

Managing Systems Integrity of Terminal and Tank Facilities

Managing the Risk of Liquid Petroleum Releases

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Regulatory and Scientific Affairs

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Prepared under contract by SPEC Consulting, LLC, for API
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FOREWORD

This publication provides an overall approach for risk management, including the principles of risk management and an approach to risk assessment. It presents an industry approach to the management practices necessary to implement the principles of risk management and risk assessment for terminal and tank operations. In addition, it illustrates a method for selecting environmental protection control measures from liquid releases based upon the control measures hierarchy presented in API Publication 340, *Liquid Release Prevention and Detection Measures for Aboveground Storage Facilities*.

Although this document is intended for petroleum terminal and tank facilities associated with marketing, pipeline, and other facilities covered by API Standard 2610, *Design, Construction, Inspection and Maintenance of Petroleum Terminal and Tank Facilities*, and was developed to guide the management of terminal and tank facilities in evaluating cost-effective methods for protecting the environment, workers, and the public, it can be used in many ways, including the development of an overall corporate integrity/risk management program for terminal and tank facilities. Other potential uses include:

- Development of a corporate risk assessment methodology or utilization of the risk assessment methodology presented in the appendices of this document
- Motivation to consider modification of inspection intervals from those stipulated in API Std 653, *Tank Inspection, Repair, Alteration and Reconstruction*, and API Std 570, *Piping Inspection Code: Inspection, Repair, Alteration and Re-rating of In-Service Piping Systems*
- Provision of a risk-based approach to screen, evaluate, and if appropriate, select control measures that may prevent, detect, or protect the environment from liquid releases of petroleum
- Provision of an API-endorsed, consistent, and repeatable approach to risk management of terminal facilities
- Provision of a tool for negotiating with regulators in regards to implementation of proscriptive control measures that may not provide cost-effective control of terminal risks

The approaches detailed in this document are not mandatory; they are intended as a guide for those desiring to implement and/or use a risk assessment. Typically, a risk assessment is performed when a facility is changing equipment or processes. The appendices of this document present optional methods for conducting a risk assessment if a facility decides to do so. Other methods are available outside the scope of this document, or a company can decide to create its own method. API does not intend to imply sole endorsement of any particular method or that a risk assessment is required in all cases. The optional methods presented in this document are for demonstration purposes.

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SECTION 1—INTRODUCTION

An overall effective Risk Management Program (RMP) consists of several core elements which involve responsible management oversight, inclusion of site and corporate staff and an organized approach for determining and evaluating risks specific to the facility of operation. A typical RMP exhibits the following characteristics:

- Guided by a defined management philosophy
- Is planned, prepared and structured in an organized program which is repeatable through out the organization
- Is pertinent to the operations performed at the facility
- Includes a realistic and comprehensive evaluation of the facility risks
- Is capable of being performed in a reasonable time frame with a reasonable level of resources
- Is based on existing information, practices and technology but is capable of adapting to future improvements in this information, practices or technology
- Is capable of being economically implemented relative to the risks evaluated including the screening of mitigation measures
- Publicized within the organization

This document is intended to provide users with such an approach to managing and assessing risks specific to aboveground petroleum storage tank facilities. Furthermore, it can be used as part of an overall management program that will provide a consistent approach to:

- Identifying specific terminal risks
- Evaluating the potential consequences of those risks
- Evaluating the overall risk of a facility, a specific asset, or group of assets
- Evaluating comparative risks of facilities, individual assets, or group of assets

This document is not intended to define the absolute requirements of a risk management program for a company or to prescribe a specific approach to risk assessment or risk management. It also does not define a specific risk tolerance or mandate the mitigation measures for specific risks.

The information contained within this document can be further utilized in conjunction with API Publ 340, *Liquid Release Prevention and Detection Measures for Aboveground Storage Facilities*, to screen available control technologies that may mitigate risks (i.e., the frequency of occurrence and/or consequences) if deemed by management to be of value.

Ultimately, it is the corporation that typically defines, develops, and implements an RMP that follows its guiding corporate principles and details its specific tolerance for certain risks. The definition of risk tolerance, the level of acceptable risks, and the consequences of those risks will vary from organization to organization based on corporate philosophy, economic constraints, asset criticality, health and safety issues, environmental sensitivity, environmental awareness, regulatory drivers, public relations, corporate reputation, asset desired reliability, return on investment goals, market conditions, long-term asset viability, financial strength, and other principles defined by corporate management. These different risk tolerance drivers and corporate values will affect the focus and emphasis of the overall RMP and will affect the development of the risk assessment program that will in turn further affect the results of the risk assessment model. For example, a company whose primary corporate principle focuses on equipment reliability may elect to assign a higher risk assessment ranking (priority) to higher frequency events that affect equipment reliability even though the event has a low consequence when it occurs. Conversely, a company whose primary guiding principle is protection of the environment and which has a facility located in an ecologically sensitive area, may elect to mitigate very low-frequency events with potentially high consequences (e.g., a company with a facility located over a sole source aquifer may elect to provide added tank bottom integrity even though the overall risk is lower than other risks). Thus, corporate

1-1

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philosophy will not only affect the RMP, risk assessment methodology, and risk ranking, but it will also affect the approach to mitigation of risks.

1.1 PURPOSE AND OBJECTIVES

A risk management system (RMS) at liquid petroleum storage facilities provides the means to reduce the risks to the environment, population, and business from potential liquid releases. This is accomplished by implementing an overall facility program designed to establish procedures to identify, analyze, mitigate, and manage the inherent risks in operating a petroleum storage facility. This involves developing a management program and procedures to reduce the likelihood of failure (LOF) and/or the consequences of failure (COF) from a specific piece of equipment (e.g., tank, piping, loading area) or from a specific operation at a specific facility, such as a tank truck overfill. The purpose of this document is to provide:

- The basic elements for developing and implementing an RMS for aboveground liquid petroleum storage tank facilities
- A structured approach to risk assessment
- An organized methodology for the user to assess and evaluate risks between similar components (e.g., tank vs. tank risk), dissimilar components (e.g., tank overfill protection vs. diked area liners), and facility-to-facility risks
- Guidance on ranking and prioritization of risks
- Guidance on evaluating and selecting mitigation measures, such as those presented in API Publ 340

This document cites a number of references. The API references listed in Section 3 will aid the user in the development of an RMP. The other references cited in Section 3 were mentioned in this document or aided in the development of the publication, but they are not necessary for the development of an RMP.

1.2 SCOPE

Although the risk management principles and concepts in this document are universally applicable, this publication is specifically targeted at integrity management of aboveground liquid petroleum storage facilities. The applicable petroleum terminal and tank facilities covered in this document are associated with distribution, transportation, and refining facilities as described in API Std 2610 and API Publ 340.

This document covers the issues of overall risk management, risk assessment, risk ranking, risk mitigation, and the performance measures applicable to an overall integrity management program. The appendices include two possible methodologies for conducting a risk assessment and a workbook that can be used to perform the risk assessment method outlined in Appendix A. **It is important to note that it is not always necessary to perform a risk assessment. Typically, a risk assessment is performed if changes are being made to the facility. If a facility chooses to perform a risk assessment, it can use multiple methods. The appendices of this document present two available methodologies. If a facility decides to perform a risk assessment, it may elect to use one of these methods or a method obtained from a different source. The facility also may elect to develop its own risk assessment methodology. API does not intend to imply sole endorsement of any particular method used, and the ones presented in this document are for demonstration purposes only.**

The values stated for this document are in U.S. customary units with the International System of Units (SI) provided in parentheses.

1.3 TARGET AUDIENCE

The primary audience for this publication is corporate managers, who are responsible for the overall development of an RMP for their facilities, and the facility operators and engineering personnel who are primarily responsible for the mechanical integrity and operability of equipment, design or re-design of

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new and existing equipment, and the environmental conditions within which the facility operates (e.g., soil types, depth to groundwater, distance to sensitive ecological receptors, cost of remediation). The optional comprehensive analysis detailed in the appendices of this document requires that ONLY experienced personnel familiar with the facility and experienced in terminal facility design, operation, maintenance, and inspection be involved in the performance of analysis. The comprehensive nature of this document may require that the analysis be performed by teams of personnel from areas such as engineering, environmental, and operations. Others who are involved with terminals can benefit from the methodology, information, and approaches detailed in this document; however, they typically do not perform the risk assessment analysis detailed in the appendices without the proper training and experience.

