



**GUIDELINES FOR**

**MECHANICAL  
INTEGRITY  
SYSTEMS**



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**GUIDELINES FOR  
MECHANICAL INTEGRITY SYSTEMS**

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# **GUIDELINES FOR MECHANICAL INTEGRITY SYSTEMS**

**Center for Chemical Process Safety of the  
American Institute of Chemical Engineers**



**WILEY-INTERSCIENCE**

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# CONTENTS

<i>List of Tables</i>	<i>xiii</i>
<i>List of Figures</i>	<i>xv</i>
<i>Items on the CD Accompanying This Book</i>	<i>xvii</i>
<i>Acronyms and abbreviations</i>	<i>xxi</i>
<i>Glossary</i>	<i>xxv</i>
<i>Acknowledgments</i>	<i>xxix</i>
<i>Preface</i>	<i>xxx</i>
<i>Management Overview of the Guidelines</i>	<i>xxxiii</i>

<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.1	What is Mechanical Integrity?	2
1.2	Relationship to Other Programs	3
1.3	Expectations for the MI Program	3
1.4	The Effect of RAGAGEPs	5
1.5	Structure of this Guidelines Book	6
1.6	References	8
<b>2</b>	<b>MANAGEMENT RESPONSIBILITY</b>	<b>9</b>
2.1	Facility Leadership's Roles and Responsibilities	9
2.1.1	Organizational Roles and Responsibilities	10
2.1.2	Roles and Responsibilities Matrix	10
2.1.3	Reporting Mechanisms	11
2.1.4	Auditing	14
2.2	Technical Assurance Responsibilities	14
2.2.1	Defining Acceptance Criteria	14
2.2.2	Providing Technical Content	15
2.2.3	Establishing Metrics	15
2.2.4	Ensuring Technical Review	16

<b>3</b>	<b>EQUIPMENT SELECTION</b>	<b>17</b>
3.1	Reviewing Program Objectives	17
3.2	Establishing Equipment Selection Criteria	18
3.3	Defining Level of Detail	21
3.4	Documenting the Equipment Selection	22
3.5	Equipment Selection Roles and Responsibilities	23
	Appendix 3A. Sample Guidelines for Selecting Equipment for the MI Program	25
<b>4</b>	<b>INSPECTION, TESTING, AND PREVENTIVE MAINTENANCE</b>	<b>29</b>
4.1	ITPM Task Planning	30
4.1.1	ITPM Task Selection	30
4.1.2	Developing Sampling Criteria	42
4.1.3	Other ITPM Task Planning Considerations	44
4.1.4	ITPM Task Scheduling	45
4.2	Task Execution and Monitoring	46
4.2.1	Defining Acceptance Criteria	46
4.2.2	Equipment and ITPM Task Results Documentation	47
4.2.3	ITPM Task Implementation and Execution	49
4.2.4	ITPM Task Results Management	49
4.2.5	Task Schedule Management	51
4.2.6	ITPM Program Monitoring	52
4.3	ITPM Program Roles and Responsibilities	53
4.4	References	53
	Appendix 4A. Common Predictive Maintenance and Nondestructive Testing Techniques	58
	Appendix 5A. Sample Training Survey	75
<b>5</b>	<b>MI TRAINING PROGRAM</b>	<b>61</b>
5.1	Skills/Knowledge Assessment	61
5.2	Training For New and Current Workers	64
5.3	Verification and Documentation of Training Effectiveness	64
5.4	Certification	66
5.5	Ongoing and Refresher Training	69
5.6	Training for Technical Personnel	69
5.7	Contractor Issues	71

5.8	Roles and Responsibilities	71
5.9	References	74

## **6 MI PROGRAM PROCEDURES 77**

6.1	Types of Procedures Supporting the MI Program	79
6.2	Identification of MI Procedure Needs	81
6.3	Procedure Development Process	83
6.4	MI Procedure Format and Content	87
6.5	Other Sources of MI Procedures	90
6.6	Implementing and Maintaining MI Procedures	91
6.7	Procedure Program Roles and Responsibilities	92
6.8	References	92

