF before access can be made to the Shunt circuitry.

   The rack doors are interlocked so that if the doors are left open and the Tev power supply key is returned, the Tev breakers cannot be turned ON.

   The connections to the Tevatron Bus run through a knife switch assembly in the top of one of the Shunt racks. The switch may be opened and the compartment housing the switch may be LOTOed so that no one can reconnect the system to the Tev bus. The input end of the switch is shielded from contact, and the switch compartment allows for visual confirmation that the switch is OPEN.

2. The 120 Vac powering the bias suuply can be LOTOed at its wall breaker.

3. The 120 Vac presenting incidental contact hazards can be LOTOed as in #2 above.

LOTO PROCEDURE

A written LOTO procedure will be followed to insure that personnel accessing the Shunt racks have mitigated the hazards before working within the racks.

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HINS Klystron Modulator With Temporary Charging Supply (2007)

The following is an example of a safety analysis report, which would be included in the final documentation. It includes different hazards and hazard mitigations.

SAFETY ANALYSIS REPORT
HINS KLYSTRON MODULATOR
WITH TEMPORARY CHARGING SUPPLY
1/19/07

H. Pfeffer, C. Jensen

HAZARDS:

1. MULTIPLE POWER SOURCES
   The charging supply is powered by 480 VAC, 60 A and by 120 VAC, 15 A and the modulator is powered by 120 VAC, 15 A. There is also 120 VAC derived from the 480 VAC to drive the shorting relays in the modulator and the contactor in the charging supply.

2. MULTIPLE HAZARDOUS VOLTAGES
   The modulator charging supplies generate 12kV output voltage. The bouncer capacitors resistively charge to 1/7 the main capacitor bank voltage. The main capacitor crowbar gate supply generates 200 VDC.

3. STORED ENERGY
   The modulator cabinet houses two capacitor banks. The main cap bank is 4.2 mF charged to a maximum of 12 kV for approximately 300 kJoules (nominal is 9.5 kV @ 190 kJ).
   The bouncer cap bank is 6 mF charged to a maximum of 1.7 kV for approximately 8.7 kJoules (nominal is 1.4 kV @ 5.9 kJ).

4. OIL
   The main capacitor bank contains rapeseed/canola oil.
   The pulse transformer tank contains 750 gallons of Diala AX ® transformer oil in the transformer section and 200 gallons in the output section.
   The Klystron itself has a tank with approximately 80 gallons of Diala AX ®.
   The undershoot capacitors have a small volume of Dielektrol VII oil
   The output snubber capacitor, choke snubber capacitor and bouncer switch snubber capacitor have ~ 8 oz of SAS-40E oil each.
   The bouncer capacitor bank is dry.
   The bouncer and 50 uH inductors are dry.
   (MSDS sheet for all oils are available)

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Meson Long Pulse Modulator Safety Analysis Review 1/19/07

HAZARD MITIGATION:

1. MULTIPLE POWER SOURCES

   There are no exposed 480 VAC terminals in the equipment. When maintenance is to be performed, the 480 VAC source is isolated at a wall disconnect, PHP–MDB-8-1, ckts 20–22–24 then unplugged and the plug is LOTOed. The transformer for deriving the 120 VAC for shorting relays and contactor is from this same source.

   All the 120 VAC terminals within the cabinets are covered to prevent incidental contact. The modulator 120 VAC circuit breaker is PP–ML–8A–1–1A, ckt 15. The charging supply 120 VAC is plug connected to an outlet fed by circuit breaker PP–ML–8A–1–1A, ckt 17

2. MULTIPLE HAZARDOUS VOLTAGES

   The charging supply high voltage output is only exposed within the modulator cabinet. The supply is further isolated from the capacitor bank with diodes in the modulator. Access to the terminals in the modulator can only be had after the LOTO procedure has been done and the source of the voltage has been locked out.

   The 200 VDC and 120 VAC terminals are covered to prevent incidental contact.

3. STORED ENERGY

   The cabinet housing the capacitor banks has door interlocks which cause discharge relays to close and discharge the capacitors if a door is opened.

   The cabinet doors are locked and a Kirk key is required to gain entry.

   A LOTO procedure is followed before entering the cabinet. In the procedure, the capacitor discharge relays are observed to be closed, the individual capacitor terminals are monitored with a high-voltage meter, each capacitor is grounded with a ground stick and both cap banks are shorted with large ground clips.

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4. OIL

Oil spilled from the modulator capacitors is contained within the sealed modulator cabinet and then drained through a special drain tube into an external collection container.

Small spills from the pulse transformer are collected with absorbent socks. The floor is sealed. There are no floor drains in the area.

NOTE: The modulator has two cap banks with hazardous energy storage that require careful consideration in regards to safety engineering.

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BNB Horn Supports (2014)

The following is an example of final documentation. It clearly organizes relevant information by Chapter in the beginning of the document, followed by supporting material.

Fermilab

Engineering Document

Team Center Item Number: ED0002499
Solid Model of the Assembly is: F10037175

Date: 11 February 2014

Project: BNB Horn Supports

Title: Revised Horn Support Calculations

Author(s): Dave Pushka

Reviewer(s):

Key Words: Horn Support

Applicable Codes: ASD 2010

Abstract Summary:

Existing BNB Horn Support and Adjustment device no longer operates to adjust the horn position.

A new horn is being installed.

This document provides the calculations for the new horn support and positioning mechanism.

Calculations and correspondences follow the engineering manual requirements:

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Fermilab Engineering Manual Requirements:

Chapter 1: The specification is the verbal instruction to prepare a design for an alternate horn support and positioning mechanism by Kris Anderson.

Key specifications include:

Explicit Specifications (verbally stated):

Horn weight = 5000 pounds

Desired vertical travel = 3.5 inches (was 3.0 inches before requirements review on 2/3/2015)

Desired horizontal travel = 0.5 inches (to either side from center)

Implicit Specifications (not necessarily stated but understood):

Use materials understood to survive high radiation areas

Use materials wich will become less-highly radioactivated.

Achieve alignment precision on order 1 mm vertically and horizontally

Avoid use of organic materials including grease

Don't do anything stupid

Quality is more important than time

Time is more important than cost

Hard anodizing has been shown to survive similar radiation environments.

Half of the horn weight will be on the upstream support

The other half of the horn weight will be equally divided between the two downstream supports.

Must fit in existing target pile and be easily removed without getting stuck.

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Chapter 2: Risk analysis:

Engineering Risk Assessment

Project: BNB Horn support and positioning system
Lead Engineer: Dave Pushka
Department: AD/Target
Date: February 15, 2015

		Engineering Risk Element							High		
Chapter		A	B	C	D	E	F	G	Risk	Subtotal	Assessment
1	Requirements and Specifications	1	1				3		≥ 10	5	Standard Risk
3	Requirements and Specification Review	1	1		2	3	3		≥ 16	10	Standard Risk
4	System Design	1	1	1		3	3	2	≥ 19	11	Standard Risk
5	Engineering Design Review	1	1	1		3	3	2	≥ 19	11	Standard Risk
6	Procurement and Implementation		1		2	3	3	2	≥ 16	11	Standard Risk
7	Testing and Validation	1				3	3	2	≥ 13	9	Standard Risk
8	Release to Operations						3		≥ 4	3	Standard Risk
9	Final Documentation		1				3		≥ 7	4	Standard Risk

Project Risk Element								High		
H	I	J	K	L	M	N	O	Risk	Subtotal	Assessment
4	1	1	1	1	2	1	1	≥ 25	12	Standard Risk

Engineering Risk Elements	
A	Technology
B	Environmental Impact
C	Vendor Issues
D	Resource Availability
E	Safety
F	Quality Requirements
G	Manufacturing Complexity

Project Risk Elements	
H	Schedule
I	Interfaces
J	Experience / Capability
K	Regulatory Requirements
L	Project Funding
M	Project Reporting Requirements
N	Public Impact
O	Project Cost

Chapter 3: Written Requirements and specification reviews have not been formally prepared. However, a review was held on 2/2/2015 with all interested parties and the preliminary design evaluated for both explicit and implicit requirements. Small group discussions (with engineers, engineering physicists, physicists, and technicians) have been held frequently (almost daily) during design development. Verbal comments have been incorporated in this design.

Chapter 4: This engineering note has been specifically prepared to address chapter 4 of the engineering manual.

NOTE: This example used an earlier version of the Engineering Risk Analysis worksheet. The current version no longer uses the term "Standard Risk".

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Chapter 5: The 'reviewed by' signature on the cover page of this document or a review signoff within team center addresses Chapter 5 of engineering manual. The generation of this document precedes the review of the document.

Chapter 6: No materials were purchased as part of the preparation of this document. Materials will be purchased as part of this project but are outside the scope of work assigned to the design task and will occur in the future with respect to the preparation of this document.

Chapter 7: The horn support mechanism will be assembled and tested prior to use. This testing has not yet occurred as of the date when this document was prepared.

Chapter 8: The horn support and positioning mechanism will be released to operations after satisfactorily passing the performance tests. These tests have not occurred as of the date when this document was prepared.

Chapter 9: Unless there are lessons learned from this effort, this engineering document and the other material posted in team center will be considered the final written Project Report as described in Chapter 9. This note will be placed in team center as a means of Archiving and Control.

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Calculations:

Given Conditions:	value	units	comments:
Horn Weight:	5000	pounds	
Desired Vertical Travel	3.5	inches	revised from 3 inches on 2/3/15
Desired Horizontal (lateral) travel from center to extreme:	1/2	inch	
Material Properties and Strengths:			
Reference: Aluminum Design Manual 2010. Abbreviated as "ADM"			
Aluminum Alloy Used (unless otherwise noted)	6061-T6		
Assumed Temperature Limit	212	F	
Fu, Ultimate Stress,(tension)	260	MPa	
Fu, Ultimate Stress,(tension)	38	ksi	
Fy, Yield Stress, (tension)	240	MPa	
Fy, Yield Stress, (tension)	35	ksi	
Fy, Yield Stress, (compression)	35	ksi	
E, Young's Modulus	69,600	MPa	
E, Young's Modulus	10,100	ksi	
k sub t	1		
Values for heat affected zone for welded areas:			
Fu, Ultimate Stress,(tension)	165	MPa	
Fu, Ultimate Stress,(tension)	24	ksi	
Fy, Yield Stress, (tension)	105	MPa	
Fy, Yield Stress, (tension)	15	ksi	
E, Young's Modulus	69,600	MPa	
E, Young's Modulus	10,400	ksi	
Fasteners (60561-T6 aluminum)			
Ftu, Ultimate Stress,(tension)	290	MPa	
Ftu, Ultimate Stress,(tension)	42	ksi	
Fsu, Ultimate Shear Stress,	170	MPa	
Fsu, Ultimate Shear Stress,	25	ksi	

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Allowable Stresses:			
Omega for tensile rupture for building -type structures	1.95		
Omega for tensile rupture for bridge -type structures	2.2		
Omega for tensile Yielding for building -type structures	1.65		
Omega for tensile Yielding for bridge -type structures	1.85		
For Building - Type structures:			
Allowable Axial Tensile Stress on net area	19.5	ksi	
Allowable Axial Tensile Stress on gross area	21.2	ksi	
Allowable Bearing on bolt holes	39	ksi	
Allowable Bearing on slots, pins on holes, flat surfaces	25.9	ksi	
For use in High Radiation Areas, reduce the allowable stress values to:	0.8		this is an ratio which has been chosen using careful engineering judgment (SWAG) for materials used in high radiation areas is static application and not subject to fatigue due to stress reversals.
Allowable Axial Tensile Stress on net area	15.6	ksi	
Allowable Axial Tensile Stress on gross area	16.96	ksi	
Allowable Bearing on bolt holes	31.2	ksi	
Allowable Bearing on slots, pins on holes, flat surfaces	20.72	ksi	
Friction Coefficients:			
Anodized Aluminum on Anodized Aluminum, mu	0.2		typical value achieved
Design friction factor used in the calculations, mu:	0.4		assumed value after exposure to beam

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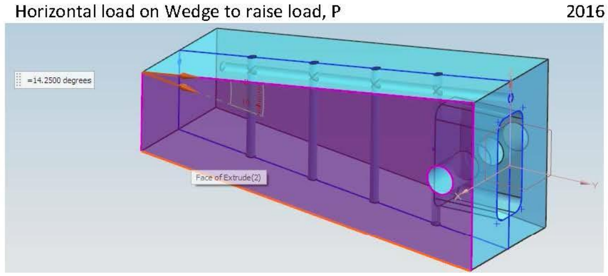
VERTICAL MOVEMENT:

Data Based on Design Choices:

Included Angle of wedge	14.25	degree	
Included Angle of wedge	0.2487094	rad	
Half angle of wedge, theta	7.125	degree	
Half angle of wedge, theta	0.1243547	rad	
Horizontal length of ramp	28	inches	
Vertical Travel of ramp	3.5	inches	
Angle of ramp	7.1250163	degrees	
Length of Ramp (along ramp angle)	28.217901	inches	
Length of Wedge (along ramp angle)	16.1245	inches	
Horizontal Length of Wedge	16	inches	
Maximum Travel of wedge on ramp (along ramp angle)	12.1	inches	
Maximum Horizontal Travel of wedge riding on ramp	12.0	inches	
Rise to run ratio	0.2917		
New vertical travel requirement	3.5000		
Required length of horizontal wedge travel for new vertical travel	12.0000		
Assumed weight on a single wedge	2500	pounds	assumes half horn weight on one wedge
Normal Force = W/cos(theta)	2519.5	pounds	
Frictional force = Normal force * mu	1007.8	pounds	uses higher friction for after exposed condition
Since the Wedge is sloped on both the top and bottom, the horizontal force is twice the above calculated value:			
Horizontal load on Wedge to raise load, P	2016	pounds	



Wedge Pin Diameter	1.25	inches
Wedge Pin Span	2	inches
Wedge Pin length in actuator rod	1.75	inches

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Wedge Pin Number of Shear Planes	2		
Wedge Pin cross sectional area (Shear Area)	1.2271846	sq inches	
Wedge Pin Shear Stress, Tau = P/(# planes * Plane Area)	821.2	psi	
Wedge Pin projected Bearing Area	2.1875		
Wedge Pin projected Bearing Stress, = P/bearing area	921.4	psi	
Calculated stress << Allowable stress in rows 49 to 52			
Wedge Push- Pull Rod Width	1.75	inches	
Wedge Push- Pull Rod vertical height	3	inches	
Wedge Push- Pull Rod length	132	inches	
Wedge Push-Pull Rod rectangular X-section area	5.25	sq. inches	
Wedge Push-Pull Rod Circular portion diameter	1.25	inches	
Wedge Push-Pull Rod Circular X-section area	1.227	sq inches	
Push- Pull Rod rectangular section compressive stress when raising horn, sigma = P/A	383.9	psi	
Push- Pull Rod circular compressive stress when raising horn, sigma = P/A	1642.4	psi	
Wedge Push-Pull Rod compressive column "k" factor	2		
Wedge Push-Pull Rod compressive length, l	132.5	inches	
Wedge Push-Pull Rod radius of gyration, r	0.8660254	in	0.867
k*L/r	306.00		
L/r	153		
Slenderness Limit, S1, (L/r) = 9.5			
Slenderness Limit, S2, (L/r) = 66			
Therefore, the L/r exceeds slenderness limit S2.			
Allowable stress, Fa = 51,352 /((l/r)^2))	2.1937487	ksi	see ADM Table 2-19 for unwelded

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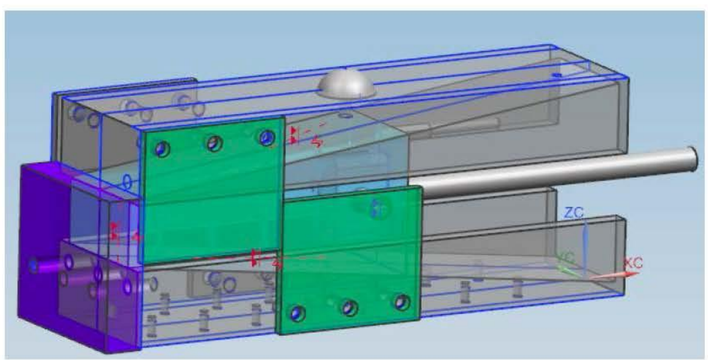
Upper Wedge horizontal Displacement Restraint Block (Wedge End Plate):

Check Bending on Plate:

Plate thickness	2	inches	
Plate Width	7	inches	use DS wedges since narrower
Distance from Bottom Edge to Bolt Centerline	3	inches	
Plate Height	8	inches	
Assume horizontal load applied at the upper edge.			
Horizontal load, P from above	2016	pounds	
Lever arm, a	5	inches	
Bending Moment , M = P*a	10078	in-pounds	
Moment of Inertia of section, I = (1/12)*a*b^3	5.3	in^4	
Distance to extreme fibre, y	1	inches	
Bending Stress, sigma = My/I	1890	psi	