1.3.1 How to Use This Document

Users can benefit from this document in several ways. First, it gives readers a brief overview of a basic RMP that they can use to develop their own corporate program. This is the first step in establishing an RMS. Second, users can develop their own risk assessment method, or they can use part, or all, of the optional risk assessment approaches detailed in the attached appendices. Third, users can develop a relative ranking of risks for various items, and using the guidance provided in this document, establish a risk-ranking matrix that helps them identify risks that may require remediation. Fourth, the user can use the approach detailed in the optional appendices to screen potential mitigation measures that are presented in API Publ 340. Last, users are provided a workbook, forms, checklists, and worked examples to aid in implementing their program. From these examples, the user can see the potential benefits in building a comprehensive Risk Assessment Program which meets the overall objectives of minimizing and mitigating the effects of liquid releases on the environment. Figure 1-1 illustrates the different approaches for using the document.

The framework for using this document, outlined in Figure 1-2, is a step-by-step process that allows users to customize a program to fit their individual needs. It includes the following steps:

Step 1—Users develop an overall company RMP that includes the program elements presented in Sections 4 and 5.

Step 2—Users determine if they want to perform a risk assessment as part of their overall RMP. There are varying types and complexities of risk assessments as outlined in section 5.2.2 and Section 6. Users may also elect to use one of the optional risk assessment approaches outlined in this document. This publication's optional risk assessment approach is briefly discussed in section 6.7, with detailed information and a workbook presented in the appendices.

Step 3—Users gather the appropriate facility information and data needed to develop an RMP and perform a risk assessment (if the user elects to perform a risk assessment), described in Sections 6 and 7.

Step 4—Performing the risk assessment requires determining the frequency or likelihood that a specific event will occur and the consequences if the event does occur (section 4.1).

Step 5—Once the risks are quantified by determining the likelihood and consequence, they can be ranked and evaluated (Section 4.2 and 8).

Step 6—Owners can determine, based upon their corporate principles, what risks, if any, require mitigation. This is discussed in Sections 5.2.3, 8, and 10.

Step 7—Mitigation measures are selected or screened for selection, and their effects on risk reduction are examined (Section 8).

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Step 8—The likelihood and consequences of an event for each mitigation measure selected are recalculated. This allows the owner to select a mitigation measure based upon the owner-specified risk reduction goals, such as cost-benefit analysis (section 4.2.3).

Step 9—Once the previous step is complete, users can perform any necessary updates to the RMP (e.g., updating procedures or training).

Step 10—Finally, owners can monitor the management of change to the facility, equipment, procedures, process, etc., and perform periodic program audits to insure that the program is up-to-date, effective, and achieving owner-established performance measures (Sections 9, 10, and 11).

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Approaches to Using the Document

