

TEMPORARY CHANGE REQUEST

TCR NO. **TCR-ENG-008,R0-002**

(e.g., TCR-ENG-021,R0-001)

The Temporary Change Request (TCR) Form is to be used to process urgent or minor changes for PPPL Policies, Organization/Mission Statements and Procedures. The TCR should be used when changes are:
1) urgent, and can not wait the 2-4 week period for Department Head review/comment, or
2) minor, and do not warrant Department Head review.

Person Requesting Change: Michael Zarnstorff Phone Ext: 3581

Department Name: Deputy Director, Research

Document Number: ENG-008 Revision No.: 0

Document Title: Failure Modes and Effects Analysis

Reason for change:

Added a requirement that Lithium work requires a failure modes and effects analysis (FMEA) to be developed during the design process.

Change description: (Summarize and attach changed pages, with changes clearly indicated)

In the Applicability section: Added a requirement that Lithium work involving more than 1 gram of lithium or any amount of finely divided lithium (such as powder) requires a failure modes and effects analysis (FMEA) to be developed during the design process.

1. Does this TCR significantly alter the intent or scope of the document? YES: NO: X

2. Does this TCR significantly impact **ES&H**? YES: NO: X

If 1 or 2 is **YES**, Explain why the changes should not be routed for Department Head review:

Michael Zarnstorff
Department/Division Head Approval

6/8/2015
Date

J.B. Graham for J. DeLooper
Head, Best Practices and Outreach/designee

6/8/2015
Date

Release/Effective date of this TCR: 6/8/2015

Incorporate this TCR into next revision of this document? YES: X NO:

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| Subject: Failure Modes and Effects Analysis | | Effective Date: April 20, 1999 | Initiated by: Associate Director, Engineering and Infrastructure |
| | | Supersedes: TOP 22.019 dated 11/1/88 | Approved: Director |

Applicability

This procedure applies to all activities at C and D-Sites of the Laboratory where need for failure modes and effects analysis (FMEA) has been determined., all Lithium work involving more than 1 gram of lithium or any amount of finely divided lithium (such as powder) requires a FMEA to be developed during the design process. The FMEA shall be performed for the required equipment or levels as defined in project requirements documents, work planning documents, or by management directive. The FMEA shall be documented as part of the projects' system design processes and may be included as part of a project's safety documentation (e.g., Safety Analysis Report, Safety Assessment Document, etc.). (TCR-ENG-008,R0-002)

Introduction

This procedure establishes the requirements for the preparation, review, and release of the FMEA. The depth of the analysis, and its documentation, will vary with the system or project under analysis. In situations where failure probability and severity must be determined, the FMEA should be expanded into a Failure Modes, Effects and Criticality Analysis (FMECA). FMECA is also useful in situations where many multiple failures are a concern. However, the analyst should be aware that a statistically significant reliability database is needed to make the probability estimates used in a FMECA. Guidance for performing a FMECA is available in both of the reference documents below.

Reference Documents

- IEC Standard 812 Procedure for Failure Mode and Effects Analysis (FMEA)
- MIL-STD-1629A Procedures for Performing a Failure Mode, Effects and Criticality Analysis

Responsibility

Action

- | | |
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| Responsible Line Manager | 1. Assigns individual to perform FMEA (analyst) and another individual to review it (reviewer). The reviewer shall be qualified by having like or greater expertise and technical experience as the analyst. |
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| Analyst | <ol style="list-style-type: none"> 2. Describes system under analysis and either prepares system diagrams or uses existing documentation to depict all major components and their performance criteria. The level of assembly will vary with the level of the analysis. 3. Performs FMEA using the guidance of Attachment 1. 4. Documents results using the guidance of Attachment 2. 5. Signs FMEA and provides it to the reviewer. |
| Reviewer | <ol style="list-style-type: none"> 6. Reviews FMEA for technical content and signs if no significant problems are identified. Otherwise discusses the FMEA with the analyst. |
| Analyst | <ol style="list-style-type: none"> 7. Files FMEA in the Operations Center. |

Attachments:

1. Guidelines for Performance of a FMEA
2. Guidelines for Documenting a FMEA.
3. FMEA Documentation Example

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| Guidelines for Performance of a FMEA | | | Attachment 1 |

Purpose

This attachment describes the standard steps involved in performing an FMEA.