Bending Stress << allowable bending stress from above



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Check Horizontal Displacement Side Restraint Plates:

vertical distance from bolt group to bolt group at max elevation	9	inches	
Assume lever are = max distance /2	4.5	inches	
Horizontal load (assume same as needed to raise the wedge)	2016	pounds	
Number of bolts	3		
Bolt size	1/2 - 13 tpi		
Bolt gross area (per bolt)	0.196	sq inches	
Total bolt area for all bolts combined	0.59	sq inches	
Bolt shear	3422	psi	
Check secondary shear due to eccentric load:			
Centroid of the bolt group is the center bolt.			
therefore, r1 = r2 =	3	inches	
Moment =	9070	in-pounds	
Force to counter moment, F = M/(#bolts*lever arm)	1512	pounds	
Additional shear stress on outer two bolts:	7699	psi	
Total bolt shear stress for outer bolts = sqrt(sum(shear^2))	8425	psi	
Assumed bolting material	304 SS		this is relatively highly stressed, Use SS bolting
Assumed bolting ultimate stress	60	ksi	
Assumed bolting allowable working stress, Fa = Fu/3	20	ksi	

Adj Nut Capture Plate Bolting tensile stress << allowable stress

Check Prying action on bolts for the Wedge End Plate:

Bolt reaction T = P*plate height / bolt height	5375	pounds
Number of bolts:	3	
Tension per bolt, T = P/# of bolts	1792	pounds
Bolt Size:	3/4 - 10 TPI	
Bolt gross diameter	0.75	inches
Gross bolt area, A	0.442	sq inches
Nominal bolt stress, sigma = T/A	4055	psi

Nominal bolt tensile stress << allowable tensile stress from above

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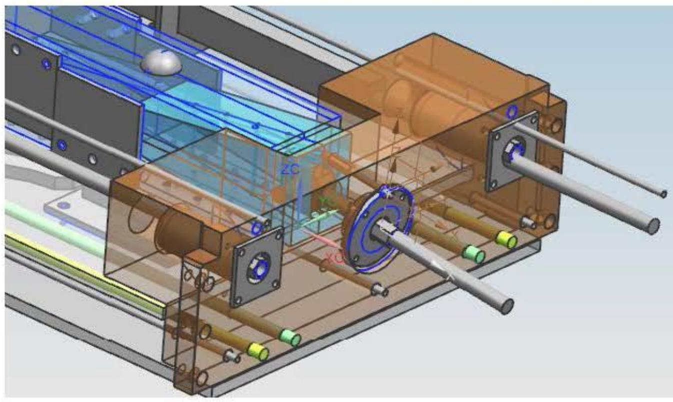

Check Bolt Stress on the Adjusting Nut Capture Plate to the US block:

Number of bolts in tension		4		
Bolt size	1/2 - 13 tpi			
Bolt gross area (per bolt)		0.196	sq inches	
Total bolt area for all bolts combined		0.79	sq inches	
Bolt tensile load from above		2016	pounds	
Tensile stress on bolt group		2566.3	psi	
Assumed bolting material	304 SS			since outside of chase
Assumed bolting ultimate stress		60	ksi	
Assumed bolting allowable working stress, Fa = Fu/3		20	ksi	

Adj Nut Capture Plate Bolting tensile stress << allowable stress

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HORIZONTAL MOVEMENT:

Data Based on Design Choices:

Downstream Bell Crank Pull Pin lever lengths	13.5	inches
Downstream Bell Crank Lateral Pin lever length (maximum)	9.75	inches
Downstream Bell Crank Lateral Pin lever length (minimum)	8.25	inches
DS Bell Crank Ratio at center postion	0.611	
DS Bell Crank Ratio at extreme postion	0.722	
Upstream Bell Crank Pull Pin lever lengths	10	inches
Upstream Bell Crank Lateral Pin lever length (maximum)	7.5	inches
Upstream Bell Crank Lateral Pin lever length (minimum)	6	inches
US Bell Crank Ratio at center postion	0.6	
US Bell Crank Ratio at extreme postion	0.75	
Bell Crank Pull Rod Diameter	1	inches
Bell Crank Pull Rod End Width	3	inches
Bell Crank Pull Rod Hole to Edge Distance	1.5	inches
Bell Crank Pivot Pin Diameter	2.995	inches
Bell Crank Pull Pin Diameter	1.25	inches
Assumed Load on Horizontal Slide Pads	2500	pounds
Assumed friction on Horizontal Slide Pads	0.4	pounds
Force to move load laterally	1000	pounds
Tensile load in US Bell Crank Pull Rod at extreme position	750	pounds
Tensile load in DS Bell Crank Pull Rod at extreme position	722	pounds
Therefore, US bell-crank geometry drives design		
Use bell-crank load, P =	750	pounds

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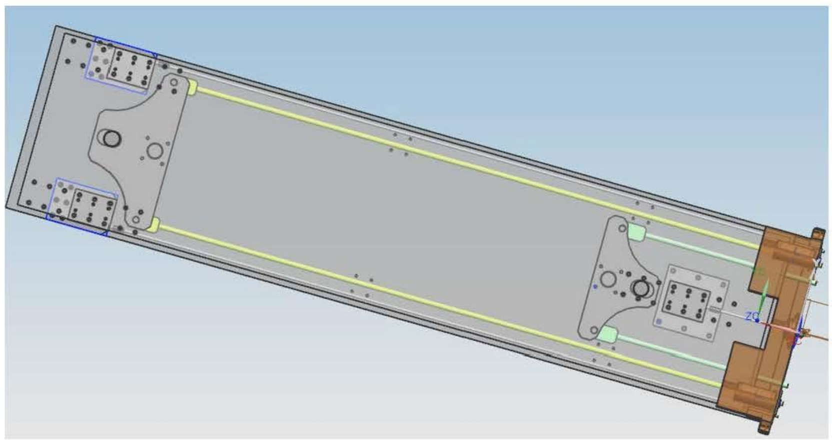

Check the stress on the long rod used to pull bell-crank:		
Pull Rod Tensile Stress, Sigma = P/A	955	psi
Pull Rod tensile Stress << allowable shear from above		
Check the shear on the pin between the rod and the bell crank:		
Pull Rod Pin shear plane number	2	
Pull Rod Pin shear area per plane	0.785	sq. in
Pull Rod Pin shear Stress, Sigma = P/A	608	psi
Pull Rod Pin shear Stress << allowable shear from above		
Check the tensile and shear on the rectangular end of the rod where the vertical pin is located:		
Pull Rod End Tensile width, w = (actual width - hole dia)	2	inches
Pull Rod End Tensile height, h	1	inches
Pull Rod End Tensile Area, A = (width * Height)	2	sq. inches
Pull Rod End Tensile Stress, sigma = P/A	375	psi
Pull Rod Pin tensile Stress << allowable shear from above		
Pull Rod End Shear width, (distance from edge to hole CL)	1.5	inches
Pull Rod End Shear height, h	1	inches
Pull Rod End Shear Area, A = (width * 2 planes* Height)	3	sq. inches
Pull Rod End Shear Stress, Tau = P/A	318	psi
Pull Rod End Shear Stress << allowable shear from above		

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Check Pivot Pin on the Bell-Crank:

Pivot Pin diameter, d	2.995	inches
Pivot Pin length from center of bottom plate to center of bell-crank plate assembly (pin cantilever), a:	2.5	inches
Pin moment of inertia for bending, I = pi()*(1/64)d^4	3.95	in^4
Pin Load from above, P	1000	pounds
Pin Cross sectional area, A	28.2	sq. inches
Pin Shear Stress, Tau = P/A	35.5	psi
Pin Bending Moment, M = P*a	2500	in-pounds
Pin Bending Stress, sigma = My/I	947.9	psi

Bolting from Slide Pad Block to Mid - Plate:

Number of bolts in shear	6	
Bolt size	1/2 - 13 tpi	
Bolt gross area (per bolt)	0.196	sq. in
Total bolt area for all bolts combined	1.18	sq. in
shear load from above	1000	pounds
Shear stress on bolt group	848.8	psi

Mid-Plate Pad Block Bolting shear stress << allowable shear from above

Bolting from Base Slide Plates to the base plate:
Number of bolts in shear

Bolt size
Bolt gross area (per bolt)
Total bolt area for all bolts combined
shear load from above
Shear stress on bolt group
Mid-Plate Pad Block Bolting shear stress << allowable shear from above

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Bearing Stresses on Bearing Surfaces:

US Wedge:		
Length	16	inches
Width	6	inches
Load	2500	pounds
Bearing Stress	26.0	psi
DS Wedge:		
Length	16	inches
Width	6	inches
Load	1250	pounds
Bearing Stress	13.0	psi
US Slide Plate:		
Length	8	inches
Width	6	inches
Load	2500	pounds
Bearing Stress	52.1	psi
DS Slide Plate:		
Length	8	inches
Width	6	inches
Load	1250	pounds
Bearing Stress	26.0	psi

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Check required Rotation at Spherical Washers for the DS adjustment Rods:

Horizontal Distance from center of Spherical Washer Assy to Wedge Pin centerline when ramp raised	130.9809	inches
Horizontal Distance from center of Spherical Washer Assy to Wedge Pin centerline when ramp lowered	116.9809	inches
Vertical Distance from center of Spherical Washer Assy to Wedge Pin centerline when ramp raised	0.75	inches
Vertical Distance from center of Spherical Washer Assy to Wedge Pin centerline when ramp lowered	-0.976	inches
Angle when Lowered, theta = arctan (rise/run)	-0.4780215	degrees
Angle when Raised, theta = arctan (rise/run)	0.3280735	degrees
So, the spherical washers need to rotate +/- :	0.4780215	degrees
spherical washers modeled have 4 degrees of correction, see McMaster-Carr P/N	91944A042	part number

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NuMI Focusing Horn Power Supply (2012)

The following is an example of final report. It includes equipment components, system controls, procedures and supporting documents.

NuMI

Focusing Horn Power Supply Information Manual

Ken Bourkland
THSR Edition
12-Oct-04

NuMI Horn P.S. Manual.doc

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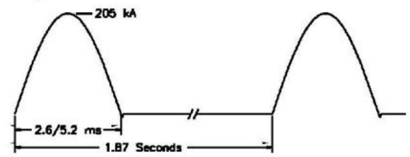
NuMI Focusing Horn Power Supply Specifications:

Power Supply System Output, operational level:

Pulse width	2.6/5.2 ms
Bank Voltage	860/515 V
Pulse	½ sine
RMS current	5125/7250 A
Peak current	205 kA peak
Repetition rate	1.87 seconds
Duty	Continuous
di/dt, horn	268/146 A/us



Pulse train waveform

Capacitor Bank Specifications

Peak current, maximum	240 kA (Design Rating; 120%)
Peak current, operating	205 kA
RMS current	8700 A (Design Rating; 120%)
Capacitance/unit	7,500 uF
Number of cells	12
Installed capacitors/cell	10
Total No. Caps installed	120
Max. No. capacitors/cell	12
Maximum No. capacitors	144
Capacitance/cell	18.75 mF / 75 mF
Installed Capacitance	0.9 Farad
Max. capacitance	1.08 Farad
Capacitor voltage rating	670 $V_{Working}$ /1340 $V_{Hi\text{-}pot}$
Switching element	SCR array, 12 parallel devices
SCR Mfg, Part Number	Eupec, Inc., T2710N20TOF
SCR ratings	
V_{DSM}, V_{RSM}	2,200, 2,300 V
I_{av}	3,700 A
I_{rms}	5,800 A
I_{tsm}	54,000 A

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Charging power supply:

PEI (Power Energy Industries)	240 kW
Maximum output voltage, Volts	200/400/800
Maximum output current, Amps	1200/600/300
Voltage regulation	0.1 %
Current regulation	0.05 %

Monitored system parameters:

- Output current of each cell to 0.4 % or better
- Current in each transmission line pair
- Current imbalance between stripline pairs
- Total output current
- Capacitor voltage in each cell
- Capacitor bank over voltage and over current
- PEI over current
- Ground faults
- Over temperature conditions of horns
- Coolant flow loss to horns, PEIs, capacitor bank
- Capacitor over-pressure
- Equipment entry

Horn current reversal: Provided by mechanical means.

Transmission line parameters:

Conductor material	6101-T61 Aluminum alloy
Conductor width	12 inches, (30.5 cm)
Conductor thickness	0.375 inches, (0.953 cm)
Conductor spacing	0.375 inches, (0.953 cm)
No. parallel pairs	4
Inductance @ 100Hz	4.9 nH/ft., 16 nH/m of length
Resistance @ 100Hz	3.05 uΩ/ft., 10 uΩ/m of length
Power loss, 2.6 mS	80 W/ft., 260 W/m of length
Power loss, 5.2 mS	160W/ft., 530 W/m of length

Enclosure, Mechanical:

Length	209 inches, (5.31 m), without doors installed
Width	70 inches, (1.78 m), without doors installed
Height	79 inches, (2 m), [81" including C-channel]
Weight	22,000 lbs., (10,000 kg)

Water Flow, typical:

Capacitor bank	9 gpm @ 80 psi differential
PEI, each	6 gpm @ 80 psi differential
Δp Switch setting	60 psi, PEIs and Cap.Bank, each
Cap-bank test pressure	275 psi, Hydrostatic

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Maintenance Activity Advisory

All maintenance activity in the capacitor bank, PEIs, or on the stripline should be conducted with utmost care. Be certain that tools or conductive components are not left in the equipment or on electrical busses. Any hardware; nuts, bolts, washers, etc., that is dropped or lost in the performance of maintenance activities must be recovered and removed prior to returning the equipment to service. Removal of debris must be by vacuum cleaning equipment, never by blowing with ones breath or by compressed air or gasses. Use of vacuum cleaning equipment will give full assurance of the safe whereabouts of such debris. Any electrical fault initiated by accidental shorts from hardware, debris, etc., will be followed by very substantial fault currents and subsequent damage with potential risk to personnel.

Horn Power Supply Design

General Description

The circuit used to provide current to the horns is a damped R-L-C discharge circuit as shown in Figure 1. It will achieve the peak current when the SCR (Silicon Controlled Rectifier) switch releases stored energy from the capacitor bank to the horns via the stripline. The load element values, listed in Table 1, are for the full complement stripline design for the Target Hall and factors in skin effects and temperature rise. Pulse widths and power dissipation will be somewhat less than stated in the table for the truncated walkway stripline as presently installed for the single (low energy beam) position of horn 2.

Table 1. Beamline installation load elements; (Stripline truncated at L.E. beam position.)

	L, uH	R, mΩ	$P_{2.6}$ / $P_{5.2}$, kW
Horn #1	0.689	0.270	7.1 / 14.2
Horn #2	0.510	0.071	1.9 / 3.7
Transmission line:			
P. S. to beamline, 10.5 m.	0.168	0.105	2.7 / 5.5
Between horns, 53.5 m.*	0.856	0.535	14.1 / 28.1
Cap. Bank, connections	0.1	0.050	1.3 / 2.6
Stripline connections*	0.1	0.010	0.26 / 0.52
Total	2.423 uH	1.041 mΩ	27.36 / 54.62 kW

(*Estimate; from drawings, 12-Oct-2004)

Energy to provide the high current pulse for the NuMI horns is supplied by DC power sources (PEIs) that are used to charge the capacitor bank during the quiescent period between horn pulses. When the capacitor bank is configured to provide 2.6 ms pulse widths, the stored energy in the bank is 85 kJ. When configured for 5.2 ms pulse widths, the operating level of stored energy is 120 kJ.

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With any array of capacitors connected in parallel, as is required for the horn power supply system, a capacitor experiencing a fault will have to absorb in addition to its own stored energy, the energy of all the capacitors connected in parallel with it and do so without case rupture. For this reason the capacitor bank is divided into twelve isolated sections, or cells, making the maximum amount of stored energy in any cell 12 kJ or less. All of the cells are isolated from each other and the charging source by diodes, and from each other and the load by SCRs. Consequently, the cells cannot communicate with each other under fault conditions. Having the capacitor cells isolated from each other also forces current sharing among each of the twelve SCRs switching load (horn) current.

The style of case construction specified for these capacitors utilizes 14 gauge steel, instead of the normal 16 gauge, and have a fault energy containment rating of 25 kJ to provide a safety factor greater than two in each of the cells. The capacitor bank is assembled in four groups of three cells. Each group of three cells is referred to as a 'quadrant.' The quadrants are labeled "A" through "D."

The bank normally operates with 120 capacitors in service, ten in each cell. Provision was made to accommodated a maximum of 144 capacitors. The extra space can be utilized to store spares or with the extension of the row buses, to make all 144 slots active. All safety margins are determined for the maximum capability (240 kA design level) of the capacitor bank when used for NuMI beamline service. Descriptions of the various design and safety features are covered in detail on the following pages. A basic schematic diagram of the high power elements is shown in Figure 1, below.

FNAL drawing 9820-ED-370111 includes additional detail.

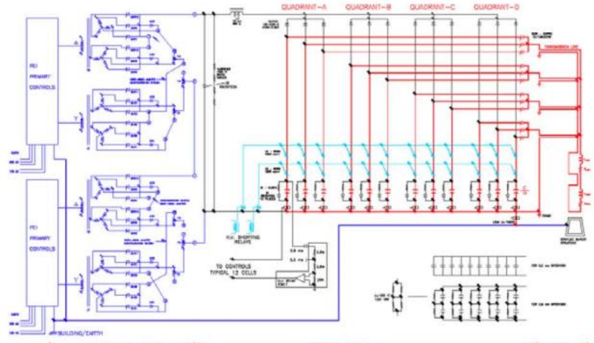

Figure 1. Power Supply system schematic diagram.