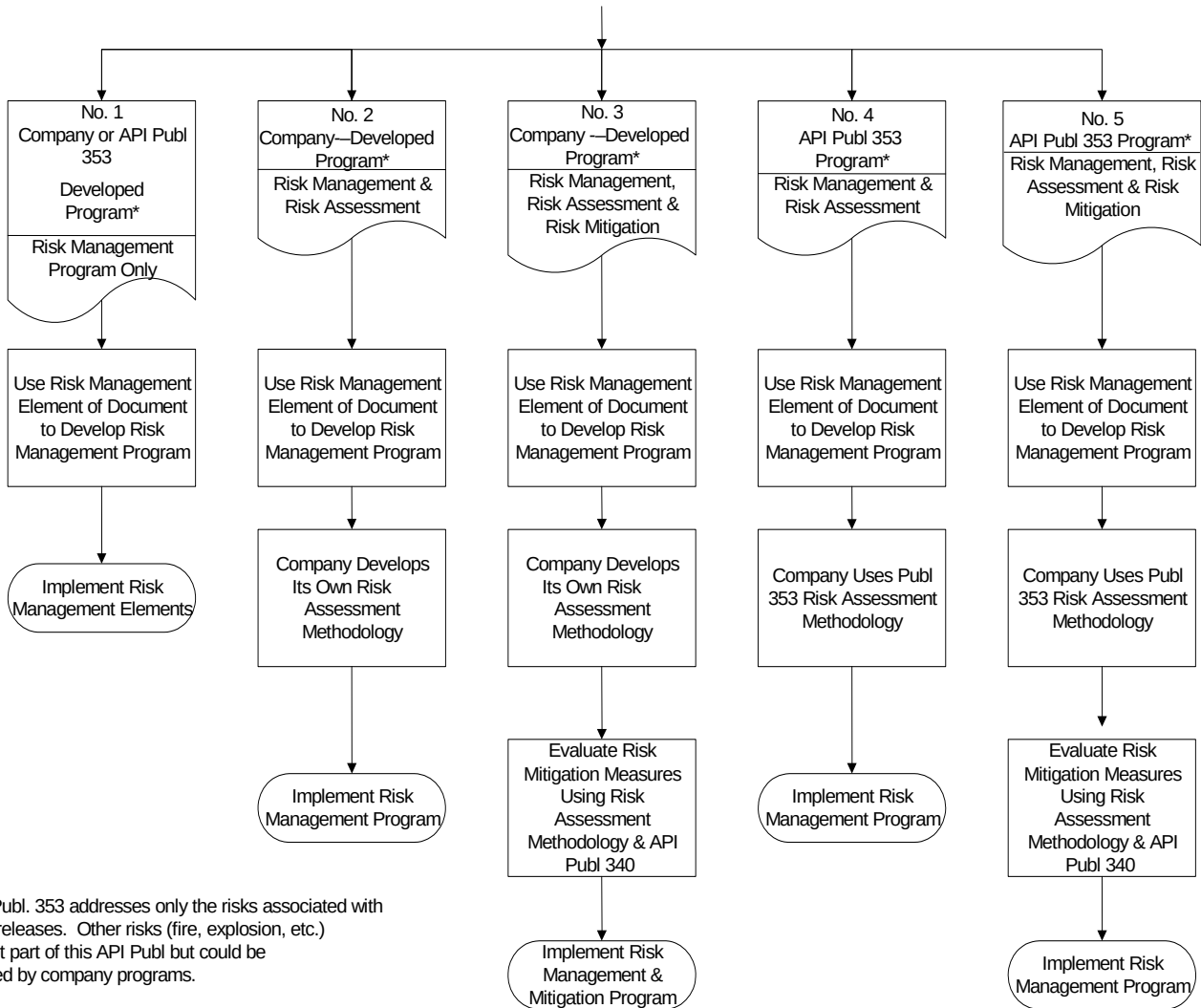


Figure 1-1: Approaches to Using the Document

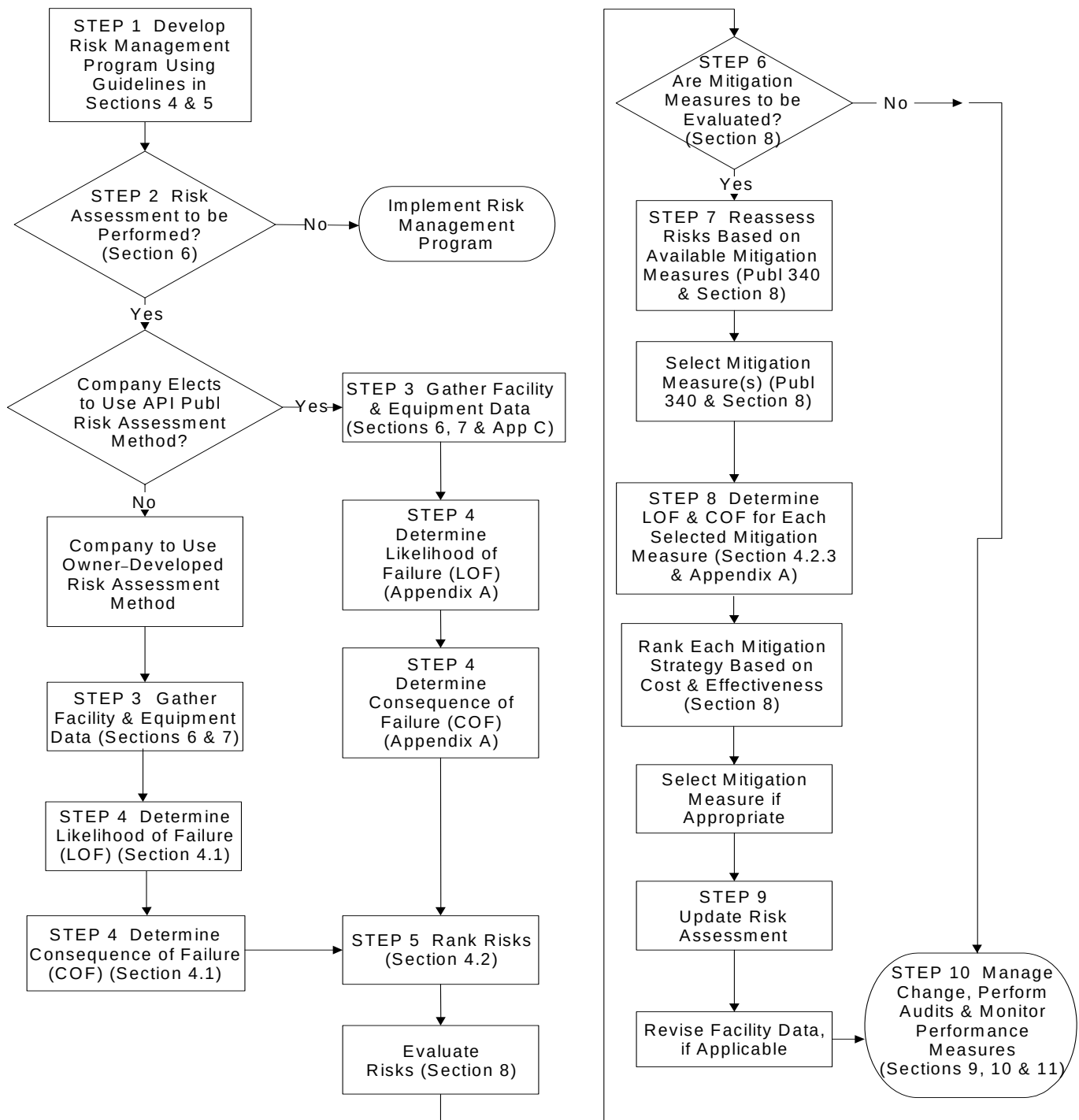


Figure 1-2: Framework for Using This API Publication

1.3.2 Roles and Responsibilities

Generally, one individual does not possess the background in all elements necessary to single-handedly conduct the analysis. Typically, a team of people with the requisite experience of the specific facility, the surrounding environment, the individual equipment, and the methodology presented in this document are essential to implementing the assessment. The required individuals or team members suggested in API RP 580 are listed below.

- *Team Leader*—This person is very familiar with terminal facilities and assembles the qualified individuals for the team. The team leader should be knowledgeable about the approach detailed in this document.
- *Risk Assessment Personnel*—This person(s) is responsible for assembling all of the data and carrying out the risk-based assessment including defining data required from other team members, defining the accuracy levels of the required data, verifying the quality of the data, completing workbook forms and calculating the LOF and the COF, summarizing the data, and recalculating the LOF and COF based on selected mitigation measures. They also may calculate the risk/benefit analysis of proposed mitigation measures.
- *Local Facility Operations Personnel*—These individuals are facility staff familiar with specific facility equipment, configuration, and inspection data. Operations and maintenance personnel are the persons responsible for providing data on occurrences when operations deviate from the limits of the process-operating envelope. They are also responsible for verifying that equipment repairs/replacements/additions have been included in the equipment condition data supplied by the equipment inspector. Operations and maintenance personnel are responsible for implementing recommendations that pertain to process or equipment modifications and monitoring.
- *Engineering Personnel*—These team members are company or contract staff who are familiar with terminal and tank facilities, including the applicable codes, standards, corrosion/degradation mechanisms, inspection requirements associated with tanks, piping, high-level alarms, containment, leak rates, risks, and LOF and COF. The facility engineer is responsible for providing the basis of design information, the as-built conditions, and the design operating conditions information. This information generally will be in the form of record drawing information, process flow diagrams, piping and instrumentation diagrams (P&IDs), equipment data sheets, etc. The engineer can evaluate/recommend methods of risk mitigation (likelihood or consequence) through changes in process conditions.
- *Environmental and Safety Personnel*—These are company or contract staff who are familiar with the local conditions including soil type, depth to groundwater, distance to and type of sensitive ecological receptors, regulatory requirements, etc. They can also recommend and assess mitigation measures on the COF. Environmental and safety personnel are responsible for providing data on the cost of the facility/equipment being analyzed and the financial impact of the shutdown of pieces of equipment or the facility. They also can recommend methods for mitigating the financial consequences of failure.
- *Inspection Personnel*—The equipment inspector or inspection specialist is generally responsible for gathering data on the condition and history of equipment in the risk assessment study. Generally, this information will be located in equipment, inspection, and maintenance files. If condition data are unavailable, the inspector/specialist, in conjunction with the materials and corrosion engineering or technical specialists, can provide predictions of the current condition. The inspector, along with company or contract engineers, is responsible for assessing the effectiveness of past inspections. The equipment inspector is typically responsible for implementing any recommended inspection plan derived from the risk assessment study.

- *Management*—These are the representatives of the company who set the management drivers and goals by which the RMP is established. Management's role is to provide sponsorship and resources (personnel and funding) for development of the RMP and performance of the risk assessment studies. They are responsible for making decisions on risk management or providing the framework/mechanism for others to make these decisions based on the results of the risk assessment studies. Finally, management is responsible for providing the resources and follow-up system to implement the risk mitigation decisions.
- *Financial/Business Personnel*—These individuals are the representatives of the company who provide financial input on the cost of money, money constraints, and some of the drivers to be utilized as part of the decision-making behind risk mitigation.

1.3.3 Training and Qualifications

The team leader and risk assessment personnel typically have a thorough understanding of risk analysis either through training, education, or experience. Moreover, they have usually received detailed training in the methodologies and procedures presented in this publication, including how data input and data assumptions may affect the final results. At facilities where internal risk assessment personnel conduct the analysis, management can have a procedure to document that personnel are sufficiently trained and qualified in the methodologies and procedures detailed in this document. Outside contractors or consultants who provide risk assessment services typically have a documented program of training qualified and experienced individuals in the methodologies presented in this publication. Individuals who are not experienced in the terminal facilities covered by this document are typically limited to completion of forms, inputting of data, and performance of calculations.

1.3.4 Governmental Requirements

This document is not intended to be utilized as a substitute for the requirements or reviews required by applicable federal, state, or local requirements. These requirements may include but are not limited to requirements for prescriptive inspection requirements and requirements for mandated engineered control measures.

This document could be utilized as a tool for negotiations with regulators to:

- Show the risk drivers and consequences of failure at regulated facilities
- Illustrate that control or mitigation measures are available that are as effective or more effective than proposed or mandated government requirements or serve as a means to demonstrate compliance with government regulations by utilization of the principles of risk management
- Illustrate that prescriptive inspection or control measures may not provide a reasonable benefit to environmental protection

1.4 Applicable Facilities

The petroleum industry is engaged in the manufacture, storage, transportation, blending, and distribution of crude oil and refined petroleum products. Individual terminal facilities and plants may perform one or more of these functions. This document is applicable to a range of liquid petroleum storage facilities from small distribution facilities (e.g., bulk plants) to large storage and distribution facilities (e.g., pipeline and marine terminals and wholesale plants). The specific application of this document is to those types of operations discussed below.