## **7 QUALITY ASSURANCE 95**

7.1	Design	96
7.2	Procurement	97
7.3	Fabrication	98
7.4	Receiving	99
7.5	Storage and Retrieval	99
7.6	Construction and Installation	100
7.7	In-service Repairs, Alterations, and Rerating	101
7.8	Temporary Installations and Temporary Repairs	102
7.9	Decommissioning/Reuse	103
7.10	Used Equipment	103
7.11	Spare Parts	104
7.12	Contractor-Supplied Equipment and Materials	104
7.13	QA Program Roles and Responsibilities	104
7.14	References	104
	Appendix 7A. Design Review Suggestions	107
	Appendix 7B. Sample Vendor QA Plan	110
	Appendix 7C. Positive Material Identification	112
	Appendix 7D. Sample Service QA Plan	116
	Appendix 8A. Fitness for Service (FS)	131

## **8 EQUIPMENT DEFICIENCY MANAGEMENT 119**

8.1	Equipment Deficiency Management Process	119
8.2	Acceptance Criteria	120
8.3	Equipment Deficiency Identification	122
8.4	Responding to Equipment Deficiencies	123

8.5	Equipment Deficiency Communication	127
8.6	Permanent Correction of Equipment Deficiencies	127
8.7	Deficiency Management Roles and Responsibilities	128
8.8	Reference	128

## **9 EQUIPMENT-SPECIFIC INTEGRITY MANAGEMENT 135**

9.1	Fixed Equipment	137
9.2	Relief and Vent Systems	142
9.3	Instrumentation and Controls	144
9.4	Rotating Equipment	145
9.5	Fired Equipment	151
9.6	Electrical Systems	151
9.7	Fire Protection Systems	153
9.8	Miscellaneous Equipment	154
	9.8.1 Ventilation and Purge Systems	154
	9.8.2 Protective Systems	155
	9.8.3 Solids-handling Systems	156
	9.8.4 Safety-critical Utilities	157
	9.8.5 Other Safety Equipment	157
9.9	Equipment-specific MI Activity Matrices	158
9.10	References	182

## **10 MI PROGRAM IMPLEMENTATION 183**

10.1	Budgeting and Resources	183
	10.1.1 Program Development Resources	183
	10.1.2 Initial Implementation Resources	187
	10.1.3 Ongoing Efforts	193
10.2	Use of Software in MI Programs	196
	10.2.1 Use of CMMS	197
	10.2.2 Other Software Used in MI Programs	198
10.3	Return on Investment (ROI)	200
	10.3.1 Improved Equipment Reliability	200
	10.3.2 Cost Avoidance	201
10.3.3	Regulatory Compliance and Industry Association Commitments	202
10.3.4	Reduced Liability and Reduced Damage to Corporate Reputation	202
10.4	References	202

**11 RISK MANAGEMENT TOOLS 203**

11.1	Introduction to Common Risk-based Analytical Techniques Used in MI Programs	205
11.2	Incorporating Risk into MI Decisions	210
11.3	FMEA/FMECA	212
11.4	RCM	213
11.5	Risk-based Inspection	218
	11.5.1 Equipment and Process Data	221
	11.5.2 Risk Modeling	221
	11.5.3 Inspection Planning Strategies/Guidelines	222
	11.5.4 Other RBI Program Issues	223
11.6	Protection Layer Analysis Techniques	225
11.7	References	229

**12 CONTINUOUS IMPROVEMENT OF MI PROGRAMS 231**

12.2	Program Audits	233
12.3	Performance Measurement and Monitoring	238
12.4	Equipment Failure and Root Cause Analyses	240
	12.4.1 Failure Analysis	243
	12.4.2 Root Cause Analysis	245
12.5	References	248