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To minimize the voltage from the outer conductor of horn 1 to the target, located within the throat of horn 1 for low energy beam, horn 1 is installed in the return side of the transmission line, nearest (electrically) to the capacitor bank. To achieve current flow in the proper direction, i.e. current in the center conductor of the horn in the same direction as the beam, it is necessary to make the positive side of the capacitor bank 'ground.' The capacitors in the bank are non-polarized and the PEIs can operate equally well with either terminal declared 'ground' since the PEI output floats. Figure 2 shows a pictorial equivalent circuit of the capacitor bank and transmission line (stripline) connections to the horns using co-ax to represent the stripline.

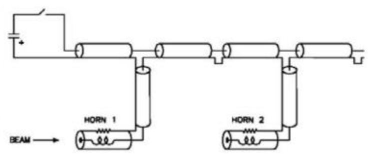

Figure 2. Co-ax line equivalent circuit.

Single-point Grounding

The 'single-point grounding' technique is employed to prevent circulating currents from occurring in the enclosure structure, particularly during capacitor bank discharge. The low-side bus from each capacitor cell (row) within each quadrant is connected to all of the others, and frame ground, via the 12" copper bus of their respective SCR switch panels, and the interconnecting 2" and 4" ground bus in the bottom of the center bay, shown in Figure 3, The connection from the interconnecting bus to the enclosure frame is made at a single location, or point. All connections to an earth ground and the horn modules in the beamline installation are made to this point via the LEM® current monitor. The LEM provides for detection of fault currents in the grounding cables. Its signal output is tied into the controls interlock chain to terminate system operation in the event significant ground currents are detected.

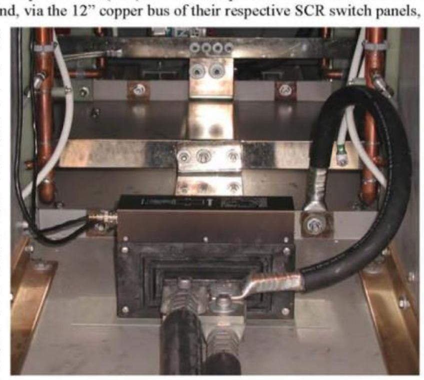
Figure 3. Single point grounding bus and LEM, located under the output stripline.

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Ground Fault Detection

Any electrical fault from the stripline or horns to the mounting structures, target, or shielding steel in the beamline installation will allow capacitor bank output current to return to the capacitors by an alternate path, and ultimately through the cables connecting to the single point frame ground of the enclosure. Current in these cables will be detected by the LEM® current transducer, Figure 3, above. Under normal operating conditions a small amount of current will be seen in these cables due to stray capacitance between the stripline and horn installation and surrounding grounded objects, i.e. radiation shielding, supports, etc. The threshold for detection for ground faults is set above this 'background' level. The control for setting the trip point is located within control module #370142. The 75 Ω LEM burden resistor is located within and at the 'LEM' input on the rear panel of that module. Refer to the documentation on 'Controls', available in th AD-E/E Support Group for calibration information

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Capacitor Bank Electrical Components

Capacitor Construction

The capacitors used in the bank utilize a segmented, metalized polypropylene film dielectric system. The capacitance per 'can' is 7500 uF, with a tolerance of ± 5%. Built to FNAL specification 9520-ES-370004, the insulation film thickness is 5.5 microns (0.00022") and has an aluminum deposition of approximately 100 angstroms in thickness applied to it. Should a voltage breakdown occur in this style of construction the arc energy will vaporize the aluminum film in the immediate region, clearing the fault. However, some gaseous by-products are produced in the process. With enough instances of dielectric breakdown, a pressure buildup will occur within the capacitor case. Each capacitor is fitted with an over-pressure switch to detect this condition.

To assure balanced current in the four striplines, a sort was carried out among the measured values of capacitance (by vendor, from label) of the132 units purchased. From the midrange of values twelve units were selected and set aside as spares, one for each of the twelve cells in the capacitor bank. The remaining units were sorted to yield twelve closely matched sets of ten capacitors. The sets, 75 mF each, match within 2 uF

Capacitors are installed in each row of the bank with their values ranging from highest to lowest, starting from the SCR end. See: *Appendix: A, Capacitor Sort List.*

Capacitor Mounting

All of the energy storage capacitors are mounted by their flanges in a horizontal orientation; i.e. with the terminals oriented toward the doors. This orientation was chosen to accommodate ready removal/replacement in the confines of the underground cavern location. The capacitors are connected by a planar bus constructed of ¼" x 4" copper. The high and low side conductors of this bus are separated by insulation consisting of 0.032" G-10 layered on each side with 0.005" Kapton. The insulation extends approximately ½" beyond the copper conductor on each edge to provide a long creapage path against voltage breakdown. While the G-10 is quite rugged, Kapton is prone to tearing easily if mishandled. Care should be used when working in the vicinity of the bus structure to prevent damage to the Kapton. If damage should occur, the Kapton must be replaced with new material.

Capacitor Over-pressure Switches

The switches provided with these capacitors have normally closed contacts that will open at 15 psi on rising pressure, and reset at approximately 3 psi on decreasing pressure. All of the capacitor switches (144 maximum) are connected in series and control a 120 Vac relay mounted inside a utility box located on the ceiling of quadrant 'C'. See Figure 4. A contact of this relay is tied into the controls (24 Vdc) interlocks. Each row (cell) of capacitors in the four quadrants of the

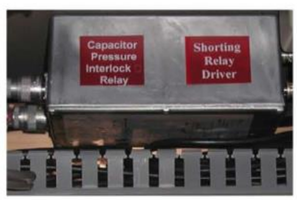

Figure 4. Interlock relay box in C quadrant.

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capacitor bank has its aggregate of switches connected to a terminal strip that is mounted on the adjacent G-10 (SCR) panel of the enclosure center bay, indicated by the green arrows in Figure 5. The terminal strip is provided to facilitate trouble-shooting. If an over-pressure interlock fault is indicated, probe each of the respective terminal strips with a voltmeter to isolate the capacitor row wherein the open switch is located.

The capacitors are mounted in all of the positions within the capacitor bank with the pressure switch toward the top of the terminal face. This orientation is chosen to minimize the amount of impregnant oil that could potentially be lost from a damaged switch. Experience has show that with care and technique, a switch can be removed and replaced with the capacitor insitu and an oil loss of less than 0.1 cc. Oil can escape during this exchange but spillage will be minimal if one's finger is rapidly placed and held over the switch port during the transition. Position absorbent material (Kim-wipe) under the port prior to the switch exchange to catch any spillage. Any appreciable loss of oil shall be cause for replacement of the capacitor.

Capacitor Row Buses

The capacitor row tab extension buses are constructed of .063" copper sheet stock. The extensions, orange arrows in Figure 5, connect to the respective positive and negative bushings of every second capacitor in the row. This every-other-one arrangement allows the free terminals of the capacitor pairs to be connected in a series or parallel arrangement, depending on the pulse width desired. Figure 34 shows the series arrangement in service. To convert to 'parallel,' see *Procedures: Pulse Width Change.*

For the high current capacity needed, the .063 copper bus is laminated to ¼" thick x 4" wide, full radius edge extruded copper bus stock, yellow arrow, Figure 5. The lamination is accomplished by full penetration soldering of the interface between the .063" and .250" bars using 96/4 Sn/Ag alloy soft solder.

Figure 5. Portion of a typical capacitor row and bus.

Figure 5 shows the completed assembly installed in a typical capacitor row. It consists of the two sets of laminated conductors, one high-side and one low-side, clamped together with a sandwich of 0.005" polyimide film (Kapton®), 0.032" G-10, and 0.005" Kapton insulation between them.

Important Note: In the event that water should enter the bus assembly electrical insulation, in any amount, it is mandatory that the bus assembly be removed from the capacitors, disassembled, thoroughly dried, re-assembled and re-installed to prevent the

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possibility of voltage breakdown. Voltage breakdown, should it occur, will be followed by high fault currents, resulting in damage, possibly substantial, to the bus conductors and potentially to the capacitors as well.

SCR Modules

The SCRs used in the capacitor bank to switch stored energy from the capacitors are assembled into modular sub-assemblies as shown in Figure 6. Twelve assemblies, one for each capacitor row, are used in the capacitor bank. The assembly includes two water cooled heatsinks, an SCR, bus bar terminals, and a compression clamp to hold the SCR under 10,000 lb. pressure. Thermal compound is utilized in the compression interface of all SCRs.

Figure 6. Typical SCR module installation.

The modular approach is instituted to allow quick change-out in the event of an SCR failure. The mounting holes for the modular assemblies are arranged such that proper polarization is assured. Each module is secured by eight nuts, four at the top and four on the bottom. When changing out a module, it is first necessary to turn off the cooling water to the capacitor bank. Water in the modules can be drained via the Hansen® quick disconnects located near the floor, adjacent to the SCR panel of interest, as shown in Figure 7. A drain hose equipped with the appropriate fitting has been provided. Do not drain water into the enclosure. Air will have to be allowed into the system to facilitate complete drainage. The supply and return hoses to each SCR module are pitched to enhance water drainage.

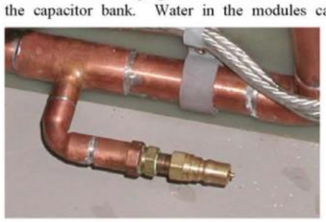

Figure 7. Quadrant water drain port

A torque wrench shall be used when installing a replacement module. Proper tightening will assure reliable electrical contact and, at the same time, preclude stud breakage. Replacement of a broken stud will incur significant down-time. The torque value, 30 ft-lbs, is posted adjacent to each module. Be certain the water hose fittings are properly installed. See *Procedures: Parker Hose Fittings.*

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Two preloaded assemblies are included among the spare parts inventory. When replacing an SCR in a heatsink assembly to complete a spare module, care must be taken to install the SCR in the proper polarity. Eight SCRs of the same part number are used in the temporary power supply capacitor bank and are potentially a source of additional spares.

Note: The spacing between the push on connector on the SCR gate terminal and the cathode bellows, arrow in Figure 6, is vary minimal. Be certain that the gate lead connector does not make contact with the cathode bellows. If contact occurs, the gate signal to the SCR will be shorted and triggering of the device will not take place. Proper orientation of the terminal on the center conductor of the gate cable (red co-ax) relative to the SCR will assure the necessary clearance. DO NOT bend the gate terminal on the SCR to gain clearance. Doing so may cause a fracture of the hermetic seal of the SCR package with subsequent failure of the device as a consequence of moisture entering the package and silicon fusion.

SCR Snubber

A snubber network is installed across each output SCR to protect it from voltage transients. The combination of a 1 uF capacitor in series with two parallel connected non-inductive resistors is used. The respective snubber circuits are mounted adjacent to each SCR. In the event of an SCR failure, it is important to evaluate the snubber circuit for integrity. A failure of the snubber may be the cause of the failure of the SCR.

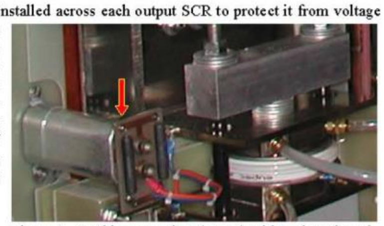

Figure 8. Snubber capacitor (arrow) with resistor board.

Firing Circuits

Firing circuits, Figure 10, provide the signal to the respective SCR gate terminals that initiates conduction of the devices. The firing circuits used to trigger the output SCRs are adapted from the Fermilab Low Beta Power Supply system. Circuit modifications are incorporated to increase the trigger pulse current amplitude to 6 Amps during the initial micro-second, decaying in several additional micro-seconds to 1 Amp for the remainder of the pulse. These modifications are documented by drawing 9820-EC-370116.

Figure 9. SCR gate pulse.
Top trace: Current; 2A/div.
Bottom trace: Voltage; 2 V/div.
Sweep: 5 µs/division.

Figure 9 shows the pulse waveforms as seen at the SCR gate under static conditions; i.e., no voltage on the anode and, consequently, not

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switching current.

Each of the 12 output SCRs in the capacitor bank has a dedicated firing circuit. Three identical circuits are included on a single printed circuit board. Four printed circuit boards are installed, one for each quadrant of the capacitor bank. All are mounted in the center bay of the enclosure on the stripline G-10 support structure.

The over-all pulse width of the gate signal for the SCRs is controlled by the electronics in the Trigger Fan-out Box and must be adjusted such that the pulse width does not exceed the on-time of the SCRs. Once triggered, the SCRs will remain in conduction until the first current zero occurs. The trigger signal to the SCRs ***must not*** remain 'ON' after that time. A trigger pulse width setting in the range of 60-70% of the horn current pulse width is ideal. Example: Horn current pulse width is 2.7 ms. Set the SCR trigger pulse width to approximately 1.9 ms, over-all.

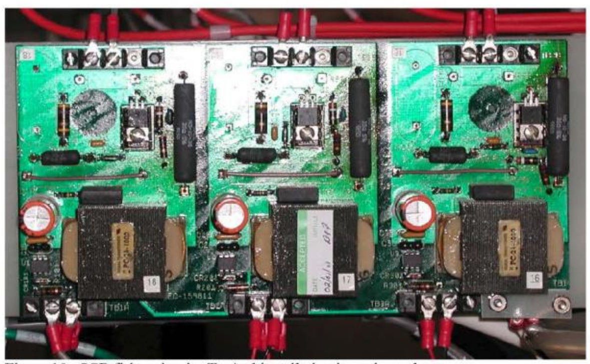

Figure 10. SCR firing circuit. Typical installation in each quadrant.

The output SCRs of the capacitor bank float at the operating voltage of the system. The firing circuit board components provide 1,500 Vdc isolation between the low-level input pulse and 120 Vac power, and the output pulse to the SCRs. Consequently, the majority of the components on the circuit board and the co-axial cables carrying the trigger pulse to each SCR float at high voltage as well. The co-axial cable outer jacket is not rated, with respect to ground, for the potentials the system may be operating at. Subsequently, the gate pulse co-axial cables are dressed away from structures at ground potential, or double insulated in areas where structures are unavoidable. Red colored RG-58 co-ax cable was installed to signify the application is operating at high voltage.

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Trigger Fan-out Box

The trigger fan-out box, Figure 11, is mounted to the ceiling of the enclosure, above the 'C' quadrant capacitor structure. It receives the 'SCR Trigger' pulse from the controls via fiber optic cable. A second fiber optic cable carries a 'status' signal back to the controls to verify that the trigger fan-out circuit has all of the appropriate voltages present. The status information is included in the interlock chain and must be present for system operation.

Figure 11. Trigger fan-out box.

Four parallel outputs from this circuitry are connected to the respective SCR firing-circuit pc-board of each quadrant. Two additional 'sync pulse' outputs are generated within and are available externally at the connector feed-thru panel, located above quadrant 'C.' The two sync signals are 1-µs in width, TTL level, buffered and synchronous with the trigger for the capacitor bank output SCRs. They are provided for field use of diagnostic equipment.

Internal Stripline

The internal stripline of the capacitor bank is constructed of ¼" x 12" copper extruded bus. Copper was chosen to facilitate fabrication and its lower resistance to reduce the heat load in the enclosure. The stripline configuration and routing within the capacitor bank was chosen to keep all conductors to the four capacitor quadrants of equal length, thus assuring current balance in the four stripline pairs.

Provision is also made to allow the output current direction to be reversed by the exchange of "jumper" placement. See: *Procedures: Polarity Reversal of Output Current.*

Figure 12. Internal stripline, one side.

Figure 13. 'Internal' to 'output' connection.

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Output Stripline

The output stripline is that section leading from the center bay of the capacitor bank to the outside of the enclosure. It is constructed of 3/8" x 12" 6101-T6 aluminum electrical bus conductor alloy. This alloy is formulated especially for electrical bus, offering 94% the conductivity of pure aluminum but with enhanced mechanical properties. Its conductivity is 59% that of copper

The assembly of eight conductors, four conductor pairs, is held together by bar type compression clamps and utilizing G-10 insulating spacers between layers. The clamps are spaced at 12 inch intervals. The assembly is supported from an aluminum I-beam running the length of the enclosure. The I-beam serves two purposes. It serves as a spreader bar when the enclosure is being lifted by a crane for transport, but more importantly it facilitates the removal of the output stripline should it become necessary for repair or replacement. In the cavern installation, the output (stripline) end of the capacitor bank is closely positioned with respect to the cavern wall, preventing removal of the output stripline on that end of the enclosure. The stripline suspension incorporates a jacking mechanism and is equipped with rollers that trolley on the I-beam, allowing the suspension and stripline to pass through the enclosure and out the opposite end. Pre-drilled holes in the I-beam flanges at each end allow extensions to be coupled and secured to the beam, as needed, to extend trolley travel. The jack drive-screw is as indicated in Figure 14, show at the right.

Figure 14. Output stripline and clamp.

Prior to lifting with the jacking mechanism, the stripline compression clamp in the center bay of the enclosure must be loosened or removed. For safety, it is recommended that supports be placed under the stripline and incremented with cribbing as the assembly is raised. The brake on the trolley must be released prior to transit and secured after re-installation.