1.4.1 Petroleum Terminals

Petroleum terminals may include tank farms, loading and unloading areas, pipeline manifolds, storage areas, warehouses, docks, garages, laboratories, and office buildings. Products at these terminals are received and distributed by pipeline, marine transport, rail, or truck. Bulk quantities of refined products

1-8

The following scenarios are merely examples for illustration purposes only. Each company should develop its own approach. They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document. Users of this document should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein. Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the instructions. At all times users should employ sound business, scientific, engineering, and safety judgment when using this bulletin.

are stored in aboveground tanks for distribution in smaller quantities to industrial and commercial customers, and to retail and wholesale marketing facilities. Petroleum terminals may also store petroleum products in consumer packaging, bulk containers, or inside tanks and drums.

1.4.2 Pipeline Tankage Facilities

Pipeline tankage facilities consist of tanks and tank farms used to receive petroleum products (e.g., crude oil and refined products) from pipelines, trucks, railcars, or marine facilities and to provide surge relief from pipeline operations (see Title 49 Code of Federal Regulations (CFR), Part 195 and 33 CFR Parts 154 and 156).

1.4.3 Bulk Plants

Although bulk plants typically handle smaller quantities of product, operations and facilities at these plants are similar to those at petroleum terminals. Bulk plants typically receive and distribute product by truck, although some are serviced by rail, marine transport, or pipeline. Bulk plants may also store an inventory of petroleum products in consumer packaging, bulk containers, and inside tanks and drums.

1.4.4 Lube Blending and Packaging Facilities

Lube oil blending and packaging facilities blend refined base stock products with additives and then package the finished products in drums, pails, portable tanks, or consumer-size containers or ship to consumers in bulk. The additives and lube base stocks may be received and stored either in bulk or in containers. Lube blending and packaging facilities typically include warehouses, blending and packaging areas, quality control labs, base stock and additive storage areas, shipping and receiving areas, and office buildings.

1.4.5 Asphalt Facilities

Asphalt plants receive asphalt from petroleum refineries and blend it with additives to produce paving, roofing, and industrial-grade asphalt products. Asphalt facilities typically consist of a laboratory for quality control, a rail siding or marine dock, an aboveground tank farm, a warehouse, one or more unloading areas for raw materials and products, a manufacturing area, a package heating system, a truck scale, a loading rack, and an office.

1.4.6 Aviation Service Facilities

Aviation service facilities store light petroleum fuels in aboveground or underground storage tanks. Services provided may include the following: refueling, defueling, de-icing, washing, maintenance, and repair of aircraft. Aircraft fuel may be loaded into refueling trucks that service the aircraft or dispensed directly into aircraft from a fixed dispenser system or hydrant system cart.

1.4.7 Overlapping Facilities Coverage

This document may have overlapping applicability to facilities covered by API Standard 1160 (pipelines) and those covered by API RP 580 (refinery equipment).

Where overlapping coverage exists, users can select the most appropriate API document as their primary resource, but may also adopt elements from the other documents as part of their program. For example, a refinery would use API RP 580 as its primary reference document for risk-based inspection, but it could use the RMP elements described in the main text of this document to formulate its overall facility risk management program. Likewise, pipeline facilities covered under API Std 1160 would use that document as their primary reference document but could also use the tank risk assessment methodologies presented in the appendices of this document.

1.4.8 Non-applicable Facilities

The RMP features presented in this document can be utilized at a wide array of facilities other than those identified above. However, regulatory requirements may mandate specific programs, such as the Occupational Safety and Health Administration's (OSHA's) Process Safety Management or the Environmental Protection Agency's (EPA's) Risk Management Plan. The optional risk assessment methodologies presented in the appendices to this document were not intended to apply to the following installations:

- Retail facilities, such as service stations, garages, and automotive lubrication facilities
- Tanks that are part of oil and gas production or storage, natural gas processing plants, or offshore operations
- LNG facilities
- Facilities with primary storage of liquid petroleum in underground tanks
- Agriculture

SECTION 2—TERMS, DEFINITIONS, AND ACRONYMS

This section presents the terms, definitions, and acronyms used as part of the risk vocabulary including some terminal and tank definitions.

2.1 Terms and Definitions

For the purposes of this publication, the following definitions apply:

aboveground storage tank (AST): Atmospheric vertical, cylindrical, closed-top, open-top, or covered open-top steel aboveground storage containers of various sizes and capacities whose entire bottom is supported uniformly on the ground. An AST may also be a horizontal cylindrical container on saddles or other supports.

absolute risk: An ideal and accurate description and quantification of risk.

berm: The annular raised area around the tank, inside the dike, normally used for access to the tank and the equipment surrounding it.

combustible liquid: A liquid having a flash point at or above 100°F (37.8°C). (See NFPA 30 for discussion of combustible liquid classification.)

consequence: Outcome from an event. There may be one or more consequences from an event and they may range from positive to negative; however, consequences are always negative for safety aspects. Consequences may be expressed qualitatively or quantitatively.

deterioration: The reduction in the ability of a component to provide its intended purpose of containment of fluids. This can be caused by various deterioration mechanisms (e.g., thinning, cracking, mechanical). Damage or degradation may be used in place of deterioration.

event: Occurrence of a particular set of circumstances. The event may be certain or uncertain. The event can be singular or multiple. The likelihood associated with the event can be estimated for a given period of time.

external event: Events resulting from forces of nature, acts of God or sabotage, or such events as neighboring fires or explosions, neighboring hazardous material releases, electrical power failures, tornados, earthquakes, and intrusions of external transportation vehicles, such as aircraft, ships, trains, trucks, or automobiles. External events are usually beyond the direct or indirect control of persons employed at or by the facility.

facility: Any building, structure, installation, equipment, pipeline, or other physical feature used in petroleum refining, storage, transportation, and distribution. The boundaries of a facility may depend on several site-specific factors, including but not limited to, the ownership or operation of buildings, structures, and equipment on the same site, and the types of activity at the site.

failure: Termination of the ability of a system, structure, or component to perform its required function of containment of fluid (i.e., loss of containment). Failures may be unannounced and undetected until the next inspection (unannounced failure), or they may be announced and detected by any number of methods at the instance of occurrence (announced failure).

failure mode: The manner of failure. For risk-based assessment, the failure of concern is loss of product outside of the primary containment. Examples of failure modes are a through hole, crack, rupture, overfill, flange leak, etc.

flammable liquid: A liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 pounds per square inch (absolute) (2069 mm Hg) at 100°F (37.8°C). This is also classified as Class I liquid (see NFPA 30 for additional definitions and subclassifications).

hazard: A physical condition or a release of a hazardous material that could result from component failure and result in human injury or death, loss or damage, or environmental degradation. Hazard is the source of harm. Components that are used to transport, store, or process a hazardous material can be a source of hazard. Human error and external events may also create a hazard.

hazard and operability (HAZOP) study: A HAZOP study is a form of failure modes and effects analysis. HAZOP studies, which were originally developed for the process industry, use systematic techniques to identify hazards and operability issues throughout an entire facility. The study is particularly useful in identifying unforeseen hazards designed into facilities due to lack of information, or introduced into existing facilities due to changes in process conditions or operating procedures. The basic objectives of the techniques are to:

- produce a full description of the facility or process, including the intended design conditions
- systematically review every part of the facility or process to discover how deviations from the intention of the design can occur
- decide whether these deviations can lead to hazards or operability issues
- assess the effectiveness of safeguards

installations: Tanks, pumps, compressors, accessories, controls, piping, and all other associated equipment required for the receipt, transfer, storage, blending, packaging, and shipment of petroleum products.

integrity assessment: The process for determining the suitability of the equipment or system to serve its intended purpose without loss of its contained contents outside of the primary containment.

integrity management program: An overall program consisting of identifying potential threats to or from a facility, process, or discrete piece of equipment; assessing the risk associated with those threats in terms of incident likelihood and consequences; mitigating risk where appropriate by reducing the likelihood, the consequences, or both; and measuring the risk-reduction results achieved (see definition of *risk management program*).

likelihood: Extent to which an event is likely to occur within the time frame under consideration (see definition of *probability*).