**INDEX 249**

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# LIST OF TABLES

<b>TABLE 1-1</b>	Potential MI Interfaces with Other Programs	4
<b>TABLE 1-2</b>	Chapters Addressing Management Systems for MI Activities	7
<b>TABLE 2-1</b>	Roles and Responsibilities Matrix for MI Program Management	12
<b>TABLE 3-1</b>	Example Roles and Responsibilities Matrix for Equipment Selection	24
<b>TABLE 4-1</b>	Typical Equipment File Information for Selected Types of Equipment	34
<b>TABLE 4-2</b>	Example ITPM Task Selection Decision Matrix (Ref. 4-1)	39
<b>TABLE 4-3</b>	Factors Affecting ITPM Tasks for Relief Valves, Instrumentation, and Rotating Equipment	41
<b>TABLE 4-4</b>	Example ITPM Plan in Tabular Format	43
<b>TABLE 4-5</b>	Example Roles and Responsibilities Matrix for the ITPM Task Planning Phase	55
<b>TABLE 4-6</b>	Example Roles and Responsibilities Matrix for the ITPM Task Execution and Monitoring Phase	56
<b>TABLE 5-1</b>	Training Approach Considerations	65
<b>TABLE 5-2</b>	General Electrician Training Matrix	67
<b>TABLE 5-3</b>	Widely Accepted MI Certifications	68
<b>TABLE 5-4</b>	Mechanical Engineer Training Plan	70
<b>TABLE 5-5</b>	Example Roles and Responsibilities Matrix for the MI Training Program	72
<b>TABLE 6-1</b>	Example MI Procedures	80
<b>TABLE 6-2</b>	Example Risk Ranking Results for Procedure Determination	84
<b>TABLE 6-3</b>	Example Roles and Responsibilities Matrix for the MI Procedure Program	93
<b>TABLE 7-1</b>	Typical Design Code Applications	96
<b>TABLE 7-2</b>	Sample of Codes and Standards Having QA Requirements Applicable to Repair, Alteration, and Rerating	101

<b>TABLE 7-3</b>	Example Roles and Responsibilities Matrix for the QA Program	106
<b>TABLE 8-1</b>	Acceptance Criteria Resources	121
<b>TABLE 8-2</b>	Examples of Acceptance Criteria for Common Types of Equipment	124
<b>TABLE 8-3</b>	Example Roles and Responsibilities Matrix for Equipment Deficiency Resolution	129
<b>TABLE 9-1</b>	RAGAGEPs for Pressure Vessels	138
<b>TABLE 9-2</b>	RAGAGEPs for Atmospheric and Low-pressure Storage Tanks	139
<b>TABLE 9-3</b>	RAGAGEPs for Process Piping	140
<b>TABLE 9-4</b>	RAGAGEPs for Pressure Relieving Devices	143
<b>TABLE 9-5</b>	RAGAGEPs for Instrumentation and Controls	146
<b>TABLE 9-6</b>	RAGAGEPs for Pumps	147
<b>TABLE 9-7</b>	RAGAGEPs for Compressors	148
<b>TABLE 9-8</b>	RAGAGEPs for Turbines	149
<b>TABLE 9-9</b>	RAGAGEPs for Fans and Gearboxes	150
<b>TABLE 9-10</b>	RAGAGEPs for Fired Heaters and Furnaces	152
<b>TABLE 9-11</b>	Summary of Commonly Used NFPA Codes for Fire Protection Systems	153
<b>TABLE 9-12</b>	Summary of RAGAGEPs for Selected Safety Equipment	158
<b>TABLE 9-13</b>	Mechanical Integrity Activities for Pressure Vessels	159
<b>TABLE 9-14</b>	Mechanical Integrity Activities for Piping Systems	162
<b>TABLE 9-15</b>	Mechanical Integrity Activities for Pressure Relief Valves	165
<b>TABLE 9-16</b>	Mechanical Integrity Activities for SISs and ESDs	168
<b>TABLE 9-17</b>	Mechanical Integrity Activities for Pumps	172
<b>TABLE 9-18</b>	Mechanical Integrity Activities for Fired Heaters/Furnaces/Boilers	176
<b>TABLE 9-19</b>	Mechanical Integrity Activities for Switch Gear	179
<b>TABLE 10-1</b>	Summary of Resources Required for MI Program Development Activities	185
<b>TABLE 10-2</b>	Typical Initial Implementation Tasks by Activity	188
<b>TABLE 10-3</b>	Examples of Ongoing QA Activities	195
<b>TABLE 11-1</b>	Summary of Risk-based Analytical Techniques	206
<b>TABLE 11-2</b>	Sample FMEA Worksheet	214
<b>TABLE 11-3</b>	Sample RCM FMEA Worksheet	216
<b>TABLE 11-4</b>	Final Failure Management Strategy Selection for Pump 1A	218
<b>TABLE 11-5</b>	Example Inspection Strategy for Pressure Vessel - External Deterioration Identified by External Visual Inspection	223
<b>TABLE 11-6</b>	ISA S84.01 SILs	228
<b>TABLE 12-1</b>	MI Audit Approach	235