Performing the FMEA

The basic steps for an FMEA are:

- 1) Define the system and its functional and operating requirements;
 - 1.1 Include primary and secondary functions, expected performance, system constraints, and explicit conditions that constitute a failure. The system definition should also define each mode of operation and its duration.
 - 1.2 Address any relevant environmental factors such as temperature, humidity, radiation, vibration, and pressure during operating and idle periods.
 - 1.3 Consider failures that could lead to noncompliance with applicable regulatory requirements. For example, a failure that could result in a release that exceeds environmental permit limits.

- 2) Develop functional block diagrams showing the relationships among the elements and any interdependencies. Separate diagrams may be required for each operational mode. As a minimum, the block diagram should contain:
 - 2.1 a breakdown of the system into major subsystems including functional relationships;
 - 2.2 appropriately and consistently labeled inputs and outputs and subsystem identification;
 - 2.3 any redundancies, alternative signal paths, and other engineering features that provide "failsafe" measures.

Existing drawings developed for other purposes may be used for the FMEA if the above elements are adequately described.

- 3) Identify failure modes, their cause and effects.
 - 3.1 IEC 812 1985 provides a list of failure modes, reproduced here as Table I, to describe the failure of any system element.
 - 3.2 Identify the possible causes associated with each postulated failure mode. The list in Table I can be used to define both failure modes and failure causes. Thus, for example, a power supply may have a specific failure mode "loss of output" (29), and a failure cause "open (electrical)" (31).
 - 3.3 Identify, evaluate, and record the consequences of each assumed failure mode on system element operation, function, or status. Consider maintenance, personnel, and system objectives as well as any effect on the next higher system level.

- 4) Identify failure detection and isolation provisions and methods. Determine if other failure modes would give an identical indication and whether separate detection methods are needed.

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| Guidelines for Performance of a FMEA | | | Attachment 1 |

- 5) Identify design and operating provisions that prevent or reduce the effect of the failure mode. These may include:
 - 5.1 redundant items that allow continued operation if one or more elements fail;
 - 5.2 alternative means of operation;
 - 5.3 monitoring or alarm devices;
 - 5.4 any other means permitting effective operation or limiting damage.

- 6) Identify specific combinations of multiple failures to be considered. The more multiple failures considered, the more complex the FMEA becomes. In many such cases it would be advantageous to perform a FMECA using the guidance of IEC Standard 812 or MIL-STD-1629A. Using the FMECA, the severity of failure effects are categorized, the probability is determined, and the number of redundant mitigating features needed to keep probability of failure acceptably low are better determined.

- 7) Revise or repeat, as appropriate, the FMEA as the design changes. Changes may be in direct response to the results of the previous FMEA or may be due to unrelated factors.

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| Guidelines for Performance of a FMEA | | | Attachment 1 |

TABLE I Generic Failure Modes (IEC 812-1985)

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| 1 Structural failure (rupture) | 17 Restricted flow |
| 2 Physical binding or jamming | 18 False actuation |
| 3 Vibration | 19 Fails to stop |
| 4 Fails to remain (in position) | 20 Fails to start |
| 5 Fails to open | 21 Fails to switch |
| 6 Fails to close | 22 Premature operation |
| 7 Fails open | 23 Delayed operation |
| 8 Fails closed | 24 Erroneous input (increased) |
| 9 Internal leakage | 25 Erroneous input (decreased)_ |
| 10 External leakage | 26 Erroneous output (increased) |
| 11 Fails out of tolerance (high) | 27 Erroneous output (decreased) |
| 12 Fails out of tolerance (low) | 28 Loss of input |
| 13 Inadvertent operation | 29 Loss of output |
| 14 Intermittent operation | 30 Shorted (electrical) |
| 15 Erratic operation | 31 Open (electrical) |
| 16 Erroneous indication | 32 Leakage (electrical) |
| 33 Other unique failure conditions as applicable to the system characteristics, requirements and operational constraints | |

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| Guidelines for Documenting a FMEA | | | Attachment 2 |

DOCUMENTING THE FMEA

The following information is required to be documented for an FMEA. The headings below presume use of the sample form shown on the next page: Complex systems may need more extensive descriptions preceding the tabular portion of the FMEA.