mitigation or mitigative action: Taking appropriate action based on an assessment of risk factors to reduce the risk level and/or the consequence level to a point acceptable to facility management. Such action may consist of, but is not limited to, further testing and evaluation, changes to the physical environment, operational changes, continued monitoring, administrative or procedural changes, repairs, or any of the prevention, detection, or protection measures outlined in API Publ 340.

petroleum: Any crude oil, liquid, or gaseous complex combination of hydrocarbons and related derivatives (natural or manmade) that may be processed from crude oil for fractions, including natural gas, gasoline, naphtha, kerosene, fuel and lubricating oils, paraffin wax, additives, asphalt, and various derivative products.

probability: Extent to which an event is likely to occur within the time frame under consideration. The mathematical definition of probability is “a real number in the scale 0 to 1 attached to a random event.” Probability can be related to a long-run relative frequency of occurrence or to a degree of belief that an event will occur. For a high degree of belief, the probability is near one. Frequency rather than probability may be used in describing risk. Degrees of belief about probability can be chosen as classes or ranks such as “rare/unlikely/moderate/likely/almost certain” or “incredible/improbable/remote/occasional/probable/frequent.”

qualitative risk analysis (assessment): Methods that use engineering judgment and experience as the basis for the analysis of probabilities and consequences of failure. The results of qualitative risk

analyses are dependent on the background and expertise of the analysts and the objectives of the analysis. Failure modes, effects, and criticality analysis (FMECA) and HAZOPs are examples of qualitative risk analysis techniques that become quantitative risk analysis methods when consequence and failure probability values are estimated along with the respective descriptive input.

quantitative risk analysis (assessment): An analysis that:

- identifies and delineates the combinations of events that, if they occur, will lead to a severe accident (e.g., major explosion) or any other undesired event
- estimates the frequency of occurrence for each combination
- estimates the consequences

Quantitative risk analysis integrates into a uniform methodology the relevant information about facility design, operating practices, operating history, component reliability, human actions, the physical progression of accidents, and potential environmental and health effects, usually in as realistic a manner as possible.

Quantitative risk analysis uses logic models depicting combinations of events that could result in severe accidents and physical models depicting the progression of accidents and the transport of a hazardous material to the environment. The models are evaluated probabilistically to provide both qualitative and quantitative insights about the level of risk and to identify the design, site, or operational characteristics that are the most important risk. Engineering judgment and experience-based parameters may be part of data gathering or analysis. A quantitative risk analysis may also be used to rank options for relative comparison.

Quantitative risk analysis logic models generally consist of event trees and fault trees. Event trees delineate initiating events and combinations of system successes and failures, while fault trees depict ways in which the system failures represented in the event trees can occur. These models are analyzed to estimate the frequency of each accident sequence.

relative risk: The comparative risk of a facility, process unit, system, equipment item or component to other facilities, process units, systems, equipment items or components, respectively.

release prevention barrier (RPB): The second lined bottom of double steel bottom tanks, synthetic materials, clay liners, and all other barriers or combination of barriers (e.g., a reinforced concrete slab under the full bottom of the tank without a membrane liner) placed in the bottom of or under an aboveground storage tank. The functions of the RPBs are to prevent the escape of contaminated material and contain or channel released material for leak detection. (See non-mandatory Appendix I of API Standard 650.)

release prevention system (RPS): The suite of API standards designed to maintain aboveground storage tank integrity, thus protecting the environment. These standards cover topics such as the frequency of routine external inspections, internal inspections, application of risk-based inspection principles, overfill prevention, lining the bottom of the tank interior, fitting the tank with RPBs, installing cathodic protection, or some combination of these measures depending on the operating environment and service of the tank. (See API Standard 2610.)

risk: A measure of loss in terms of both the incident likelihood of occurrence and the magnitude of the consequences.

risk analysis: A systematic analytical process to identify and evaluate potential hazards from facility operations (see definition of risk assessment).

risk assessment: A systematic analytical process, in which potential hazards from facility operations are identified, and the likelihood and consequences of potential adverse events are determined. Risk

assessments can have varying scopes and be performed at varying levels of detail depending on the operator's objectives (see Section 6).

risk management program (RMP): An overall program consisting of identifying potential threats to or from a facility, process, or discrete piece of equipment; assessing the risk associated with those threats in terms of incident likelihood and consequences; mitigating risk where appropriate by reducing the likelihood, the consequences, or both; and measuring the risk-reduction results achieved (see definition of integrity management program).

semi-quantitative risk analysis (assessment): An analysis that utilizes a combination of the two methods—the qualitative risk analysis method and the quantitative risk analysis method.

system: the facility's equipment and infrastructure whose intended purpose is to contain, transfer, or regulate petroleum product.

2.2 Acronyms

The following acronyms are used throughout this document.

AG:	aboveground
AIChE:	American Institute of Chemical Engineers
API:	American Petroleum Institute
ASME:	American Society of Mechanical Engineers
AST:	aboveground storage tank
CBA:	cost benefit analysis
CCPS:	Center for Chemical Process Safety
COF:	consequences of failure
EPA:	United States Environmental Protection Agency
FMEA:	failure modes and effects analysis
FMECA:	failure modes, effects, and criticality analysis
HAZOP:	hazard and operability study
IMP:	integrity management program (also known as risk management program)
LOF:	likelihood of failure
MOC:	management of change
NACE:	National Association of Corrosion Engineers
NDE:	non-destructive examination
NFPA:	National Fire Prevention Association
O&M:	operations and maintenance
OPA:	Oil Pollution Act
OSHA:	United States Occupational Safety and Health Administration
PHA:	process hazards analysis
P&ID:	piping and instrumentation diagram
Publ:	publication
QA/QC:	quality assurance/quality control
QCP:	quality control program
RBI:	risk-based inspection

RMP:	risk management program (also known as integrity management program)
RMS:	risk management system
ROI:	return on investment
RP:	recommended practice
RPB:	release prevention barrier
RPS:	release prevention system
SI:	International System of Units
SPCC:	spill prevention control and countermeasures plan
Std:	standard
UG:	underground
UT:	ultrasonic testing

SECTION 3—REFERENCES AND STANDARDS

Unless otherwise specified, the most recent editions of the following publications, standards, codes, and specifications should be used. The provisions of these publications are incorporated into this document only as explicitly specified in the text. The following API documents will aid users in the development of their systems integrity program.

API

Publ 340 Liquid Release Prevention and Detection Measures for Aboveground Storage Facilities

Publ 351 Overview of Soil Permeability Test Methods

Std 570 Piping Inspection Code: Inspection, Repair, Alteration, and Re-rating of In-Service Piping Systems

Std 650 Welded Steel Tanks for Oil Storage

RP 651 Cathodic Protection of Aboveground Storage Tanks

RP 652 Lining of Aboveground Petroleum Storage Tank Bottoms

Std 653 Tank Inspection, Repair, Alteration, and Reconstruction

RP 2350 Overfill Protection for Storage tanks in Petroleum Facilities

Std 2610 Design, Construction, Inspection and Maintenance of Petroleum Terminal and Tank Facilities

Publ 4700 Primer for Evaluating Ecological Risk at Petroleum Release Site

NFPA¹

NFPA 30 Flammable and Combustible Liquids Code Handbook

The following references were used in the development of this document.

API

RP 580 Risk Based Inspection

Publ 581 Base Resource Document on Risk-Based Inspection

Std 1160 Managing System Integrity for Hazardous Liquid Pipelines

Publ 580 Risk Based Inspection Base Resource Document

RP 575 Inspection of Atmospheric and Low Pressure Storage Tanks

RP 572 Inspection of Pressure Vessels

ASME²

B31.8S Managing System Integrity of Gas Pipelines

¹ National Fire Protection Administration (NFPA), 1Battymarch Park, Quincy, Massachusetts, 02169-7471, www.nfpa.org.

²ASME International, Three Park Avenue, New York, NY 10016-5990, www.asme.org.

CCPS³

Guidelines for Hazard Evaluation Procedures, 2nd Edition

Greenberg & Cramer. "Risk Assessment & Risk Management for the Chemical Process Industry," Stone & Webster Engineering. VanNostrand Reinhold: New York, NY.