# LIST OF FIGURES

<b>FIGURE 2-1</b>	Definition of the operating window.	15
<b>FIGURE 4-1</b>	ITPM task selection process.	31
<b>FIGURE 5-1</b>	Training flow chart.	62
<b>FIGURE 6-1</b>	MI procedure hierarchy.	81
<b>FIGURE 6-2</b>	Basic procedure development process.	85
<b>FIGURE 8-1</b>	Technical evaluation condition selection.	121
<b>FIGURE 11-1</b>	Example risk matrix with ALARP region (Ref. 11-4).	211
<b>FIGURE 11-2</b>	Example RCM decision tree.	217
<b>FIGURE 11-3</b>	Management of risk using RBI.	219
<b>FIGURE 11-4</b>	RBI program flowchart.	220
<b>FIGURE 11-5</b>	Sample LOPA worksheet (Page 1 of 2).	227
<b>FIGURE 12-1</b>	MI program continuous improvement model.	232
<b>FIGURE 12-2</b>	Example MI process map with suggested performance measures.	241
<b>FIGURE 12-3</b>	Sample failure analysis process.	244
<b>FIGURE 12-4</b>	Sample fault tree.	246
<b>FIGURE 12-5</b>	Sample causal factor chart.	246

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# ITEMS ON THE WEB ACCOMPANYING THIS BOOK

## LOCATION

The following files can be found at:

<http://www.aiche.org/ccps/resources/publications/books/guidelines-mechanical-integrity-systems>

Password: Integrity2008

## Chapter 4 Resources

- *Imperfection vs. type of NDE method*, ASME Section V, Article 1, Nonmandatory Appendix A (reproduced with permission)
- Common RAGAGEPs
- Example condition monitoring (CM) techniques:
  - Temperature measurement
  - Dynamic monitoring
  - Oil analysis
  - Corrosion analysis
  - Nondestructive testing (NDT)
  - Electrical testing and monitoring
  - Observation and surveillance
  - Performance monitoring

## Chapter 5 Resources

- Sample training guide (repairing a mechanically sealed pump)
- Sample of skills/knowledge list for an electrician
- Sample of skills/knowledge list for a mechanic

## Chapter 6 Resources

- Sample procedures:
  - Mass Flowmeter Calibration

- Level-Indicating Transmitter Function Test and Calibration
- Heater Inspection
- Contractor Safety
- Circuit Breaker Inspection and Maintenance
- Centrifugal Pump Specification Sheet
  
- Example procedure formats:
  - Flat procedure format
  - Outline procedure format
  - Playscript or information mapping procedure format
  - T-bar procedure format
  - Checklist procedure format
- Comparison of procedure formats
- Procedure writing checklist