Compression Clamps and Stripline Contacts

At locations where it is necessary to couple/decouple the eight layer stripline, a special compression clamp is utilized. As shown in Figure 14, the clamp incorporates twelve spring loaded pistons in each bar to establish equal pressure across the width of the stripline conductors. The spring on each piston is comprised of a series stack of 2,700 lb. rated conical compression washers, Solon Mfg. P/N 6-M-70. Pistons are held in their respective bores by o-rings used as a friction element to facilitate retention of the piston/spring assemblies during routine handling of the clamping bars. The pistons can

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be readily removed, if necessary, by pulling them straight out. A suction effect may impede removal. The clamp assembly is capable of 30,000 lbs. total clamping force. The clamp through bolts are to be tightened until the distance from the clamp bar to the top of the piston surface is between 0.510" and 0.540" at all piston locations.

The mating ends of the stripline conductors are beveled to facilitate alignment during engagement. The silver plated surfaces of the stripline should be inspected prior to assembly to ascertain their condition. Any dings or scratches should be dressed out and re-plated as needed. The mating surfaces have been coated with Dow-Corning #4 silicon lubricating compound to both ease assembly and to exclude moisture in the contact regions. Use additional Dow Corning No, 4 compound as needed for maintenance purposes, keeping film thickness to a bare minimum.

Voltage Dividers

A voltage divider is installed in each of the capacitor cells (rows) to monitor the performance of the respective cells. The control electronics monitors these signals on a continuous basis throughout the operating cycle, looking for any imbalance. The frequency compensated voltage divider circuitry includes a voltage-to-current converter, or current driver, with a low impedance output. This approach was implemented for improved noise immunity and the ability to drive long signal lines to the control electronics.

Two input jacks are provided on each unit. The sense leads from the capacitor buses must be connected to the appropriate input depending on the operating pulse width the capacitor bank is set up to provide, 5.2 ms or 2.6 ms. The jacks on the panel of the current driver box are so labeled. The divider ratios are 125:1 and 250:1 respectively. All twelve current drivers must be configured the same way before successful system start-up can be achieved. A schematic is available as drawing 9820-EC-370119

Figure 15. Typical voltage divider installation.

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Output Current Transformers

A passive current transformer (CT) is installed in the low-side bus of each capacitor row, located as shown by the arrow in Figure 15. Its output is 1 volt/kA and appears as a voltage source with 50 Ωs in series. The twelve individual signals, one from each CT, pass through the connector panel located above quadrant C of the enclosure. Termination for the current transformers is provided by the 50 Ω input impedance of each channel of the control electronics. These signals can be observed externally with an oscilloscope by teeing off the BNC connectors above the panel. CT signal outputs *must not* be interrupted while the system is running nor should an additional external termination be added. Any signal interruption, or the addition of a termination changing the calibration scale factor, will create the appearance of a current imbalance to the controls interlocks and cause the system to trip off.

Reverse Energy Discharge Resistor and Diode

Energy reflected from the load inductance will be stored in the capacitor bank, but of the opposite polarity. Because of the relatively large amount of resistance in the stripline and horns the amount of energy reflected is approximately 1.5 kJ (15%), to low to have made the additional components necessary for energy recovery circuitry economically cost effective. Consequently, the reverse energy is dissipated in a resistor switched into the circuit by a free-wheeling diode. The resistor-diode combination is connected in anti-parallel across each capacitor cell. The diode for each cell is mounted as a water cooled assembly to the capacitor low-side bus, adjacent to the current transformers.

The resistors are constructed of 0.312" O.D. x 0.035" wall, type 316L stainless steel tubing, 132" long. They are mounted just below the capacitor bushings in each row as show by the blue arrow in Figure 5. They are cooled by water flowing through the tubing. Allowing for no heat transfer to the cooling water during the nominal 50 ms duration of the reverse energy discharge current, the mass of the tubing can safely absorb 17 kJ/pulse. Heat transfer to the water follows the pulse. The thermal mass of the resistor yields a safety factor of more than 10.

Charging Choke and By-Pass Diode

A 10 mH inductor is connected between the PEI charging source (supply) and the capacitor bank. Its purpose is to limit undershoot current that occurs as a result of reverse recovered charge on the capacitor bank at the end of each discharge pulse. Design specifications of the choke are provided in FNAL Specification # 9820-ES-370036.

The physical placement of the choke, deep within the enclosure, was chosen to balance off the weight of the output stripline during transport of the capacitor bank into the underground cavern. The choke, with accessory components attached, weighs approximately 2,000 lbs. To facilitate installation and removal of the choke it has been mounted on aluminum C-channel "rails." After removal

Fig. 16. Choke installation.

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of its anchor bolts, the choke can be slid along the rails to the end of the enclosure with the aid of a 'come-along' winch and lifted out via fork-lift.

A by-pass diode is located within the capacitor bank enclosure, adjacent to the choke. This single diode appears electrically across the multiple series by-pass diodes of the PEIs and is meant to carry all of the remaining undershoot current, diverting it around the PEIs. Its anode is connected to the input end of the choke (PEI negative connection) and its cathode to ground (PEI positive connection).

Charge Isolation Diodes

Diodes are installed between the capacitor bank side (electrical) of the charging choke and each capacitor cell of the bank. Their purpose is two-fold. First, they provide isolation of the PEIs to prevent the delivery of stored energy from the capacitor bank into any fault that may occur in the charging supplies. Their second purpose is to provide isolation from cell to cell, preventing stored energy delivery into a faulted cell from the remainder of the capacitor bank.

The diodes are of modular construction and are installed in sets of three on water cooled heatsinks. The assemblies are located between the capacitor support structure and the G-10 SCR switch panel, in each quadrant, near the floor of the enclosure.

Signal Feed-thru Panel

A connector panel for passage of control and sensor signals into and out of the capacitor bank enclosure is located in the ceiling of the "C" quadrant as shown in Figure 17. The panel is labeled both inside the enclosure and, externally, on top of the enclosure. Spare BNC, Twin-ax, and multi-pin connectors have been provided for possible future needs.

The panel is installed with sealant between it and the enclosure to resist leakage into the enclosure of any water that may accumulate on the top surface.

Figure 17. Connector feed-thru panel

AC Utility Strip

A utility plug-strip is installed in the "C" quadrant at the top, inside, of the enclosure. It is connected to a separate circuit breaker to provide 120 V_{AC} for the ground-stick detector, trigger fan-out, SCR trigger circuits, and shorting-relay driver. It is equipped with its own 15 A circuit breaker. If any or all of the AC loads

Figure 18. AC utility strip in "C" quadrant

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connected to the strip are inoperative, check this breaker as well as the fuses in the individual loads. Two outlets remain available.

PEI Load Resistors

The PEI power supplies used for the capacitor bank were originally designed for powering magnets under constant current or programmed functions. When used for charging capacitors, the charging current will go to zero once the capacitors have archived the desired voltage, confusing the power supply regulator. As an aid to voltage regulation, a resistor is installed across the PEI output to pull a small amount of current at all times. The resistor is constructed of four series connected water cooled elements as used in domestic electric water heaters. They are mounted within two chambers, two elements within each, on the outward face of the charging choke, Figure 16. The combined series resistance and power rating of the four elements is 154 Ohms, 6 kW.

Humidity Sensor

A humidity sensor, recycled into this equipment from the D-0 experiment, is installed within the capacitor bank enclosure on the ceiling of the "C" quadrant. It was included in the equipment to monitor enclosure humidity, possibly indicating a collection of water from a small leak The unit is manufactured by Vaisala Sensor Systems, Helsinki, Finland. It has a measuring range of 0-100% and an accuracy at 20°C of;

+/- 2% from 0 – 90% RH,
+/-3% from 90 – 100% RH.
Temperature dependence: +/- 0.02 °C /°C.

Figure 19. Humidity sensor.

It operates on +15 Vdc and has an output of 0 to +1 V with respect to common for 0 – 100 % RH indication. Connection to it is via a dedicated connector on the enclosure feed-thru panel. See data sheet, Appendix: B, for complete specifications. Data output from it is available via a monitor connector on the rear panel of the Temperature Monitor Chassis located in the controls equipment rack.

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Electrical Safety Components

Bleeder Resistor P.C. Board

When the capacitor bank is configured with series pairs of capacitors, bleeder resistor boards must be installed as a safety measure. The low side terminal of all series pairs is grounded via the high current bus in each capacitor row. The high side terminal of the pair will be grounded when the LOTO procedure in carried out to completion. The mid-point between the capacitors, however, is not grounded and could retain a charge relative to ground. The installation of the bleeder resistors will provide a leakage path to effect discharge of any remaining stored energy after the system is shut down. Additionally, bleeder resistors will prevent any accumulation of stored charge from incidental energy sources; static charge, RF transmitters, etc.

Figure 20. Bleeder resistor boards.

By necessity, the resistance value must be high, 100 kΩ in this application, to keep power loss in the aggregate of the bleeder networks to an acceptable level. Redundancy for safety is established on each PC board by the use of four resistor elements connected in a bridge configuration, two in series by two in parallel with the mid point of the seriesed resistors connected together. Hence, two resistors must fail before the bleeder network becomes inoperative.

The time required to achieve full discharge is equal to five R-C time constants. With each capacitor being 7,500 uF, five time constants is equal to 63 minutes. The bleeder resistors are not to be relied upon to discharge the capacitor bank for maintenance purposes. LOTO procedures must be followed before any maintenance is to be performed within the capacitor bank enclosure or the PEI power supplies.

The bleeder boards are mounted to the respective capacitor terminals, Figure 20, by placement over the bushings *after* the ½-13 hex nuts securing the bus tabs have been installed and tightened to 17.5 ft-lbs. A ½-13 elastic stop nut is then used on each bushing to secure the circuit board to the capacitors. Elastic stop nuts are used to guard against loosening due to vibration. Tighten these nuts to approximately 4 ft-lbs, sufficient to make reliable contact without damaging the foils on the circuit board.

The bleeder boards can be tested in place to determine if all resistors on the board are operative. Recall that the low side of the series pairs of capacitors is already grounded by virtue of its installation. For this test, the ground clips placed during the LOTO procedure will also tie the high side of the series capacitor pairs to ground. To get correct ohmmeter readings, it will also be necessary to ground the "Z" link connecting the two capacitors of interest together for the duration of the ohmmeter application. The hard-ground ground stick can be used for grounding the "Z" link. With an ohmmeter connected from the mid-point of the bleeder resistor network to frame ground, the reading should be 25 kΩ, ± 5%. Values higher than this indicate a defective resistor on the bleeder board. If

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necessary, the circuit board can be removed from the capacitors to allow testing of each individual resistor. If the boards show any signs of damage, repair or replace with a spare board.

Energy Dump Resistors and Shorting Relays

A separate dump resistor is installed for each capacitor cell and is connected to a common shorting (grounding) relay, maintaining the cell to cell isolation necessary for safety. The shorting relay is indicated by an arrow in Figure 21. A second identical set of resistors and shorting relay is also installed to provide redundancy. They are located on the ceiling of the enclosure center bay, one set on each side. These resistors are

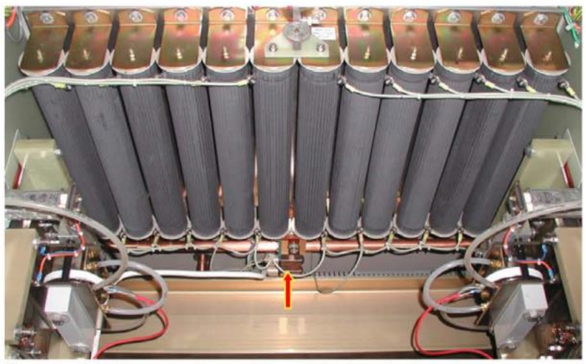

Figure 21. Capacitor energy dump resistors and shorting relay (arrow).

air cooled and rated to absorb 27 kJ each, sufficient for the maximum stored energy of system operation with greater than a factor of two safety margin. When system shut-down occurs during a charge cycle, or an interlock interrupts normal cycling, energy stored in the capacitors will be switched by the shorting relay into the dump resistors where it will be safely dissipated. The shorting relays are equipped with optional high current, high temperature copper-tungsten alloy contacts for additional reliability and long life.

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Shorting Relay Driver Box

The capacitor bank H.V. shorting (Ross®) relays require 120 V_{AC} to operate their pull-in coils. That power is switched by a single signal level relay also located within this box. This signal level relay is driven by the control electronics. The AC power for the shorting relay coils is sourced from the utility plug-strip located on the ceiling above the 'C' quadrant capacitor structure. The shorting relay driver box is also mounted in this location.

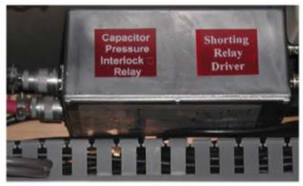

Figure 22. Shorting relay driver box.

Ground-sticks

A pair of ground-sticks are provided on each side of the capacitor bank enclosure, secured to the inside of one of the center bay doors. One of the pair includes a resistor assembly that will limit potential discharge current to a safe level. It is readily identified by its green handle and resistor assembly. The resistors used, three in parallel in each of the resistive sticks, are of bulk ceramic construction having a combined peak energy rating of 45 kJ. This rating provides a factor of three safety margin

The 'hard-ground' stick does not use resistors and is identifiable by its white handle and lack of resistors.
Figure 23 shows the two ground-sticks inserted into the retaining mounts on the center bay door of one side of the enclosure. The storage points on the doors are equipped with interlock switches to assure the system is not energized while a ground-stick may be applied to the capacitor bank circuitry. When the ground-sticks are stowed it is essential they be fully seated in the holders in order to make-up the interlocks.


Figure 23. Ground-sticks

Ground-stick Test Points

Test points are provided to confirm continuity of the ground-sticks. Three test points are provided on each side of the enclosure, one in the center bay and one in each end bay. All are located near the top of the enclosure at each location and so labeled. Figure24 shows the center bay test point, Figure 25 the quadrant test points.

Probing the test points with a resistive ground-stick will result in an intermittent tone response from its associated audio transducers. If a continuous tone, or no tone, is heard, the resistive ground-stick is faulty. Only the hard-ground ground-stick applied to the test point should elicit a continuous response. If no tone is obtained with the hard-ground ground-stick, it should be considered defective and repaired or replaced.

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Figure 24. Ground-stick test points are located at top-center in the center bays of the enclosure.

Figure 25. Typical test point located at top-center in each quadrant.

The ground-sticks are made of rugged materials to provide reliability and a long service life. The resistor housing is impact resistant polycarbonate (Lexan), and insulation free of coloration was chosen for the connecting cable to facilitate thorough internal inspection. However, damage to the resistors and/or housing can occur from impact should the stick be dropped or struck. Periodic inspection of the resistors, housing, cable and cable connections is recommended.

Ground-stick Detector Electronics

The ground-stick detector electronics is installed in a cast aluminum utility box attached to the enclosure ceiling in the "C" quadrant and appears as shown in Figure 26. It is energized at all times via AC power from the utility strip also located in quadrant C. It contains its own low-level power supply for powering the internal circuitry and includes an AC-line fuse (0.5A fast blow). In the event the detector is inoperative, check for a blown fuse.

Figure 26. Gnd. stick detector box.

A schematic diagram, drawing 9820-ED-370117, is available.

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Controls

General Description ***THIS PAGE IS OBSOLETE – REPLACE WITH PAGE FROM....***

The control system was established as a joint development effort between the NuMI and MiniBoone projects since the two systems are similar in most requirements. However, they are not identical and control modules must not be interchanged between the two experiments. The controls include five plug-in modules in a rack mounted frame, as shown in Figure 27, below. A block diagram of the control connections is available as Dwg. 9820-ED-370132 .... ***FILE "REPLACEMENT CONTROLS SECTION."***

Figure 27. Complete assembly of the Control Module chassis, shown as it appears during normal operation in the NuMI Power Supply system.

Two modules of the same model, 370139, are used to monitor current and voltage balance in the capacitor bank, however they are not interchangeable due to different calibrations for the respective functions.

DC power for the control modules is provided by a separate chassis mounted just below the controls chassis.

The following figures depict the various control modules in their normal state when the system is operating properly.