Mikkola, Myers, & Power. Secondary Containment Liners for Tank Farms – A New Approach; "Hydrocarbon Processing." May 2000.

³ Center for Chemical Process Safety (CCPS) of the AIChE, 345 East 47 Street, New York, NY 10017, www.aiche.org.

SECTION 4—BASIC CONCEPTS OF RISK

In a perfect world, there would be an analytical technique that allowed a terminal owner to forecast exactly how and when a leak could occur. Equipped with this knowledge, the owner would take corrective actions, repairs, or refresher training the day before the leak was predicted and save the facility from the cost of the leak. In a perfect world, the corrections would be made at minimal cost. However, the world is full of uncertainty. The idyllic world described above is unachievable, due to uncertainty in natural processes. There exists an approach, however, that acknowledges the uncertainties in natural processes and uses that information to the best advantage of the decision-maker. That process is risk assessment and risk management. The world is full of hazards. One can never eliminate or sometimes even minimize risks, but the goal of those managing a risky business is usually to keep risks as low as reasonably practicable.

Risk assessment and risk management are strategic processes aimed at reducing either or both the likelihood (probability) and the severity (consequences) of hazardous events. It can be integrated into the decision-making process so that management can maintain risks at an acceptable level while trying to minimize cost. Once risks are understood via the risk assessment and risk management process, they can be better controlled.

4.1 Principles and Philosophy of Risk

The practice of risk management and risk assessment (risk analysis) is something that people perform on a regular basis without even realizing it. Risk management and risk assessment can be as simple as a driver slowing down while driving through a neighborhood with children playing, or glancing to the left and right before crossing a street, despite the fact that everything appears normal and safe. The thought process that causes a safe driver to slow down is risk management. The analytical process the driver follows in managing the risk is risk assessment.

A risk assessment has four fundamental tasks:

- Postulate that a certain scenario, or a chain of events, could occur
- Estimate chances that the scenario could occur
- Predict the severity of the scenario, should it occur
- Decide a course of action based on the chances and severity of the outcome

Anytime that there is the potential for an undesirable outcome, one can conduct a risk assessment. Risk assessment views scenarios as both stochastic and deterministic. The stochastic, or probabilistic view, states that there is randomness in every natural event. Therefore, predictions about natural events are uncertain. The deterministic view states that occurrences are causally determined by preceding events or natural laws. In risk analysis, the stochastic approach is used to determine likelihood, and the deterministic approach is used to estimate consequences.

4.1.1 What Is Risk?

The dictionary defines risk as “a factor, thing, element, or course involving uncertain danger; a hazard” or “the possibility of suffering harm or loss; danger.” However, the definition preferred in industrial risk analysis is “the probability of a given loss or injury to people or property,” which has several implications:

- Probability is part of the measure of risk
- Level of loss is part of the measure of risk
- The complete definition of risk requires a pair of data points, probability and consequence

4-1

The following scenarios are merely examples for illustration purposes only. Each company should develop its own approach. They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document. Users of this document should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein. Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the instructions. At all times users should employ sound business, scientific, engineering, and safety judgment when using this bulletin.

Risk is the combination of the probability of some event occurring during a specified time period and the consequences (for the purpose of this document consequences are always negative) associated with the event. In mathematical terms, risk can be calculated by Equation 4-1:

$$\text{Risk} = \text{Probability} \times \text{Consequence}$$

(Equation 4-1)

Another way of stating probability is likelihood. As a result, one might define risk as the *likelihood* of an event or condition that leads to a release (e.g., severe corrosion damage), and the *consequence* in the event of a release (e.g., petroleum entering a waterway). The mathematical representation of this statement is Equation 4-2:

$$\text{Risk} = \text{Likelihood} \times \text{Consequence}$$

(Equation 4-2)

In both equations, risks can be evaluated in a numeric (quantitative) or non-numeric (qualitative) manner.

4.1.2 Likelihood of Occurrence

The likelihood or the probability of a scenario occurring is measured in terms of the frequency or occurrences per year for a specific event. This estimate covers the chain of events from initial failure through to eventual remediation, including conditions that could worsen the effects of a consequence. The estimation process involves determining the reliability of both equipment and human techniques. Subject matter experts, human reliability analysis, or failure logic models can be used to determine the likelihood of occurrence. In this document, the likelihood of occurrence is referred to as the likelihood of failure (LOF).

For the optional risk assessment method outlined in Appendix A, the likelihood of a scenario occurring is estimated by answering the questions provided in the risk assessment model. These questions are listed in the workbook in Appendix C and require detailed information on the specific item being evaluated (tank, pipe, etc.). Depending on the response for a specific facility or equipment, factors are used to adjust the frequencies (probabilities) up or down.

4.1.3 Consequence of Occurrence

The second objective of a risk assessment is to determine the physical consequences that occur as a result of the incident. The consequence of a scenario occurring is measured in terms of the damage, disruption, or financial impact associated with a particular event. The consequence of occurrence can be expressed as a dimensionless factor or dollar value, but it is expressed in terms of consequences per event. For example, if a tank subject to deterioration from corrosion develops a leak, a variety of consequences could occur. Some of the possible consequences are that the leak:

- forms a vapor cloud that could ignite causing injury and facility damage
- results in a spill that causes environmental damage to soil, surface water, and/or groundwater
- forces a shutdown, which has an adverse economic impact
- has minimal safety, health, environmental, and/or economic impact

In this document, the consequence of occurrence is referred to as the consequence of failure (COF).

4.1.4 Risk

Combining the likelihood of one or more of these events with its consequences will determine the risk to the operation. Some failures may occur relatively frequently without significant adverse safety, environmental, or economic impacts. Similarly, some failures have potentially serious consequences, but if the likelihood of the incident is low, then the risk may not warrant immediate action. However, if the likelihood and consequence combination (risk) is high enough to be unacceptable, then a mitigation action to predict or prevent the event is recommended.

Traditionally, organizations have focused solely on the consequences of failure or on the likelihood of failure without using systematic efforts to tie the two together. They have not considered how likely it is that an undesirable incident will occur. Only by considering both factors can effective risk-based decision-making take place. The owner can develop a set of risk acceptability criteria that recognizes that not every failure will lead to an undesirable incident having a serious consequence. Conversely, the criteria can also recognize that potentially serious outcomes may be the result of extremely low likelihood events.

Understanding the two-dimensional aspect of risk allows new insight into the use of risk management for inspection prioritization and planning, resource allocation, development of mitigation strategies, and financial planning.

4.2 Risk Scoring

Risk scoring involves the determination, measurement, and presentation of risks. As previously discussed, risks can be measured and presented as qualitative or quantitative or a combination of the two approaches. Section 6 further discusses the differences in performing a risk assessment for each approach. Risk scoring provides the user with tools to evaluate and compare risks. The user can evaluate and compare risks in several different ways by evaluating the risks of:

- different types of equipment at the same facility (e.g., the risk of piping vs. the risk of tanks)
- different events at the same facility (e.g., the risk of a tank overfill vs. the risk of a tank bottom leak)
- the same equipment at the same facility (e.g., the risk of tank A vs. the risk of tank B)
- different facilities (e.g., the risk of facility A vs. the risk of facility B)

In order for the analysis to be meaningful, the user can define what constitutes an acceptable level of risk. The definition and determination of what is an acceptable risk is an owner-defined, company-specific process that is based on the company's management and guiding principles. Two different approaches to risk scoring, one qualitative and one quantitative, are presented below.

4.2.1 Risk Matrix Development

For risk ranking methodologies that use consequence and likelihood categories, presenting the results in a risk matrix is a very effective way of communicating the distribution of risks throughout a facility or equipment unit without assigning or developing numerical values. Various types of matrices can be used, but most are arranged such that the highest-ranking risk is toward the upper right-hand corner and the lowest-ranking risk is in the lower left-hand corner. Regardless of the matrix selected, the consequence and likelihood categories typically provide sufficient discrimination between the items assessed.

Risk categories may also be assigned to the boxes on the risk matrix. An example of risk categorization (higher, medium, or lower) in the risk matrix is shown in Figures 4.1 and 4.2. In this example, the risk categories are symmetrical; however, the categories could also be asymmetrical (i.e., the consequence category may be given higher weighting than the likelihood category).