## Chapter 9 Resources

- Common RAGAGEPS
- Fixed equipment matrices:
  - Pressure vessel matrix, including columns, filters, and heat exchangers
  - Storage tanks
  - Process piping, and components, including buried piping, flex hoses, and expansion joints
- Relief and vent system matrices:
  - Pressure relief valves (PRVs)
  - Rupture discs
  - Vent headers
  - Flame/detonation arresters
  - Emergency vents
  - Thermal oxidizers
  - Flares
- Instrumentation and controls matrices:
  - Safety instrumented systems (SISs) and emergency shutdown (ESD) systems
  - Process control systems
  - Critical alarms and interlocks
  - Chemical monitors and detection systems
  - Conductivity, pH, and other process analyzers
  - Burner management systems
- Rotating equipment:
  - Pumps
  - Reciprocating compressors
  - Centrifugal compressors, including specific protection systems (e.g., pressure cutouts)
  - Process fans and blowers
  - Agitators and mixers
  - Electric motors

- Gas turbines
- Steam turbines
- Gearboxes
- Fired systems:
  - Heaters/furnaces/boilers
- Electrical systems:
  - Switchgear
  - Transformers
  - Motor controls
  - Uninterruptible power supplies (UPSs)
  - Emergency generators
  - Lightning protection
- Grounding systems

## Chapter 10 Resources

- MI program development activity worksheet

## Chapter 11 Resources

- Presentation papers related to analysis approaches:
  - *Risk-Based Approach to Mechanical Integrity Success on Implementation*
  - *An Insurer's View of Risk-Based Inspection*
  - *RCM Makes Sense for PSM-Covered Facilities*
  - *Lessons Learned from a Reliability-Centered Maintenance Analysis*

## Chapter 12 Resources

- Resources for performing equipment failure analyses:
  - Additional detailed information on the analysis steps
  - An equipment failure analysis checklist
- Resources for performing root cause analyses:
  - SOURCE™ Investigator's Toolkit
  - Root cause map
  - Causal factor chart and fault tree templates
- MI program audit resources
- Presentation paper.—*Improving Mechanical Integrity in Chemical and Hydrocarbon Processing Facilities.— A Insurer's Viewpoint*

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# ACRONYMS AND ABBREVIATIONS

ACC	American Chemistry Council
ACCP	ASNT Central Certification Program
ACGIH	American Conference of Governmental Industrial Hygienists
AIChE	American Institute of Chemical Engineers
ALARP	as low as reasonably practicable
ANSI	American National Standards Institute
API	American Petroleum Institute
ASM	American Society for Metals (ASM International)
ASME	American Society of Mechanical Engineers
ASNT	American Society of Non-destructive Testing
ASTM	American Society of Testing and Materials (ASTM International)
AWS	American Welding Society
BPVC	Boiler and Pressure Vessel Code
CCPS	Center for Chemical Process Safety
CF	causal factor
<i>CFR</i>	<i>Code of Federal Regulations</i>
CI	Chlorine Institute
CM	condition monitoring
CMMS	computerized maintenance management system
CPI	chemical process industries
DOT	Department of Transportation
E&I	electrical and instrumentation
EPA	Environmental Protection Agency
ESD	emergency shutdown

FFS	fitness for service
FM	factory mutual research
FMEA	failure modes and effects analysis
FMECA	failure modes, effects, and criticality analysis
FTA	fault tree analysis
HAZMAT	hazardous material
HAZOP	hazard and operability
HI	Hydraulic Institute
IEC	International Electrotechnical Commission
IIAR	International Institute of Ammonia Refrigeration
IPL	independent protection layer
ISA	Instrumentation, Systems, and Automation Society
ISO	International Organization for Standardization
ITPM	inspection, testing, and preventive maintenance
LOPA	layer of protection analysis
MI	mechanical integrity
MOC	management of change
NB	National Board (of Boiler and Pressure Vessel Inspectors)
NBBPVI	National Board of Boiler and Pressure Vessel Inspectors
NBIC	National Board Inspection Code
NDE	nondestructive examination
NDT	nondestructive testing
NEC	National Electric Code
NFPA	National Fire Protection Association
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
P&ID	pipng and instrumentation diagram
PFD	probability of failure on demand
PHA	process hazard analysis
PM	preventive maintenance
PMI	positive material identification
PPE	personal protective equipment