- 1) Heading
Identify the system, subsystem or assembly being addressed, the modes of operation, the analyst, and the date. Where appropriate, include or reference a description of the system.
- 2) Operating Mode
For which of the operating modes is the failure being evaluated?
- 3) Failure Mode & Cause
Address each failure mode and cause separately unless two or more failures have the same basic cause and produce the same effect on the remainder of the system.
- 4) System Effect
What would be the effect of the failure on the next higher level of assembly, and if applicable, the Project objectives if no mitigating action were taken. Quantitative descriptions of affected performance parameters as well as safety related conditions (fire, toxic smoke, radiation release, etc.) should be noted.
- 5) Fault Detection/Isolation
How will the failure be detected and when (e.g. during maintenance inspection, real time monitor, etc.)? Detection of related conditions, such as fire, smoke, leakage, etc., should also be indicated. How will the location of failure be determined and how will the specific component that has failed be indicated?
- 6) Compensating Provisions/Failure Recovery
List any provisions designed into the equipment or system or available externally to circumvent or alleviate the effects of the postulated failure mode. Also, indicate by what method, if any, the failure will be repaired. Particular note should be made of any remote repair expectations.
- 7) Remarks
Any clarifications, recommendations or justification notes should be here. Recommendations should include design changes or operation restrictions intended to avoid the failure.

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| Guidelines for Documenting a FMEA | | | Attachment 2 |

Project: _____ **FAILURE MODES AND EFFECTS ANALYSIS** Page: _____ of _____

WBS Element: _____ Performed By: _____ Date: _____

Component: _____ Reviewed By: _____ Date: _____

Function: _____

| Operating Mode | Failure Mode/Cause | System Effect | Fault Detection/ Isolation | Compensating Provisions | Remarks |
|----------------|--------------------|---------------|-------------------------------|-------------------------|---------|
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Project: NSTX

FAILURE MODES AND EFFECTS ANALYSIS

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WBS Element: 1.2 Vacuum Vessel & Support Structures

Performed By: the engineer

Date: date

Component: Support Structures

Reviewed By: the reviewer

Date: date

Function: The coil support structures provide mechanical support for the outer PF coils and outer TF coil legs, and provide dielectric breaks where required (PF5). The vacuum vessel legs support the vacuum vessel and provide dielectric breaks.

| Operating Mode | Failure Mode/Cause | System Effect | Fault Detection/ Isolation | Compensating Provisions | Remarks |
|-----------------------|--|--|--|--------------------------------|---|
| Bakeout | Physical binding or jamming Failure of sliding joint of umbrella structure | Excessive stress in umbrella and vacuum vessel, possible structural deformations, failure of welds, weakening of structure | Maintenance inspection, magnetic diagnostics | None-Shutdown and repair | This is a simple, passive component unlikely to fail. No known design alternatives identified. |
| Bakeout | Physical binding or jamming Failure of sliding joint of vacuum vessel leg support | Excessive stress in leg and structure, possible structural deformations, failure of welds, weakening of structure, possible dislocation of vacuum vessel, loss of vacuum integrity | Monitoring of displacement of vacuum vessel. Maintenance inspection, | None-Shutdown and repair | This is a simple, passive component unlikely to fail. At higher cost redundant joints could be developed. |
| CHI Operations | Structural failure Failure of dielectric joint(s) associated with outer PF coils supports or vacuum vessel leg supports | Fault on CHI power supply, arcing, burning, melting. | Maintenance inspection & test, magnetic diagnostics, power supply system ground and overcurrent fault detection. | None-Shutdown and repair | This is a simple, passive component unlikely to fail. At higher cost redundant joints could be developed. |