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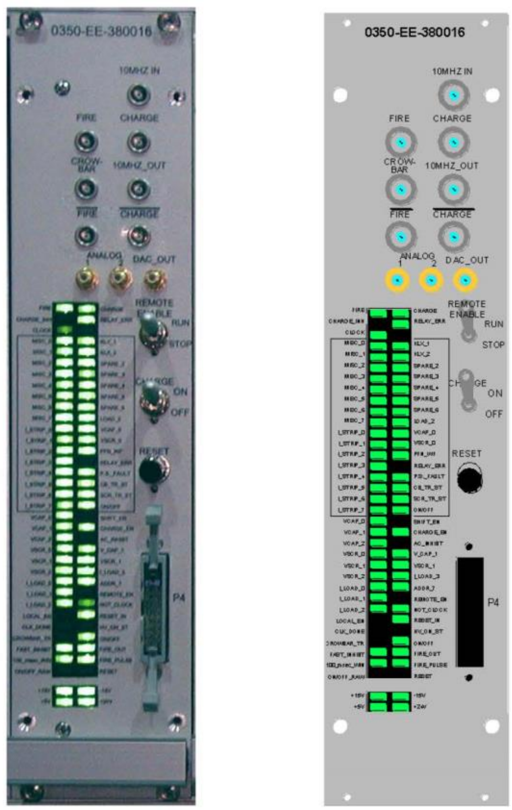

Figure 28. ***THIS PAGE IS OBSOLETE – REPLACE WITH PAGE FROM… FILE: "REPLACEMENT CONTROLS SECTION."***

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Figure 29. ***THIS PAGE IS OBSOLETE – REPLACE WITH PAGE FROM ... FILE: "REPLACEMENT CONTROLS SECTION."***

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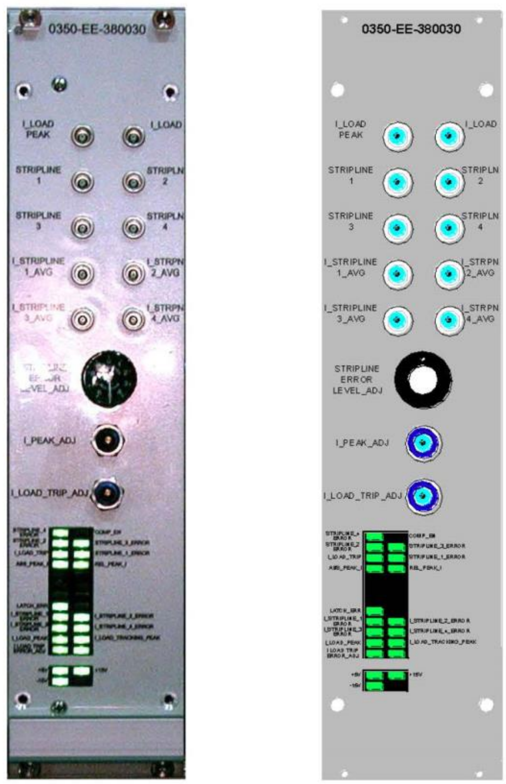

Figure 30. ***THIS PAGE IS OBSOLETE – REPLACE WITH PAGE FROM ... FILE: "REPLACEMENT CONTROLS SECTION."***

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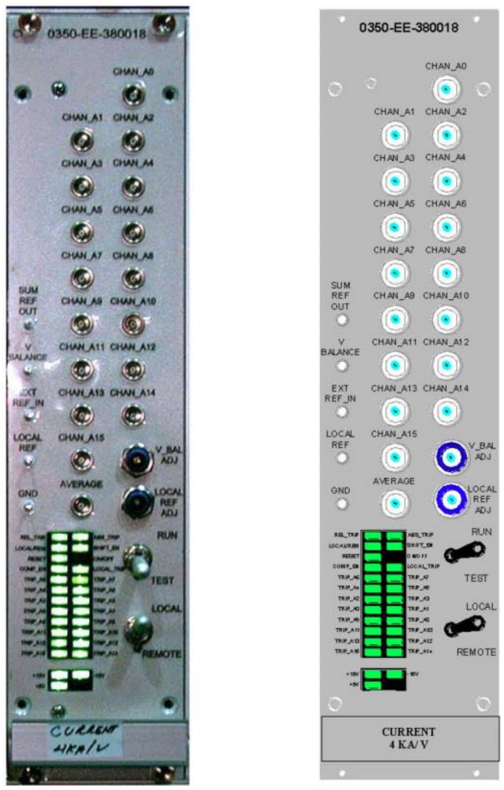

Figure 31. ***THIS PAGE IS OBSOLETE – REPLACE WITH PAGE FROM ... FILE: "REPLACEMENT CONTROLS SECTION."***

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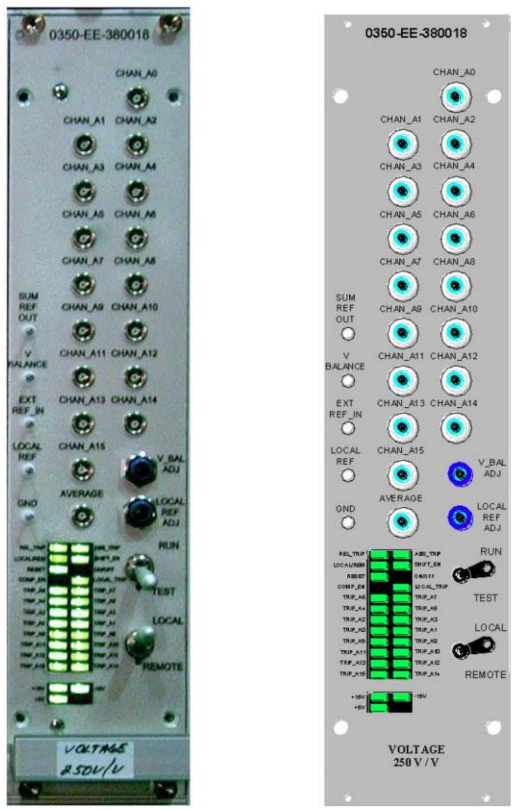

Figure 32. **THIS PAGE IS OBSOLETE – REPLACE WITH PAGE FROM ... FILE: "REPLACEMENT CONTROLS SECTION."**

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Cooling System

General Description

With two exceptions, all of the heat generating components, resistors, charging choke, diodes and SCRs associated with the capacitor bank in the enclosure, are cooled directly by water. The first exception is the capacitor energy dump resistors, which operate only momentarily when the system is turned off or the interlock system interrupts normal operation. Consequently, a negligible amount of additional heat is dissipated within the enclosure from these resistors. The second exception is the capacitor bank stripline. It is convection cooled and releases its heat to the air within the enclosure. A cooling water supply temperature of 95˚F, contributing some heat to the enclosure, plus the heat given off by the stripline serve to keep the enclosure internal temperature well above the ambient dew point temperature during operation. This heat is dissipated by conduction through the capacitor bank enclosure walls and radiated to the exterior environment.

Water is carried either by copper pipe or Nylo-Seal® nylon tubing. Nylo-Seal has a working pressure rating of 375 psi., and a burst pressure rating of 1150 psi. Swagelok and Parker fittings are used throughout for the plastic tubing. A diagram of the water circuit is shown in Figure 33.

A humidity sensor is also installed inside the enclosure to permit monitoring of the internal relative humidity.

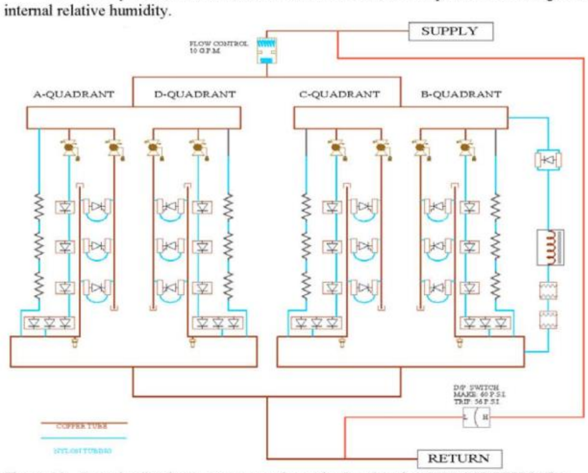

Figure 33. Capacitor bank water system schematic. See drawing 9820-MC-370054 for complete information and symbol key.

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Internal Flow-balance Valves

Flow balancing valves are installed internal to the enclosure to establish the flow rate to the various parallel water paths. The valves are manufactured by Taco, Inc., and are of size ½". They are adjusted with the aid of a differential pressure gauge, 0–10 in. WC is suggested, connected across the flow-valve venturi via the Schrader fittings on the flow-valve body. (The differential pressure gauge-set used for setting the valves was obtained from Fermilab's PPD-Mechanical Department-Instrument Group.) Figure 34 shows the installation at one of the SCR panel locations and is typical for all quadrants. The valves controlling cooling water for the diodes are located between the SCR (G-10) panel and the capacitor bank structure.

Figure 34. Internal flow-balance valve.

The calibration was carried out while the capacitor bank was installed in MI-8 and water flow externally regulated to an overall value of 10 gpm. The flow-valve bodies are equipped with bezels indicating the valve position in terms of rotation angle, with markings from 0-90°. Table 1, shows the valve position, in degrees, for each of the flow-valves when the flow was established at 0.5 gpm (2.25" WC) with the use of the calibration gauge set. See chart; ΔP vs: Flow, Appendix: C.

Quadrant	SCR	Diode
A	50°	58°
B	56°	52°
C	52°	56°
D	57°	57°

Table 1. Internal flow valve settings

External flow control valve

The total water flow rate for the capacitor bank is controlled by a self-regulating flow control valve manufactured by Griswold. The 10 gpm device is installed in the supply side water line, above and external to the enclosure.

Parker Hose Connections

Parker brand (brass) fittings are used on the output SCR modules and the water manifolds associated with the SCRs. See Appendix: D for instructions for assembling and tightening these fittings.

Swagelok Hose Connections

Swagelok (stainless steel) fittings are used in various locations within the capacitor bank. Instructions for application and tightening of these fittings will be found in Appendix: E.

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Penetration Stripline Cooling Blower

A 400 cfm blower, as shown in Figure 44, is installed in the THSR to provide cooling air to the penetration stripline leading to the Target Hall. Blower performance is monitored by an adjustable differential air pressure switch working in concert with pitot and static pressure sensors installed within the duct that connects the blower to the penetration. The flow rate (velocity) is proportional to the differential pressure between these two sensors. Both of these sensors *must* be installed with their orientation into the direction of airflow. When tightening hose connections to the sensors, care must be taken to prevent a rotation in orientation from the proper alignment. The differential air pressure switch is set to trip at approximately 50% blockage of the air filter. This calibration can be set by covering one half of a *new* filter element with a sheet of paper while the blower is running and noting switch operation. Actual pressures can be monitored by 'teeing in' a simple water manometer to the hoses. (We have used black coffee, for visibility, as the working fluid. A tiny amount of liquid detergent is also added to reduce the meniscus.)

The blower line cord is connected into the utility outlet situated downstream of the penetration. It is controlled by circuit breaker #12 in power panel PP-MI65A-5-A1 and is dedicated solely for blower use. The other utility outlet in the cage area, upstream of the penetration, shares the same circuit breaker as outlets outside of the cage. Do not use it for blower power.

To keep stripline insulators from accumulating dirt and compromising electrical hold-off do not operated the blower without the filter installed. It also serves as a physical barrier to fingers and foreign objects, preventing their entrance into the blower intake while it is running. The air filter element is the same as used in the Shop-Vac® brand of vacuum cleaners and are available from area hardware stores. It is retained by wing-nuts; no tools are required to change a filter.

A spare blower assembly is on hand in the THSR in the spares cabinet. To change out the blower, remove the mounting bolts securing it to the floor. Slide the blower and duct assembly away from the penetration, being careful not to dislodge the air lines. Separate the duct from the blower. Using new foam tape sealant, install duct to the replacement blower. Reposition blower and duct assembly and reinstall bolts into floor. Check the airflow differential switch for proper operation.

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Mechanical Design

General Description

The power supply system capacitor bank is designed to include all of the components needed to produce the high current pulse for the two horns installed in the underground beamline. The unit is designed to be able to operate at 240 kA, but to date has not been tested to that level due to lack of a suitably rated load. The system has been tested and operated extensively at 205 kA while testing prototype horns.

The installation in the MI-8 assembly building is set up to duplicate the floor plan of the cavern power supply room. By so doing, all of the present cabling to and from the control system and charging sources to the capacitor bank has been tested as well. They can be disconnected, transported, and re-connected in the underground cavern location with a reasonable level of assurance that the system will readily re-establish operation. Connection of 480 Vac power to the PEIs, and cooling water to the PEIs and capacitor bank will by necessity have to be tailored to the cavern installation. The dummy load installed for service in the MI-8 test station will not be used in the beamline installation.

Enclosure

The enclosure is constructed to Fermilab specifications per FNAL drawing number 2782.000-ME-314551. It measures 75" high x 210" long x 69" wide. It is constructed of mild steel and built in three sections; a center section housing the SCR switch assembly and the two identical capacitor bank sections, one on either side of the center unit. All are constructed as a floor pan and a roof pan, separated vertically by mullions that form the corners and supports for the enclosure doors. The sections have mating flanges secured by multiple bolts to make up the complete enclosure. In the area adjacent to each flange bolt the steel has been left un-painted and silver plating applied by the enclosure vendor. The plated areas were coated with moisture excluding grease prior to assembly to preserve optimum electrical contact between the enclosure sections. All sides of the enclosure are equipped with doors to allow full access to internal components. The door mullions in front of the capacitors in each quadrant are removable to facilitate capacitor replacement.

All doors are readily removable, with the exception of the two doors on the end of the enclosure adjacent to the output stripline. By necessity those two doors have been modified to slide on tracks, rather than swing, and are not easily removed.

Oil containment

The most likely capacitor failure mode, in terms of oil leakage, is the loss of seal under one or more bushings. Placing capacitors with their bushings "up" would be the preferred orientation, negating any leakage concerns. However, to facilitate removal and replacement and to permit a compact design that could be lowered as an assembled and tested unit into the underground cavern, the capacitors are mounted horizontally with their bushings toward the outside of the enclosure. The two inch lip-height of the floor pans in the capacitor sections of the enclosure provides 14 gallons of potential oil containment in the event of capacitor leakage. The capacitors used in the capacitor bank are impregnated with rapeseed (Canola) oil, a biodegradable vegetable oil. Each capacitor contains approximately 2.5 gallons of oil. Therefore, as many as 5 units in

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either enclosure end-section could spill their entire contents without exceeding the oil containment capacity for that section. A MSDS document is provided in Appendix: F

All penetrations in the enclosure floor pans have been sealed or curbed to prevent leakage to the outside. With any capacitor loosing oil, it is probable electrical failure of the capacitor will follow at some point. Any capacitor electrical failure will contribute to a current imbalance of the capacitor bank output and eventually be detected by the local controls, resulting in shutdown of the power supply system.

Capacitor Support Structure

The capacitors constitute approximately 50% of the total weight of the enclosure assembly. During transport the structures supporting the capacitors in each quadrant are lifted directly via the four hoist rings on top of the enclosure. Each hoist ring is rated for 10,000 lbs vertical lift capacity. Internal and external structural members cross brace the capacitor supports to allow transport of the capacitor bank as a single unit. The balance of the weight of the remaining components within the enclosure is carried through the enclosure structure to the capacitor supports. The 1" thick G-10 panels that mount the switching SCRs in each quadrant also serve as torsional webs to give the enclosure torsional stiffness.

Ground-cable Penetration

Ground-cables connecting the capacitor bank low-side terminal to the horn modules, via the LEM, for ground fault detection exit the enclosure through a curbed hole in the base of the enclosure on the output stripline end. The purpose of this curb is to maintain the oil containment capability of the enclosure floor pan. The cable opening is sufficiently large to allow for the installation of two 929 mcm cables with some room to spare. The excess opening should be sealed off after the installation in the underground power supply room to prevent the entrance of vermin. Such vermin can potentially bridge high voltage conductors, principally the stripline, and initiate a voltage strike with a follow-thru of stored energy from the capacitor bank, possibly leading to substantial damage of components.

Figure 35. Ground cable penetration.

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Procedures

LOTO Procedure

A LOTO procedure has been prepared for use with this equipment installation in the THSR location. The procedure number is BDDP-EE-9916, Rev. A.

Capacitor removal

Before any capacitor can be removed, it is necessary to remove the high-current bus assembly and water cooled stainless steel discharge resistor mounted just below the bus. The bus assembly can be removed as a unit or disassembled and reassembled in place. Note the arrangement of spacers, washers, and nuts in the various bushing positions when disassembling. Cooling water to the capacitor bank shall be shut off prior to performing the work to eliminate the potential for flooding in the event a water connection is compromised during the process. Water connections to the resistor may have to be disconnected, depending on the position (slot) of the capacitor to be removed.

The mullion supporting the doors in the center of each quadrant is designed to be removable to facilitate capacitor replacement. Bolts securing the mullion are at the top and bottom. Alternatively, the capacitors adjacent to those mounted behind the mullion can be removed to gain access for replacement of capacitors shadowed by the mullion.

The weight of each capacitor is approximately eighty pounds. This maximum weight was specified to make it possible for two people, working together, to be able to lift the units for removal and replacement in the confines of the cavern installation.

The capacitor studs, for optimum conductivity, are constructed of copper. Do not exceed the torque value of 17.5 ft-lbs for the bushing nuts when tightening. Exceeding the torque value can lead to stretching of the stud with a resultant pitch change in the threads, causing subsequent difficult removal of the nut(s). Excess torque may also lead to fracture of a bushing insulator.

The nuts securing the bleeder resistor boards should be torqued to 4 to 5 ft-lbs., sufficient to make electrical contact without damaging the board foils.

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Pulse Width Change Procedure

The width of the current pulse delivered to the horn can be changed between 5.2 ms and 2.6 ms. This is accomplished by configuring the capacitors in an all-in-parallel connection or a series-parallel connection respectively. All of the capacitors in the entire bank *must* be configured the same way before operation can resume. The following steps show the change-over process from series-parallel to all-in-parallel. Reverse this procedure to restore the capacitor bank to the series-parallel configuration

Figure 36.