PRV	pressure relief valve
PSM	process safety management
PSSR	prestartup safety review
PSV	pressure safety valve
PWHT	postweld heat treatment
QA	quality assurance
QC	quality control
RAGAGEP	recognized and generally accepted good engineering practice
RBI	risk-based inspection
RCA	root cause analysis
RCM	reliability-centered maintenance
RMP	risk management program
ROI	return on investment
RP	recommended practice
SCBA	self-contained breathing apparatus
SCE	safety-critical equipment
SHE	safety, health, and environmental
SIF	safety instrumented function
SIL	safety integrity level
SIS	safety instrumented system
SME	subject matter expert
TML	thickness measurement location
UL	Underwriters Laboratories Inc.
UPS	uninterruptible power supply
USCG	United States Coast Guard
UT	ultrasonic thickness

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# GLOSSARY

**Acceptance criteria** Technical basis used to determine whether equipment is deficient (e.g., when analyzing inspection, testing, and preventive maintenance [ITPM] results).

**Causal factor (CF)** Equipment failure or human error that caused an incident or allowed incident consequences to be worse.

**Causal factor chart** A sequence diagram that graphically depicts an incident from beginning to end; typically used to organize incident data and identify causal factors.

**Certification** Completion of the formal training and qualification requirements specified by applicable codes and standards.

**Computerized maintenance management system (CMMS)** Computer software for planning, scheduling, and documenting maintenance activities. A typical CMMS includes work order generation, work instructions, parts and labor expenditure tracking, parts inventories, and equipment histories.

**Condition monitoring (CM)** Observing, measuring, and/or trending of indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of a structure, system, or component to function within acceptance criteria.

**Cost avoidance** Return (often expressed in monetary terms) resulting from actions that prevent an incident from occurring.

**Critical operating parameter** Process condition (e.g., flow rate, temperature) that can lead to an equipment failure if limits are exceeded.

**Damage/failure mechanism** The mechanical, chemical, physical, or other process that results in equipment degradation. Identifying and inspecting for indications of the damage mechanism can be used to predict future failures.

**Decision tree** A logic tree used in reliability-centered maintenance (RCM) to help determine the correct type of maintenance (e.g., predictive, preventive) to perform to reduce the likelihood of equipment failures.

**Equipment class** A grouping of individual equipment items with similar design and operation, such that facilities should perform similar ITPM activities on all of the items.

**Equipment deficiency** A condition that does not meet the acceptance criteria.

**Equipment failure analysis** A systematic approach for analyzing equipment failures to determine the failure mechanism(s) and the root cause(s) that resulted in the failure.

**Failure mode** A symptom, condition, or fashion in which equipment fails. A failure mode might be identified as loss of function, premature function (function without demand), an out-of-tolerance condition, or a simple physical condition such as a leak.

**Failure modes and effects analysis (FMEA)** A systematic method for evaluating and documenting the causes and impacts of known types of equipment/component failures.

**Failure modes, effects, and criticality analysis (FMECA)** A variation of FMEA that includes a quantitative estimate of the significance of the consequence of a failure mode.

**Fault tree** A method for representing the logical combinations of failures that can lead to a specific main event (i.e., failure or accident of interest).

**Fitness for service (FFS)** A systematic approach for evaluating the current condition of a piece of equipment in order to determine if the equipment item is capable of operating at defined operating conditions (e.g., temperature, pressure).

**Gantt chart** A manner of depicting multiple, time-based project activities (usually on a bar chart with a horizontal time scale).

**Hazard and operability (HAZOP) analysis** A systematic method in which process hazards and potential operating problems are identified using a series of guide words to investigate process deviations.

**Inspection, testing, and preventive maintenance (ITPM)** Scheduled proactive maintenance activities intended to (1) assess the current condition and/or rate of degradation of equipment, (2) test the operation/functionality of equipment, and/or (3) prevent equipment failure by restoring equipment condition.