Assessing or associating risk levels with squares on the matrix is a reflection of a company’s policies and attitudes about risk acceptability. Many companies choose not to assign levels of risk within a matrix; however, if a company does decide to assign levels of risk, decisions can then be made regarding the disposition of various scenarios.

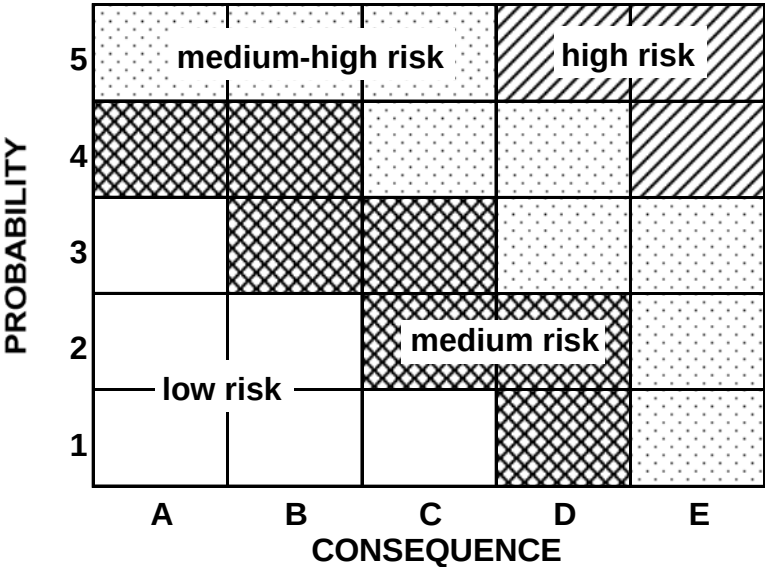


Figure 4-1: Example Risk Matrix Showing Levels of Risk (This is for demonstration only and not to be construed as endorsed matrix risk-level categorizations.)

The five-by-five matrix shown in Figure 4-1 portrays risk as neutral to likelihood or consequence. For instance, risk point C-1 has the same level of risk as A-3. To reflect aversion to one of the two elements of risk, the risk levels that are represented by the shaded areas are shifted, as shown in Figure 4-2 below. In Figure 4-2, an aversion to consequence is shown by assigning a higher risk level to higher consequences for some levels of likelihood.

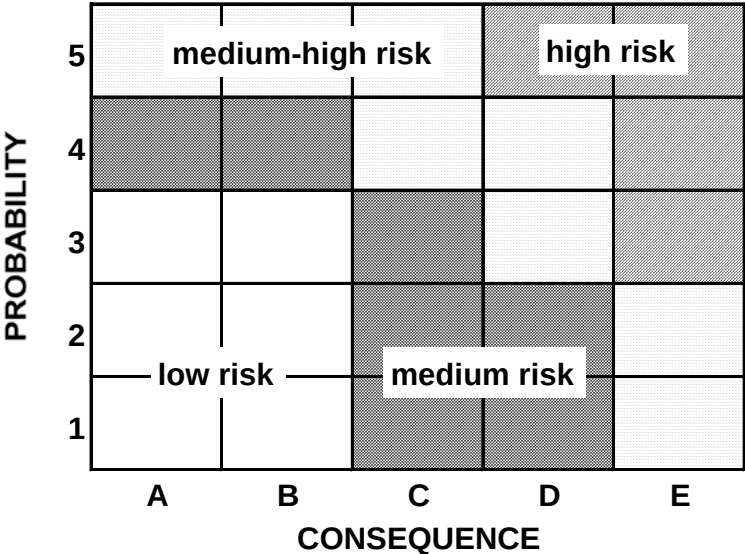


Figure 4-2: An Example Risk Matrix Showing Consequence-Aversion (This is for demonstration only and not to be construed as endorsed matrix risk-level categorizations.)

Note that, when compared to the unbiased matrix (Figure 4-1), risk point C-1 is assigned a risk level of “medium” rather than “low.” Other blocks on the matrix are changed to reflect aversion to consequence in Figure 4-2.

Equipment items residing towards the upper right corner of the plot or matrix will most likely take priority for inspection planning or other forms of mitigation because these items have the highest risk. Similarly, items residing in the lower left corner of the matrix will tend to take lower priority because these items have the lowest risk. Once the plots have been completed, the risk matrix can then be used as a screening tool during the prioritization process or for the selection of items or equipment requiring mitigation.

4.2.2 Quantitative Risk Analysis

Risks can also be presented in quantitative terms. Figure 4-3 shows an example of a quantitative numeric estimate of risk. In this plot, a scenario was found to have a likelihood of once in 1,000 years, resulting in a loss of \$100,000.

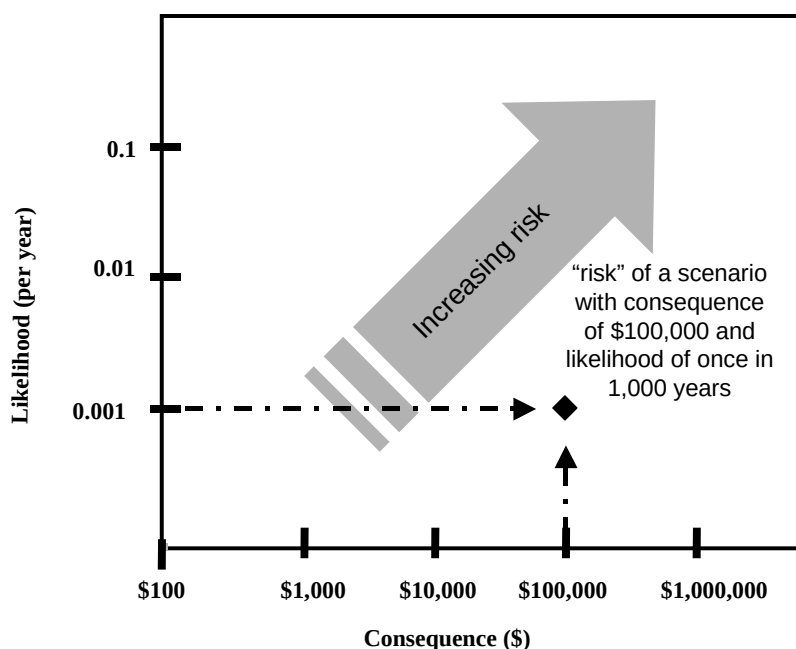


Figure 4-3: Example of Risk Point

When interpreting this plot, note that risk increases diagonally from the lower left corner to the upper right corner. Also note that the scale used in these plots is logarithmic for both likelihood and consequences. If we had eight scenarios for a given risk assessment and we estimated the likelihood and consequence of each scenario, we could produce a table similar to that of Table 4-1, where each scenario is labeled A through H.

Table 4-1: Example of Risk Points for a System

Scenario	Consequence (\$)	Likelihood (per year)
A	\$1,000	0.01
B	\$2,000	0.05
C	\$4,300	0.00035
D	\$7,000	0.0085
E	\$10,000	0.001
F	\$80,000	0.032
G	\$100,000	0.0032
H	\$125,000	0.0005

There are many different ways to process and display the risk points such as those outlined in Table 4-1. For instance, Figure 4-3 shows the likelihood-consequence pair as a single point. However, if many scenarios exist, like those listed in Table 4-1, a plot would show the range of risks. Figure 4-4 shows an example of this.