Figure 36 shows a typical capacitor pair assembled in the series-parallel configuration. Start the change-over by removing the nuts securing the bleeder resistor boards. Remove the boards and hardware; put into safe storage. Torque value for the nuts securing the bleeder boards is 4 to 5 ft-lbs.

Figure 37.

Figure 37. Remove the nuts and bronze conical washers retaining the "Z" link. Retain the hardware for re-assembly.

Figure 38.

Figure 38. Remove the "Z" link and put it into safe storage. The brass washers on the capacitor bushings that are behind the Z-link are to be left in place. They are installed to equalize the bushing height for the following step.

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Figure 39. Install the parallel bars on the upper and lower capacitor bushings. Upper bar placement is shown.

Figure 39.

Figure 40. Install the bronze conical washers and nuts on capacitor bushings, eight locations per capacitor pair. Torque all nuts to 17.5 ft-lbs. *Do not* exceed torque value. Excess torque may result in bushing insulator fracture.

Repeat the above procedures for *all* of the capacitor pairs in the capacitor bank.

Figure 40.

Figure 41. Change the position of the input lead on the voltage divider box for *all twelve* capacitor rows.

This completes the change over from 5.2 ms operation to 2.6 ms operation. Be certain the PEI program is correctly revised to prevent an over-voltage condition for the capacitors.

Maximum Rated Working Voltage for the capacitor bank is 670 V for parallel operation, and 1340 V for series-parallel operation.

Figure 41.

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Polarity Reversal of Output Current

Changing current direction in the horns is accomplished by exchanging the 'jumper' links designed into the stripline sections in the center bay of the enclosure. The procedure will require approximately 4 hours to complete

The process involves exchanging the copper links, indicated by the red arrows of Figure 42, with the G-10 place holder located above, indicated by the green arrow in the figure. This procedure must be completed in all four quadrants before re-energizing the system. If all four quadrants are not configured alike it will result in a short circuit of the capacitor bank that will not be realized until the system is energized. This will be fatal to the SCR(s). Do not operate the system without the G-10 link in place as it serves as a mechanical stiffener to the stripline assembly in the center bay, stabilizing its position.

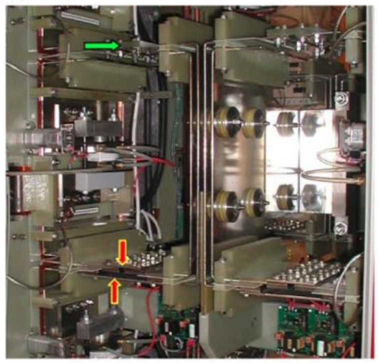

Figure 42. Current reversing connector plates and G-10 stiffener, typical of all four quadrants.

Because the nut plate, by necessity, is less than one thread diameter in thickness it is fabricated of 4340 chromium-nickel-molybdenum alloy steel to provide additional strength. The bolts used for the jumper plates are high strength, Grade-8, and should not be substituted with a lower grade. Spare bolts are provided. Torque specification for all bolts of the jumper plates is 30 ft-lbs.

Lifting For Transport

Transport of the capacitor bank has been demonstrated MI-8 and MI-65 with the use of a spreader bars and the overhead crane, as shown in Figure 43. The weight of the enclosure assembly is 22,000 lbs. The capacitor bank is well balanced and will lift squarely. No additional bracing was used nor is any necessary. An engineering note, MSD NOTE 000055, NuMI Horn Power Supply Capacitor Bank Structural Analysis Note, has been prepared and approval granted for crane transport. A copy of this document is also available in the E/E Support group departmental records library.

The possibility of a high humidity environment in the underground cavern installation requires that care and consideration be given to protecting all painted surfaces of the enclosure. The primary purpose of the applied paint coating is corrosion protection, appearance secondary. Any damage that may occur to the finish during transport and

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installation into the cavern location should be repaired. Extra paint of each color was secured from the enclosure vendor for this purpose.

It is foreseen that the capacitor bank can be loaded onto a flat-bed semi-trailer truck with use of the MI-8 building crane for transport to MI-65 where it can be similarly off-loaded. Do not allow the spreader bars to be stored on the top of the capacitor bank enclosure without proper precaution to protect the enclosure corrosion inhibiting finish.

Figure 43. Spreader bar arrangement used for lifting or moving capacitor bank. Weight without doors installed is 22,000 lbs.

For transport into the underground cavern all doors, except the two sliding doors, should be removed to protect both the doors and door hardware. Removing the doors will allow as much clearance as possible between the enclosure frame and the walls of the cavern access shaft. There will be approximately 1-1/2 inches clearance on each side during transit down the drop shaft. Protective 2"x 4" framing lumber, running the full vertical length top to bottom, should be attached to the corner posts and mullions of the enclosure to serve as fenders during the trip down the shaft. It is not recommended that tape be used to secure the 2 x 4 fenders as damage to the corrosion protective paint finish may occur during removal. Ty-raps are recommended.

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Under no condition should pry bars be applied directly against the enclosure frame to effect enclosure positioning or movement. One inch thick steel load distribution plates, 4130 alloy, are installed under each end of the enclosure to accommodate Hillmann rollers and to provide suitably robust pry-point surfaces for positioning.

Penetration Stripline Connection

The penetration stripline position is fixed at the Target Hall end by a connecting rod anchored to the 24 inch diameter steel penetration pipe. The THSR end of the penetration stripline is allowed to float in length with the expected linear thermal expansion. The expansion distance is as much as ¼" depending on power supply repetition rates. Connection between the capacitor bank output stripline and penetration stripline in the THSR is made by the installation of ridged connecting links. To accommodate the penetration stripline expansion effects the capacitor bank is mounted upon rollers and allowed to move. The total range of travel is +/- 5/8 of an inch and is limited by stops built into the eight roller assemblies positioned under the capacitor bank. The distance between the ends of the penetration stripline and capacitor bank output stripline must be pre-set at 11 inches, green arrow in Figure 44, before installation of the connecting links. This distance will correctly position the capacitor bank in the center of its range of motion. The force required to move the capacitor bank for positioning is approximately 80 pounds.

A vertical offset between centerlines of the penetration stripline and the capacitor bank stripline, approximately 1-1/2 inches due to civil construction variations from specification, is accommodated in the design of the connecting links. When installed with the proper orientation, the top surfaces of the links will be level.

See section on Compression Clamps and Stripline Contacts, page 13, for clamp tightening requirements.

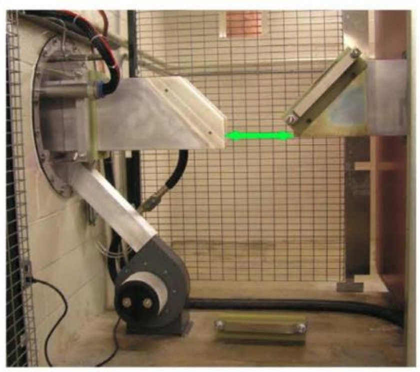

Figure 44. Penetration-to-Capacitor bank stripline alignment, without connecting links, showing 11" pre-set , vertical offset, blower installation, and blower-dedicated utility outlet location.

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NWL Capacitor data base for NuMI Horn P.S.
NWL Capacitor Cat # WB0969
Sorted by Serial Number, in aascending order.

Item #	Serial Number	C, uF	DF, %	ESL, nH
1	10478-01-01 0001	7504	0.82	96
2	10478-01-02 0001	7518	0.79	132
3	10478-02-01 0002	7567	0.86	132
4	10478-02-02 0002	7583	0.86	94
5	10478-02-03 0002	7598	0.86	97
6	10478-02-04 0002	7464	0.86	209
7	10478-02-05 0002	7564	0.86	124
8	10478-02-06 0002	7562	0.86	125
9	10478-02-07 0002	7579	0.86	107
10	10478-02-08 0002	7474	0.86	135
11	10478-02-09 0002	7462	0.86	136
12	10478-02-10 0002	7491	0.86	139
13	10478-03-01 0002	7526	0.84	171
14	10478-03-02 0002	7555	0.84	166
15	10478-03-03 0002	7472	0.84	162
16	10478-03-04 0002	7439	0.84	247
17	10478-03-05 0002	7424	0.84	245
18	10478-03-06 0002	7450	0.86	483
19	10478-03-07 0002	7450	0.86	317
20	10478-03-08 0002	7415	0.84	270
21	10478-03-09 0002	7456	0.84	458
22	10478-03-10 0002	7483	0.84	324
23	10478-04-01 0002	7540	0.54	266
24	10478-04-02 0002	7521	0.54	223
25	10478-04-03 0002	7417	0.54	550
26	10478-04-04 0002	7492	0.54	477
27	10478-04-05 0002	7430	0.53	336
28	10478-04-06 0002	7473	0.7	314
29	10478-04-07 0002	7467	0.7	386
30	10478-04-08 0002	7460	0.7	389
31	10478-04-09 0002	7457	0.7	304
32	10478-04-10 0002	7500	0.7	323
33	10478-05-01 0002	7416	0.7	223
34	10478-05-02 0002	7447	0.69	331
35	10478-05-03 0002	7512	0.7	259
36	10478-05-04 0002	7553	0.7	227
37	10478-05-05 0002	7473	0.7	219
38	10478-05-06 0002	7427	0.7	250
39	10478-05-07 0002	7597	0.72	367
40	10478-05-08 0002	7440	0.72	336
41	10478-05-09 0002	7494	0.76	266
42	10478-05-10 0002	7492	0.72	319
43	10478-06-01 0002	7494	0.7	398
44	10478-06-02 0002	7448	0.7	491
45	10478-06-03 0002	7465	0.7	234
46	10478-06-04 0002	7475	0.74	322
47	10478-06-05 0002	7489	0.52	385
48	10478-06-06 0002	7474	0.51	228
49	10478-06-07 0002	7467	0.51	414
50	10478-06-08 0002	7440	0.51	330
51	10478-06-09 0002	7487	0.59	342
52	10478-06-10 0002	7557	0.57	387
53	10478-07-01 0002	7423	0.53	315
54	10478-07-02 0002	7484	0.56	303
55	10478-07-03 0002	7507	0.56	253
56	10478-07-04 0002	7522	0.56	289
57	10478-07-05 0002	7498	0.49	281
58	10478-07-06 0002	7459	0.55	448
59	10478-07-07 0002	7423	0.53	392
60	10478-07-08 0002	7480	0.54	330
61	10478-07-09 0002	7393	0.53	415
62	10478-07-10 0002	7436	0.55	450
63	10478-08-01 0002	7486	0.53	336
64	10478-08-02 0002	7396	0.52	401
65	10478-08-03 0002	7408	0.53	335
66	10478-08-04 0002	7424	0.53	339
67	10478-08-05 0002	7513	0.55	381
68	10478-08-06 0002	7514	0.52	400
69	10478-08-07 0002	7440	0.53	296
70	10478-08-08 0002	7410	0.54	355
71	10478-08-09 0002	7423	0.52	309
72	10478-08-10 0002	7479	0.53	296

NWL Capacitor data base for NuMI Horn P.S.
Sorted by Capacitance Value, in ascending order

Item #	Serial Number	C, uF	DF, %	ESL, nH
108	10478-12-06 0003	7360	0.49	251
109	10478-12-07 0003	7360	0.49	371
89	10478-10-07 0003	7363	0.56	213
125	10478-14-03 0003	7365	0.49	237
102	10478-11-10 0003	7366	0.48	323
104	10478-12-02 0003	7366	0.49	272
107	10478-12-05 0003	7369	0.49	357
76	10478-09-03 0002	7375	0.81	248
74	10478-09-01 0002	7379	0.81	394
90	10478-10-08 0003	7382	0.54	359
92	10478-10-10 0003	7382	0.54	234
91	10478-10-09 0003	7384	0.53	214
120	10478-13-08 0003	7385	0.48	247
61	10478-07-09 0002	7393	0.53	415
64	10478-08-02 0002	7396	0.52	401
106	10478-12-04 0003	7398	0.49	310
122	10478-13-10 0003	7398	0.48	269
88	10478-10-06 0003	7400	0.53	261
132	10478-14-10 0003	7403	0.49	249
124	10478-14-02 0003	7406	0.49	213
65	10478-08-03 0002	7408	0.53	335
129	10478-14-07 0003	7409	0.49	230
70	10478-08-08 0002	7410	0.54	355
79	10478-09-07 0003	7413	0.8	89
83	10478-10-01 0003	7413	0.8	149
131	10478-14-09 0003	7414	0.49	278
20	10478-03-08 0002	7415	0.84	270
33	10478-05-01 0002	7416	0.7	223
25	10478-04-03 0002	7417	0.54	550
86	10478-10-04 0003	7418	0.8	201
87	10478-10-05 0003	7418	0.8	139
84	10478-10-02 0003	7430	0.81	144
114	10478-13-02 0003	7431	0.48	228
116	10478-13-04 0003	7431	0.48	244
62	10478-07-10 0002	7436	0.55	450
16	10478-03-04 0002	7439	0.84	247
75	10478-09-02 0002	7439	0.81	318
40	10478-05-08 0002	7440	0.72	336
50	10478-06-08 0002	7440	0.51	330
69	10478-08-07 0002	7440	0.53	296
115	10478-13-03 0003	7443	0.48	262
85	10478-10-03 0003	7446	0.81	138
34	10478-05-02 0002	7447	0.69	331
44	10478-06-02 0002	7448	0.7	491
18	10478-03-06 0002	7450	0.86	483
19	10478-03-07 0002	7450	0.86	317
73	10478-09-05 0004	7452	0.79	182
80	10478-09-08 0003	7452	0.8	92
121	10478-13-09 0003	7455	0.48	241
21	10478-03-09 0002	7456	0.84	458
117	10478-13-05 0003	7456	0.48	247
31	10478-04-09 0002	7457	0.7	304
58	10478-07-06 0002	7459	0.55	448
30	10478-04-08 0002	7460	0.7	389
81	10478-09-09 0003	7461	0.83	123
97	10478-11-05 0003	7461	0.52	118
11	10478-02-09 0002	7462	0.86	136
6	10478-02-04 0002	7464	0.86	209
45	10478-06-03 0002	7465	0.7	234
29	10478-04-07 0002	7467	0.7	386
49	10478-06-07 0002	7467	0.51	414
96	10478-11-04 0003	7471	0.52	254
15	10478-03-03 0002	7472	0.84	162
28	10478-04-06 0002	7473	0.7	314
37	10478-05-05 0002	7473	0.7	219
113	10478-13-01 0003	7473	0.49	228
10	10478-02-08 0002	7474	0.86	135
48	10478-06-06 0002	7474	0.51	228
46	10478-06-04 0002	7475	0.74	322
72	10478-08-10 0002	7479	0.53	296
60	10478-07-08 0002	7480	0.54	330
130	10478-14-08 0003	7481	0.49	340

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73	10478-09-05 0004	7452	0.79	182
74	10478-09-01 0002	7379	0.81	394
75	10478-09-02 0002	7439	0.81	318
76	10478-09-03 0002	7375	0.81	248
77	10478-09-04 0002	7423	0.81	315
78	10478-09-06 0003	7422	0.78	179
79	10478-09-07 0003	7413	0.8	89
80	10478-09-08 0003	7452	0.8	92
81	10478-09-09 0003	7461	0.83	123
82	10478-09-10 0003	7424	0.81	89
83	10478-10-01 0003	7413	0.8	149
84	10478-10-02 0003	7430	0.81	144
85	10478-10-03 0003	7446	0.81	138
85	10478-10-04 0003	7418	0.8	201
87	10478-10-05 0003	7418	0.8	139
88	10478-10-06 0003	7400	0.53	261
89	10478-10-07 0003	7353	0.56	213
90	10478-10-08 0003	7382	0.54	359
91	10478-10-09 0003	7384	0.53	214
92	10478-10-10 0003	7382	0.54	234
93	10478-11-01 0003	7425	0.54	330
94	10478-11-02 0003	7558	0.54	223
95	10478-11-03 0003	7484	0.54	158
96	10478-11-04 0003	7471	0.52	254
97	10478-11-05 0003	7451	0.52	118
98	10478-11-06 0003	7526	0.48	228
99	10478-11-07 0003	7534	0.48	215
100	10478-11-08 0003	7546	0.48	273
101	10478-11-09 0003	7544	0.48	209
102	10478-11-10 0003	7366	0.48	323
103	10478-12-01 0003	7503	0.49	281
104	10478-12-02 0003	7366	0.49	272
105	10478-12-03 0003	7490	0.49	230
106	10478-12-04 0003	7398	0.49	310
107	10478-12-05 0003	7369	0.49	357
108	10478-12-06 0003	7360	0.49	251
109	10478-12-07 0003	7360	0.49	371
110	10478-12-08 0003	7520	0.49	264
111	10478-12-09 0003	7552	0.49	305
112	10478-12-10 0003	7584	0.49	237
113	10478-13-01 0003	7473	0.49	228
114	10478-13-02 0003	7431	0.48	228
115	10478-13-03 0003	7443	0.48	262
116	10478-13-04 0003	7431	0.48	244
117	10478-13-05 0003	7456	0.48	247
118	10478-13-06 0003	7606	0.48	223
119	10478-13-07 0003	7514	0.48	242
120	10478-13-08 0003	7385	0.48	247
121	10478-13-09 0003	7455	0.48	241
122	10478-13-10 0003	7398	0.48	269
123	10478-14-01 0003	7423	0.49	254
124	10478-14-02 0003	7406	0.49	213
125	10478-14-03 0003	7365	0.49	237
126	10478-14-04 0003	7578	0.49	225
127	10478-14-05 0003	7624	0.49	242
128	10478-14-06 0003	7568	0.49	289
129	10478-14-07 0003	7409	0.49	230
130	10478-14-08 0003	7481	0.49	340
131	10478-14-09 0003	7414	0.49	278
132	10478-14-10 0003	7403	0.49	249
Total		986314		
Average		7472	0.630	268.5694