**ITPM program** A management system that develops, maintains, monitors, and manages inspection, testing, and preventive maintenance activities.

**Layer of protection analysis (LOPA)** A process of evaluating the effectiveness of independent protection layer(s) in reducing the likelihood or severity of an undesired event.

**Management of change (MOC)** A management system for ensuring that changes to processes are properly analyzed (e.g., for potential adverse impacts), documented, and communicated to affected personnel.

**Mechanical integrity (MI)** A management system for ensuring the ongoing durability and functionality of equipment.

**Nondestructive testing/examination (NDT/NDE)** Evaluation of an equipment item with the intention of measuring an equipment parameter without damaging or destroying the equipment item.

**Operating window** The parameters (i.e., safe upper and lower limits, run time) under which equipment can function without failure.

**Owner-user** Person, plant, or corporation legally responsible for the safe operation of a pressure-retaining item (e.g., a pressure vessel).

**Performance measure** A metric used to monitor or evaluate the operation of a program activity or management system.

**Positive material identification (PMI)** The determination of the materials of construction of an equipment item or component (e.g., piping).

**Predictive maintenance** An equipment maintenance strategy based on measuring the condition of equipment in order to assess whether it will fail during some future period, and then taking appropriate action to avoid the consequences of that failure.

**Prestartup safety review (PSSR)** A management system for ensuring that new or modified processes are ready for startup by verifying that equipment is installed in a manner consistent with the design intent.

**Process hazard analysis (PHA)** A systematic evaluation of process hazards with the purpose of ensuring that sufficient safeguards are in place to manage the inherent risks.

**Process safety information** A compilation of chemical hazard, technology, and equipment documentation needed to manage process safety.

**Quality assurance (QA)** Activities to ensure that equipment is designed appropriately and to ensure that the design intent is not compromised throughout the equipment's entire life cycle.

**Recommended and generally accepted good engineering practice (RAGAGEP)** A document that provides guidance on engineering, operating, or maintenance activities based on an established code, standard, published technical report, or recommended practice (or a document of a similar name).

**Reliability-centered maintenance (RCM)** A systematic analysis approach for evaluating equipment failure impacts on system performance and determining specific strategies for managing the identified equipment failures. The failure management strategies may include preventive maintenance, predictive maintenance, inspections, testing, and/or one-time changes (e.g., design improvements, operational changes).

**Remaining life** An estimate, based on inspection results, of the time it will take for an equipment item to reach a defined retirement criterion (e.g., minimum wall thickness).

**Risk** A measure of potential loss (e.g., human injury, environmental insult, economic penalty) in terms of the magnitude of the loss and the likelihood that the loss will occur.

**Risk analysis** The development of a qualitative and/or quantitative estimate of risk based on engineering evaluation and mathematical techniques (quantitative only) for combining estimates of event consequences and frequencies.

**Risk-based inspection (RBI)** A systematic approach for identifying credible failure mechanisms and using equipment failure consequences and likelihood to determine inspection strategies for equipment.

**Root cause analysis (RCA)** A method used to (1) describe what happened leading up to and during a particular event, (2) determine how it happened, and (3) identify the underlying reasons the event was allowed to occur so that workable corrective actions can be implemented to help prevent recurrence of the event (or occurrence of similar events).

**Safety instrumented functions (SIF)** A system composed of servers, logic servers, and final control elements for the purpose of taking the process to a safe state when predetermined conditions are violated.

**Safety instrumented system (SIS)** One or more SIFs combined to protect a process or a key process component.

**Safety integrity level (SIL)** Criterion defining the acceptable probability of failure on demand for a safety instrumented system.

**Technical assurance** The process for communicating that appropriate technology is being applied to process equipment.

**Technical evaluation condition** An equipment condition requiring further technical evaluation to determine suitability for continued service.

**Verification activity** A test, field observation, or other activity used to ensure that personnel have acquired necessary skills and/or knowledge following training.