22	10478-03-10 0002	7483	0.84	324
54	10478-07-02 0002	7484	0.56	303
95	10478-11-03 0003	7484	0.54	158
63	10478-08-01 0002	7486	0.53	336
51	10478-06-09 0002	7487	0.59	342
47	10478-06-05 0002	7489	0.52	385
105	10478-12-03 0003	7490	0.49	230
12	10478-02-10 0002	7491	0.85	139
26	10478-04-04 0002	7492	0.54	477
42	10478-05-10 0002	7492	0.72	319
41	10478-05-09 0002	7494	0.75	266
43	10478-06-01 0002	7494	0.7	398
57	10478-07-05 0002	7498	0.49	281
32	10478-04-10 0002	7500	0.7	323
103	10478-12-01 0003	7503	0.49	281
1	10478-01-01 0001	7504	0.82	96
55	10478-07-03 0002	7507	0.56	253
35	10478-05-03 0002	7512	0.7	259
67	10478-08-05 0002	7513	0.55	381
68	10478-08-06 0002	7514	0.52	400
119	10478-13-07 0003	7514	0.48	242
2	10478-01-02 0001	7518	0.79	132
110	10478-12-08 0003	7520	0.49	264
24	10478-04-02 0002	7521	0.54	223
56	10478-07-04 0002	7522	0.56	289
13	10478-03-01 0002	7526	0.84	171
98	10478-11-06 0003	7526	0.48	228
99	10478-11-07 0003	7534	0.48	215
23	10478-04-01 0002	7540	0.54	266
101	10478-11-09 0003	7544	0.48	209
100	10478-11-08 0003	7546	0.48	273
111	10478-12-09 0003	7552	0.49	305
52	10478-06-10 0002	7557	0.57	387
94	10478-11-02 0003	7558	0.54	223
128	10478-14-06 0003	7568	0.49	289
126	10478-14-04 0003	7578	0.49	225
112	10478-12-10 0003	7584	0.49	237
39	10478-05-07 0002	7597	0.72	367
118	10478-13-06 0003	7606	0.48	223
127	10478-14-05 0003	7624	0.49	242
36	10478-05-04 0002	7653	0.7	227
14	10478-03-02 0002	7655	0.84	166
8	10478-02-06 0002	7662	0.86	125
7	10478-02-05 0002	7664	0.86	124
3	10478-02-01 0002	7667	0.86	132
9	10478-02-07 0002	7679	0.86	107
4	10478-02-02 0002	7683	0.86	94
5	10478-02-03 0002	7698	0.86	97
Total		897223		
Average		7529	0.629417	267.6167
		7476.8583		

Spares

Sorted by capacitance, in ascending order

Line #	Serial Number	C, uF	DF, %	ESL, nH
78	10478-09-06 0003	7422	0.78	179
53	10478-07-01 0002	7423	0.53	315
59	10478-07-07 0002	7423	0.53	392
71	10478-08-09 0002	7423	0.52	309
77	10478-09-04 0002	7423	0.81	315
123	10478-14-01 0003	7423	0.49	254
17	10478-03-05 0002	7424	0.84	245
66	10478-08-04 0002	7424	0.53	339
82	10478-09-10 0003	7424	0.81	89
93	10478-11-01 0003	7425	0.54	330
38	10478-05-06 0002	7427	0.7	250
27	10478-04-05 0002	7430	0.53	336
Total		89091.00		
Average		7424.25	0.634	279.42

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Appendix: A-3

Item #	Serial Number	Parallep Cap. - uF	D.F.	ESL	Location	Series Cap. - uF
90	10478-10-08 0003	7382	0.54	359	A-1-1	3698
70	10478-08-08 0002	7410	0.54	355	A-1-2	
62	10478-07-10 0002	7436	0.55	450	A-1-3	3722
73	10478-09-05 0004	7452	0.79	182	A-1-4	
30	10478-04-08 0002	7460	0.7	389	A-1-5	3735
72	10478-08-10 0002	7479	0.53	296	A-1-6	
60	10478-07-08 0002	7480	0.54	330	A-1-7	3745
41	10478-05-09 0002	7494	0.76	266	A-1-8	
126	10478-14-04 0003	7578	0.49	225	A-1-9	3794
39	10478-05-07 0002	7597	0.72	357	A-1-10	
	TOTAL	74768				18692
	AVERAGE		0.616	321.9		
120	10478-13-08 0003	7385	0.48	247	A-2-1	3699
79	10478-09-07 0003	7413	0.8	89	A-2-2	
33	10478-05-01 0002	7416	0.7	225	A-2-3	3714
75	10478-09-02 0002	7439	0.81	318	A-2-4	
45	10478-06-03 0002	7465	0.7	234	A-2-5	3732
95	10478-11-03 0003	7484	0.54	158	A-2-6	
43	10478-06-01 0002	7494	0.7	398	A-2-7	3743
110	10478-12-08 0003	7520	0.49	264	A-2-8	
128	10478-14-06 0003	7568	0.49	289	A-2-9	3788
112	10478-12-10 0003	7584	0.49	287	A-2-10	
	TOTAL	74768				18693
	AVERAGE		0.62	245.7		
92	10478-10-10 0003	7382	0.54	234	A-3-1	3698
129	10478-14-07 0003	7409	0.49	230	A-3-2	
114	10478-13-02 0003	7431	0.48	228	A-3-3	3720
18	10478-03-06 0002	7450	0.86	483	A-3-4	
80	10478-09-08 0003	7452	0.8	92	A-3-5	3732
46	10478-06-04 0002	7475	0.74	323	A-3-6	
42	10478-05-10 0002	7492	0.72	319	A-3-7	3751
68	10478-08-06 0002	7514	0.52	400	A-3-8	
94	10478-11-02 0003	7558	0.54	223	A-3-9	3791
118	10478-13-06 0003	7606	0.49	213	A-3-10	
	TOTAL	74769				18692
	AVERAGE		0.617	275.4		
91	10478-10-09 0003	7384	0.53	214	B-1-1	3698
65	10478-08-03 0002	7408	0.53	335	B-1-2	
116	10478-13-04 0003	7431	0.48	244	B-1-3	3720
44	10478-06-02 0002	7448	0.7	491	B-1-4	
81	10478-09-09 0003	7461	0.83	123	B-1-5	3734
10	10478-02-08 0002	7474	0.86	135	B-1-6	
105	10478-12-03 0003	7490	0.49	230	B-1-7	3746
26	10478-04-04 0002	7492	0.54	477	B-1-8	
52	10478-06-10 0002	7557	0.57	387	B-1-9	3795
127	10478-14-05 0003	7624	0.49	242	B-1-10	
	TOTAL	74769				18693
	AVERAGE		0.602	287.8		
89	10478-10-07 0003	7365	0.56	213	B-2-1	3694
20	10478-03-08 0002	7415	0.84	270	B-2-2	
84	10478-10-02 0003	7430	0.81	144	B-2-3	3717
69	10478-08-07 0002	7440	0.53	296	B-2-4	
34	10478-05-02 0002	7447	0.69	331	B-2-5	3730
113	10478-13-01 0003	7473	0.49	228	B-2-6	
22	10478-03-10 0002	7483	0.84	324	B-2-7	3749
67	10478-08-05 0002	7513	0.55	381	B-2-8	
111	10478-12-09 0003	7552	0.49	305	B-2-9	3803
36	10478-05-04 0002	7653	0.7	227	B-2-10	
	TOTAL	74769				18691
	AVERAGE		0.65	271.9		
107	10478-12-05 0003	7369	0.49	357	B-3-1	3693
132	10478-14-10 0003	7408	0.49	249	B-3-2	
86	10478-10-04 0003	7418	0.8	201	B-3-3	3714
40	10478-05-08 0002	7440	0.72	336	B-3-4	
6	10478-02-04 0002	7464	0.86	209	B-3-5	3734
37	10478-05-05 0002	7473	0.7	219	B-3-6	
51	10478-06-09 0002	7487	0.59	342	B-3-7	3750
119	10478-13-07 0003	7514	0.48	242	B-3-8	
100	10478-11-08 0003	7546	0.48	273	B-3-9	3806
14	10478-03-02 0002	7655	0.84	166	B-3-10	
	TOTAL	74769				18691
	AVERAGE		0.645	259.4		

Item #	Serial Number	Parallep Cap. - uF	D.F.	ESL	Location	Series Cap. - uF
125	10478-14-03 0003	7365	0.49	237	C-1-1	3691
88	10478-10-06 0003	7400	0.49	261	C-1-2	
25	10478-04-03 0002	7417	0.54	550	C-1-3	3715
115	10478-13-03 0003	7443	0.48	262	C-1-4	
49	10478-06-07 0002	7467	0.51	414	C-1-5	3735
28	10478-04-06 0002	7473	0.7	314	C-1-6	
47	10478-06-05 0002	7489	0.52	385	C-1-7	3749
55	10478-07-03 0002	7507	0.56	233	C-1-8	
101	10478-11-09 0003	7544	0.48	209	C-1-9	3802
7	10478-02-05 0002	7664	0.86	124	C-1-10	
	TOTAL	74769				18692
	AVERAGE		0.563	300.9		
108	10478-12-06 0003	7360	0.49	251	C-2-1	3689
106	10478-12-04 0003	7398	0.49	310	C-2-2	
87	10478-10-05 0003	7418	0.8	139	C-2-3	3719
31	10478-04-09 0002	7457	0.7	304	C-2-4	
58	10478-07-06 0002	7459	0.55	448	C-2-5	3733
48	10478-06-06 0002	7474	0.51	228	C-2-6	
12	10478-02-10 0002	7491	0.86	139	C-2-7	3749
1	10478-01-01 0001	7504	0.82	96	C-2-8	
23	10478-04-01 0002	7540	0.54	266	C-2-9	3801
3	10478-02-01 0002	7667	0.86	132	C-2-10	
	TOTAL	74768				18691
	AVERAGE		0.662	231.3		
104	10478-12-02 0003	7366	0.49	272	C-3-1	3691
122	10478-13-10 0003	7398	0.46	209	C-3-2	
83	10478-10-01 0003	7413	0.8	149	C-3-3	3713
50	10478-06-08 0002	7440	0.51	330	C-3-4	
121	10478-13-09 0003	7455	0.48	241	C-3-5	3731
96	10478-11-04 0003	7471	0.52	254	C-3-6	
35	10478-05-03 0002	7512	0.7	259	C-3-7	3759
2	10478-01-02 0001	7518	0.79	132	C-3-8	
99	10478-11-07 0003	7534	0.48	215	C-3-9	3799
8	10478-02-06 0002	7662	0.86	125	C-3-10	
	TOTAL	74769				18693
	AVERAGE		0.611	224.6		
76	10478-09-03 0002	7375	0.81	248	D-1-1	3695
124	10478-14-02 0003	7406	0.49	213	D-1-2	
131	10478-14-09 0003	7414	0.49	278	D-1-3	3715
19	10478-03-07 0002	7450	0.86	317	D-1-4	
11	10478-02-09 0002	7462	0.86	136	D-1-5	3734
15	10478-03-03 0002	7472	0.84	162	D-1-6	
54	10478-07-02 0002	7484	0.56	205	D-1-7	3746
32	10478-04-10 0002	7500	0.7	323	D-1-8	
13	10478-03-01 0002	7526	0.84	171	D-1-9	3806
9	10478-02-07 0002	7879	0.86	107	D-1-10	
	TOTAL	74768				18692
	AVERAGE		0.731	225.8		
102	10478-11-10 0003	7366	0.48	323	D-2-1	3690
64	10478-03-02 0002	7399	0.52	400	D-2-2	
16	10478-03-04 0003	7439	0.84	347	D-2-3	3723
117	10478-13-05 0003	7456	0.48	247	D-2-4	
21	10478-03-09 0002	7456	0.84	458	D-2-5	3731
29	10478-04-07 0002	7467	0.7	380	D-2-6	
130	10478-14-08 0003	7481	0.49	340	D-2-7	3745
57	10478-07-05 0002	7498	0.89	281	D-2-8	
98	10478-11-06 0002	7526	0.64	228	D-2-9	3802
4	10478-02-02 0002	7683	0.86	94	D-2-10	
	TOTAL	74766				18691
	AVERAGE		0.638	300.5		
109	10478-12-07 0003	7360	0.49	331	D-3-1	3695
74	10478-09-01 0002	7379	0.81	384	D-3-2	
61	10478-07-09 0002	7393	0.53	415	D-3-3	3710
85	10478-10-05 0003	7446	0.81	120	D-3-4	
97	10478-11-05 0003	7461	0.53	134	D-3-5	3737
63	10478-06-01 0002	7466	0.53	356	D-3-6	
103	10478-12-01 0003	7500	0.49	291	D-3-7	3756
24	10478-04-02 0002	7521	0.54	223	D-3-8	
53	10478-07-04 0002	7522	0.56	289	D-3-9	3804
5	10478-02-03 0002	7694	0.86	97	D-3-10	
	TOTAL	74769				18692
	AVERAGE		0.614	266.2		

A-1-1 = Quadrant-A, Row-1 (top), Position-1 (SCR end of box)

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Appendix: B-1

VAISALA
SENSOR SYSTEMS

INSTRUCTIONS FOR USE
HMW30UYB-O0220-1.1
10/88

HUMIDITY TRANSMITTER HMW 30UB
HUMIDITY AND TEMPERATURE TRANSMITTER HMW 30YB

MOUNTING

The HMW 30UB/YB humidity and temperature transmitters are mounted directly on the wall. First attach the base plate with the two screws provided. Thread wires through the opening in the PCB support. Attach the PCB support with two screws. Notice the sign UP showing the correct mounting position. Do not damage the HUMICAP sensor on the circuit board.

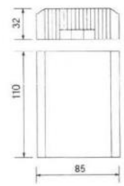

Fig. 1 Dimensions of HMW 30UB/YB

ELECTRICAL CONNECTIONS

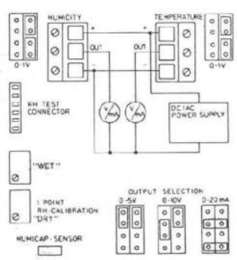

Fig. 2. Electrical connections of HMW 30UB/YB, temperature in model YB only.

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Appendix: B-2

ONE-POINT HUMIDITY CHECK/CALIBRATION

When checking the calibration of the transmitters, use Vaisala's Electronic RH Calibrator Set HMK 20. Use the one-point calibration potentiometer. The checking period is e.g. 1 year according to the operating conditions and the required accuracy of the measurement.

REPLACEMENT OF THE HUMICAP SENSOR

Remove the damaged sensor and insert a new one. Recalibrate the transmitter.

GUARANTEE Vaisala issues a guarantee for the material and workmanship of this product under normal operating conditions for one year from the date of delivery. Exceptional operating conditions, damage due to careless handling or misapplication will void the guarantee.

TECHNICAL DATA

Mechanics	Housing material	ABS plastic
Electronics	Electrical connections	Screw terminals for wires 0.5...1.5 mm² (AWG 20..16)

Output*	Supply voltage/V DC	AC	
0...1 V	10...35	9...24	
0...5 V	14...35	12...24	
0...10 V	19...35	16...24	
0...20 mA	10...35	9...24	(R_L = 0 ohm)
0...20 mA	20...35	17...24	(R_L = 500 ohm)

*Factory setting 0...1 V. Other outputs selectable by jumper connections. Changing the output causes an error which is less than 0.5 %RH without recalibration.

	Operating temperature	-5...+55°C (+23...+131°F)
	Storage temperature	-40...+55°C (-40..+131°F)
Relative humidity	Measuring range	0...100 %RH
	Accuracy at +20°C	±2 %RH (0...90 %RH) ±3 %RH (90...100 %RH) including - calibration inaccuracy - linearity - repeatability
	Temperature dependence	±0.04 %RH/°C
	Sensor	HUMICAP® H 0062
Temperature (YB-model only)	Measuring range (factory setting):	-5...+55°C (+23...+131°F)
	Accuracy of electronics at +20°C	±0.2°C
	Temperature dependence	±0.02°C/°C (typical)
	Linearity	better than 0.1°C
	Sensor	Pt 100 1/3 DIN 43760 B

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Appendix: C-1

Taco® Instruction Sheet 402-051

1/2" - 4" ACCU-FLO Circuit Setter Flow Balancing Valve

SUPERSEDES: NEW

EFFECTIVE: January 1, 1997

PLANT I.D. 001-998

VALVE INSTALLATION

1. The valve may be installed in any position. Place the valve in a position which provides for convenient access to the pressure port connections for the differential pressure gauge hoses, easy access to the memory stop screws, and easy reading of the scale.
2. Caution should be used when sweat style valves are installed to prevent overheating the valve. Use a torch with a sharp pointed flame. Direct the flame with care so that the valve body is not subjected to excessive heat. The valve should be in the closed position during sweating. The use of low temperature solders is recommended. These valves should not be brazed.

VALVE OPERATION

1. For presetting, use the appropriate slide rule setting necessary to achieve the desired pressure drop.
2. To measure flow, connect the TACO PRESSURE GAUGE (No. 779 0-10", 0-100" dual recommended, No. 775 0-135', 0-100' for higher pressure drops as an alternate) to the pressure port connections.

A–Position the meter case in a safe location adjacent to the valve.

CAUTION:

B–Take care in removing the pressure port connection caps on the ACCU-FLO valve, since they will be at the same temperature as the pipeline. There may be some fluid trapped behind the cap. Slowly unscrew the caps and look for continuous leakage. Continuous leakage may indicate a failure of the stem seal in the pressure port connection. Process fluid at temperature and under pressure may be present. If continuous leakage is present, do not remove the cap. Appropriate corrective action must be taken.

C–Connect the gauge hoses to the pressure port connections, the RED hose to the port adjacent to the name plate labeled H on the valve, and the GREEN hose to the other port labeled L on the valve.

D–The pressure port connection valves open automatically as the hoses are screwed onto the fitting, allowing fluid to flow into the meter. NOTE: If the hoses are connected one at a time, the second hose will bleed fluid as the first hose is connected and fluid flows into the meter. This will stop as the meter fills one side of the measurement cylinder.

E–Read the pressure drop on the appropriate meter scale. NOTE: If you use a meter graduated in feet of water, convert the reading to inches. Read the flow in gallons per minute on the appropriate slide rule scale.

F–When reading pressure drop, wait a sufficient amount of time to insure that all air has been bled from the hoses and meter. Refer to the gauge operating instructions.

G–Adjust the ACCU-FLO valve by turning the valve stem until the desired pressure drop is achieved. On all valves from ½" thru 4", the flow measurement is independent of indicator setting.

H–When the proper setting has been achieved, slightly loosen the two socket head cap screws and rotate the Memory Stop around until it touches the back side of the indicator. Then tighten the screws to securely set the open memory position. The Memory Stop is used to indicate the last set open position. It should not be used as a "hard" stop which can take a lot of force.

I–Review the pressure drop, and if it is correct, remove the hoses and replace the pressure port caps.

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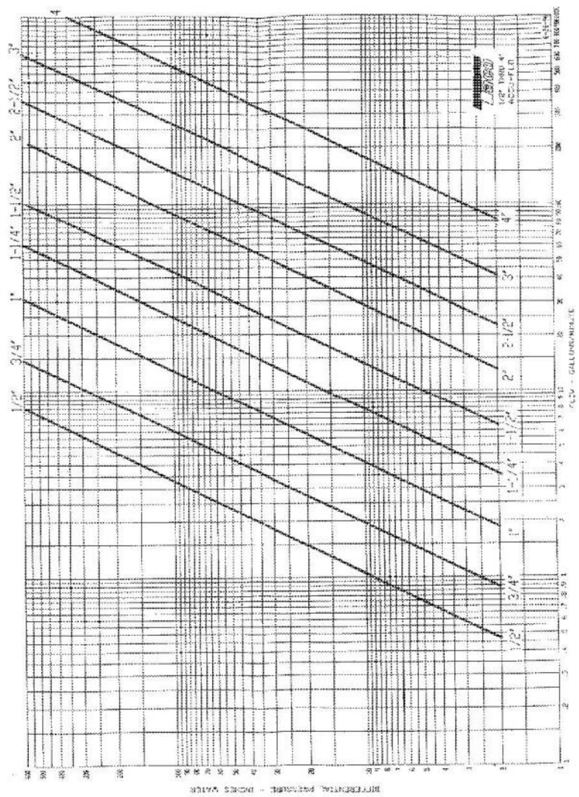
Appendix: C-2



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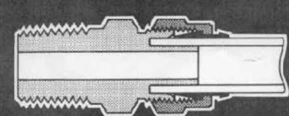
Appendix: D



Parker Poly-Tite® Fittings

Advantages
A compact brass compression fitting designed to speed any installation. Body, nut and sleeve are furnished pre-assembled, ready for installation. An exclusive acetal copolymer sleeve holds plastic tubing where it belongs, even when the system pressure exceeds the tubing burst point. Poly-Tite sleeves have superior resilience to resist creeping and stress caused from compression. The black acetal copolymer sleeve also resists ultra-violet ray attack and has excellent dimensional stability. Poly-Tite nuts will rotate around the sleeve as it tightens to prevent twisting and weakening of the plastic tubing. Poly-Tite fittings can be assembled and disassembled repeatedly.

Materials
Elbows and Tees: Brass Forgings: CA 377
Connectors, Unions, Nuts: CA 360, CA 345
Plastic Sleeves: Acetal Copolymer (Celcon®).

Applications
Use with Parker Parflex® or other high-quality thermoplastic tubing for pneumatic instrumentation circuits, lubricant and coolant lines, and applications with other gases and liquids. For use with soft metal tubing and nylon thermoplastic tubing, use brass sleeve and nut assembly 61PB.

Working Pressure and Temperature Ranges
Up to 150 PSI from 0° to +150°F. with thermoplastic tubing. Up to 300 PSI from 0° to +175°F. with soft metal tubing.

Assembly Instructions
Polyethelene, polypropolene and vinyl tubing:
Insert tube end until it bottoms in the Poly-Tite fitting and tighten knurl/hex nut finger-tight – no tools needed. Wrench tightening on tubing will provide maximum working pressure (one wrench turn after finger-tight).
Copper, aluminum and nylon tubing:
Brass sleeves are recommended. Insert tube until it bottoms in the Poly-Tite fitting and tighten one wrench turn past finger-tight.

Maximum allowable metal tube wall thickness for use with Poly-Tite fittings:
1/8", 3/16" O.D. – no limitation, 1/4" O.D. – .035
5/16", 3/8", 1/2" O.D. – .049

Order
By part number and name.

Nomenclature
Part numbers are constructed from symbols that identify the style and size of the fitting. The first series of numbers and letters identifies the style and type fitting. The second series of numbers describes the size.

Example:
66 P –4 –2
Female Connector (Tube to female pipe) — 66
Poly-Tite — P
1/4" (4/16) Tube O.D. — –4
1/8" (2/16) Pipe Thread — –2

Sizes
Tube sizes are determined by the number of sixteenths of an inch in the tube O.D.

Special Fittings
Fitting configurations and/or sizes other than those shown in the catalog can be furnished. It is suggested that a print or sketch be submitted with the inquiry.

Pricing
Only items priced in current supplementary price list PL 3501 are carried in stock. Price and delivery for non-stock items furnished on request for specified quantity.

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Appendix: E-1

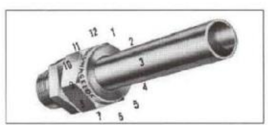
Installation Instructions

Swagelok tube fittings 1/4 to 1 in. and 6 to 25 mm

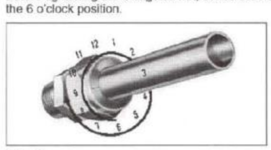
Swagelok tube fittings come to you completely assembled, finger-tight and ready for immediate use. Disassembly before use is unnecessary and can result in dirt or foreign material getting into the fitting which can interfere with sealing.

Swagelok tube fittings are installed in three easy steps:

Step 1
Simply insert the tubing into the Swagelok tube fitting. *Make sure that the tubing rests firmly on the shoulder of the fitting and that the nut is finger-tight.*



Step 2
Before tightening the Swagelok nut, scribe the nut at the 6 o'clock position.



Step 3
While holding the fitting body steady with a backup wrench, tighten the nut 1 1/4 turns.[①] Watch the scribe mark, make one complete revolution, and continue to the 9 o'clock position.

By scribing the nut at the 6 o'clock position, there wil be no doubt as to the starting position. When the nut is tightened 1 1/4 turns to the 9 o'clock position, you can easily see that the fitting has been properly tightened.

Swagelok gap inspection gages assure the installer or inspector that a fitting has been sufficiently tightened

① For 1/16, 1/8 and 3/16 in.; 2, 3, and 4 mm size tube fittings, tighten 3/4 turn from finger-tight.

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By scribing the nut at the 6 o'clock position as it appears to you, there will be no doubt as to the starting position. When the nut is tightened 1 1/4 turns to the 9 o'clock position, you can easily see that the fitting has been properly tightened.

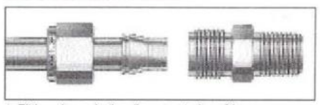
Use of the gap inspection gage (1 1/4 turns from finger-tight) ensures sufficient pull-up.

(1) For 1/16, 1/8, and 3/16 in.; and 2, 3, and 4 mm size tube fittings, only 3/4 turn from finger-tight is necessary.

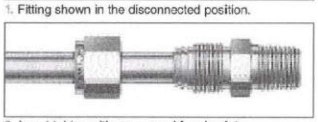
Retightening Instructions

Connections can be disconnected and retightened many times.

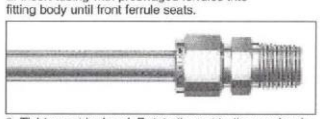
The same reliable leak-proof seal can be obtained when the connection is remade.



1. Fitting shown in the disconnected position.



2. Insert tubing with preswaged ferrules into fitting body until front ferrule seats.



3. Tighten nut by hand. Rotate the nut to the previously pulled-up position with a wrench. *At this point, an increase in resistance will be encountered.* Then tighten slightly with the wrench. Smaller tube sizes will take less tightening to reach the original position, while larger tube sizes will require more tightening. The wall thickness will also have an effect on tightening.

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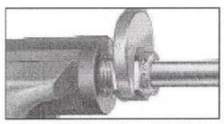
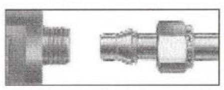
Preswaging Instructions

When installing Swagelok tube fittings in cramped quarters or where ladders must be used, it may be advantageous to use a pre-swaging tool. It allows the preswaging of ferrules onto the tube in a more open or safe area. After using the tool simply follow the retightening instructions.

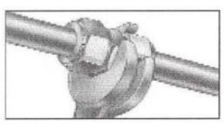
Oversized or very soft tubing may occasionally stick in the tool after pull-up. If this happens, remove the tube by gently rocking back and forth. DO NOT TURN the tube with pliers or other tools as this may damage sealing surfaces.



1. Assemble Swagelok nut and ferrules to preswaging tool. Insert tubing through ferrules until it bottoms in the preswaging tool, and tighten nut 1 1/4 turns.①



2. Loosen the nut and remove the tubing with preswaged ferrules from the preswaging tool.



3. The connection can now be made by following the Retightening Instructions shown on page 7.

①For 1/16, 1/8, and 3/16 in.; and 2, 3, and 4 mm size tube fittings, only 3/4 turn from finger-tight is necessary.

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Appendix: F-1

MATERIAL SAFETY DATA SHEET

LAMBENT TECHNOLOGIES CORP.
7247 North Central Park Avenue
Skokie, IL 60076
(847) 675-3950

CHEM-TEL EMERGENCY RESPONSE
TOLL FREE NUMBER: (800) 255-3924
INTERNATIONAL CALLS: COLLECT (813) 979-0626

1. PRODUCT IDENTIFICATION

Product Name: **OLEOCAL®* C - 102**
Synonym: Canola Oil, RBD

2. COMPOSITION / INFORMATION ON INGREDIENTS

	CAS Number	Weight %	ACGIH TLV	OSHA PEL
Rapeseed Oil, low erucic	120962-03-0		Not est.	Not est.

3. HAZARDS IDENTIFICATION

Potential Health Effects

INHALATION: Negligible unless heated to produce vapors. Vapors or finely misted materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. Remove to fresh air.

EYE CONTACT: May cause irritation. Irrigate eye with water for at least 15 to 20 minutes. Seek medical attention if symptoms persist.

SKIN CONTACT: Prolonged or repeated contact is not likely to cause significant skin irritation. Material is sometimes encountered at elevated temperatures. Thermal burns are possible.

INGESTION: No hazards anticipated from ingestion incidental to industrial exposure.

4. FIRST AID MEASURES

EYES: Irrigate eyes with a heavy stream of water for at least 15 to 20 minutes.

SKIN: Wash exposed areas of the body with soap and water.

INHALATION: Remove from area of exposure, seek medical attention if symptoms persist.

INGESTION: Give one or two glasses of water to drink. If gastro-intestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.)

5. FIRE FIGHTING MEASURES

FLASH POINT (Method Used): > 315°C (COC)
FLAMMABILITY LIMITS: None known

EXTINGUISHING MEDIA: Dry chemical, foam, halon, CO_2, water spray (fog). Water stream may splash burning liquid and spread fire.

* Registered trademark of Lambent Technologies Corp.

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Appendix: F-2

OLEOCAL C- 102 **2/1/99**

SPECIAL FIRE FIGHTING PROCEDURES: Use water spray to cool drums exposed to fire.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor.

6. ACCIDENTAL RELEASE MEASURES

SPILL CLEAN-UP PROCEDURES: Remove sources of ignition, contain spill to smallest area possible. Stop leak if possible. Pick up small spills with absorbent materials such as paper towels, "Oil Dry", sand or dirt. Recover large spills for salvage or disposal. Wash hard surfaces with safety solvent or detergent to remove remaining oil film. Greasy nature will result in a slippery surface.

7. HANDLING AND STORAGE

Store in closed containers between 50°F and 120°F. Keep away from oxidizing agents, excessive heat, and ignition sources. Store and use in well ventilated areas. Do not store or use near heat, spark, or flame; store out of sun. Do not puncture, drag, or slide this container. Drum is not a pressure vessel; never use pressure to empty.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

RESPIRATORY PROTECTION: If vapors or mists are generated, wear a NIOSH approved organic vapor/mist respirator.

PROTECTIVE CLOTHING: Safety glasses, goggles, or face shield recommended to protect eyes from mists or splashing. PVC coated gloves recommended to prevent skin contact.

OTHER PROTECTIVE MEASURES: Employees must practice good personal hygiene, washing exposed areas of skin several times daily and laundering contaminated clothing before re-use.

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point, 760mm Hg:	> 200°C
Specific Gravity, (H_20=1):	0.92
Vapor Pressure, mm Hg:	< 1
Vapor Density, (Air=1):	> 1
Volatiles, % by Volume:	Negligible
Evaporation Rate, (Butyl Acetate=1):	< 1
Solubility in Water, % by Volume:	Insoluble
Appearance and Odor:	Light amber liquid with faint fatty odor

10. STABILITY AND REACTIVITY

GENERAL: This product is stable and hazardous polymerization will not occur.

INCOMPATIBLE MATERIALS AND CONDITIONS TO AVOID: Strong oxidizing agents

HAZARDOUS DECOMPOSITION PRODUCTS: Combustion produces carbon monoxide, carbon dioxide along with thick smoke.

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OLEOCAL C- 102 **2/1/99**

11. DISPOSAL CONSIDERATIONS

Waste may be disposed of by a licensed waste disposal company. Contaminated absorbent material may be disposed of in an approved land fill. Follow local, state and federal disposal regulations.

12. TRANSPORT INFORMATION

UN HAZARD CLASS: N/A

13. REGULATORY INFORMATION

OSHA STATUS: This product is not hazardous under the criteria of the Federal OSHA hazard Communication Standard 29 CFR 1910.1200. However, thermal processing and decomposition fumes from this product may be hazardous as noted in Section 3.
TSCA STATUS: The components of this product are listed on TSCA.

CERCLA (Comprehensive Response Compensation, and Liability Act): Not reportable.

SARA TITLE III (Superfund Amendments and Reauthorization Act)
Section 312 Extremely Hazardous Substances: None
Section 311/312 Hazard Categories: Non-hazardous Under Section 311/312
Section 313 Toxic Chemicals: None

RCRA STATUS: If discarded in its purchased form, this product would not be a hazardous waste either by listing or by characteristic. However, under RCRA, it is the responsibility of the product user to determine at the time of disposal, whether a material containing the product or derived from the product should be classified as a hazardous waste. (40 CFR 261.20-24)

CALIFORNIA PROPOSITION 65: The following statement is made in order to comply with the California safe Drinking Water and Toxic Enforcement Act of 1986. The product contains no chemicals known to the State of California to cause cancer.

14. OTHER INFORMATION:

NFPA Codes: Health: 1 Fire: 1 Reactivity: 0

Revision Notes:
Reason for change: 6/28/99 Correct CAS number.

This information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any other process. Such information is to the best of the company's knowledge and believed accurate and reliable as of the date indicated. However, no representation, warranty or guarantee of any kind, express or implied, is made as to its accuracy, reliability or completeness and we assume no responsibility for any loss, damage or expense, direct or consequential, arising out of use. It is the user's responsibility to satisfy himself as to the suitableness and completeness of such information for his own particular use.

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