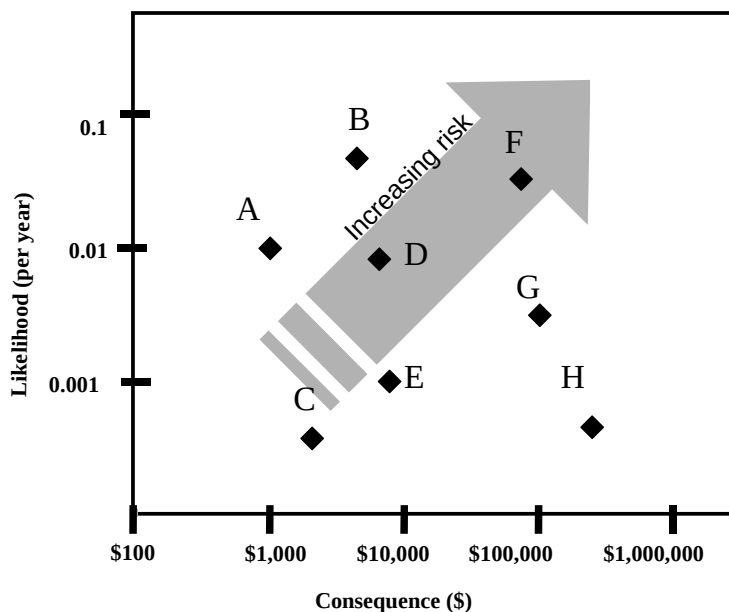


Figure 4-4: Example of Risk Plot for Multiple Scenarios

After plotting the various scenarios from Table 4-1, the following information can be readily extracted from Figure 4-4:

- Scenario B has the highest likelihood of occurrence
- Scenario C has the lowest likelihood of occurrence
- Scenario H produces the greatest consequence

- Scenario F has the highest risk
- Scenarios A and E have the same level of risk, since the “iso-risk” line is a straight line with a slope of -1

The advantage of Figure 4-4 is that it shows the risk of many scenarios plotted individually, but it does not show how the risks add up or accumulate for a facility. Since risk is a representation of a pair of points, you cannot simply add the values together to produce an accumulated risk. The approach typically used in risk analysis is to add together all of the probabilities of those particular scenarios that can produce a given loss or greater. In this way, the analyst can see the likelihood of exceeding a given level of loss. For example, the chances of having a loss between \$1.2 and \$1.3 million may be extremely small and there is little motivation for knowing those chances. What is worth knowing, however, is how often the damages may exceed \$1.3 million.

For these reasons, risk analysts have devised a plot that shows the likelihood of exceeding a given level of loss for accumulated scenarios. The plot is produced by starting with the highest loss value and working down to the lowest loss value. In the process, the analyst progressively accumulates the probabilities from all higher consequence scenarios, so that the likelihood of smaller losses becomes higher and higher. This is demonstrated in Table 4-2, using the data from Table 4-1.

Table 4-2: Data for Accumulated Risk Plot

Scenario	Consequence (\$)	Likelihood (per year)	Accumulated Likelihood (per year)
A	\$1,000	0.01	0.106
B	\$2,000	0.05	0.096
C	\$4,300	0.00035	0.046
D	\$7,000	0.0085	0.045
E	\$10,000	0.001	0.037
F	\$80,000	0.032	0.036
G	\$100,000	0.0032	0.0037
H	\$125,000	0.0005	0.0005

Start here and accumulate likelihood as consequence decreases

Figure 4-5 shows the result of plotting accumulated likelihood versus level of loss. From this plot (or from Table 4-2), an analyst can estimate that the likelihood of having at least a \$10,000 loss is about 0.037 per year or once in 27 years. The plot provides information on both the likelihood and consequence, so both elements of risk appear on the cumulative plot.

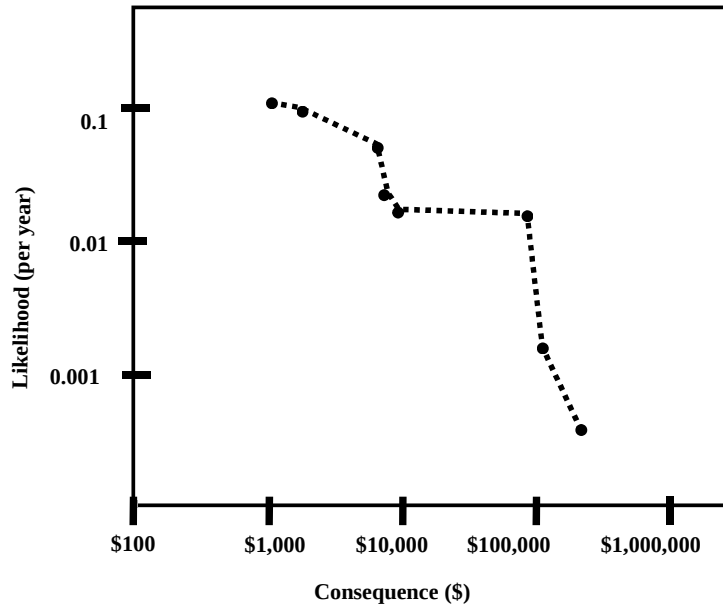


Figure 4-5: Example of a Cumulative Risk Curve

Another way to portray risk quantitatively is to produce a point-estimate of risk from the consequence-frequency data pair. Typically, this is done by multiplying the two likelihood and consequence data points together to produce a measure with units of “consequence per year.” The mathematical expression for this score was described in Equation 4-2:

$$\text{Risk} = \text{Likelihood} \times \text{Consequence}$$

(Equation 4-2)

Multiplying likelihood by consequence is convenient because it reduces the risk measure to a single point. The single risk point is often referred to as the *expected value* of risk for a scenario, and it can be thought of as a likelihood-weighted consequence estimate. In combining likelihood and consequence, however, some information is lost; namely, the individual magnitudes of the likelihood and consequence. For example, a risk point of \$100,000 at 0.01 per year has the same expected value as risk point \$50,000 at 0.02 per year. Using the above example table (Table 4-2), a table of expected values or risk scores could be produced (Table 4-3).

Table 4-3: Example of Scenarios and Risk Scores for a System

Scenario	Consequence (\$)	Likelihood (per year)	Risk (\$ per year)
A	\$1,000	0.01	\$10
B	\$2,000	0.05	\$100
C	\$4,300	0.00035	\$2
D	\$7,000	0.0085	\$60
E	\$10,000	0.001	\$10
F	\$80,000	0.032	\$2560
G	\$100,000	0.0032	\$320
H	\$125,000	0.0005	\$63

From the risk score in the above table, an analyst could determine that Scenario F has the highest risk but would be unable to determine which scenario has the highest consequence or which has the highest likelihood. Risk analysts may use other systems to produce a risk score that emphasizes one risk element over another. Typically, systems are devised that emphasize consequence over likelihood, since most people are averse to large consequence events. For instance, people are generally more outraged by a plane crash that kills 250 people than by 250 individual fatalities in car accidents. From a technical viewpoint, car crashes are of far greater risk than airplane crashes, but airplane crashes always grab headlines over car accidents.

One way to express this aversion to high-consequence events is to use an expression that is non-linear and gives preference to higher consequence events. Equation 4-3 presents such an expression.

$$Risk = Likelihood \times (Consequence^K)$$

(Equation 4-3)

In the above expression, to be consequence-averse, K would be greater than 1.0. The magnitude of K would reflect the degree of consequence aversion to be shown in the risk score. Note that the risk estimated by the above expression can only be referred to as an “expected value” when K is exactly 1.0. Typically, risk analysts use K values ranging from 1.5 to 2 when expressing consequence-aversion.

4.2.3 Risk Reduction

Risk reduction is the act of mitigating a known risk to a lower level of risk and is also referred to as hazard mitigation or risk mitigation. Risk reduction is required for those risks that the facility management determines to exceed a specific company-mandated threshold and can be accomplished through a wide range of measures including engineering and/or operational control measures. For facilities covered in this publication, the information provided in API Publ 340 provides a starting point for the screening and selection of risk reduction measures.

There are several potential approaches to decisions concerning risk reduction measures. These approaches include subjective, code-based, risk improvement, risk criteria, and cost-benefit. All are covered in more detail below.

In the **Subjective Approach**, the decision-makers consider the range of possible actions and then select those risk reduction measures that they believe are appropriate for the process. The advantage of using this approach is that it is flexible and automatically takes into account the economic and practical constraints in different operations. However, the disadvantage is that it has the potential to be inconsistent and open to abuse; therefore, this approach would be more practical for low-hazard activities.

A **Code-Based Approach** is one in which risk reduction measures are selected that conform to good engineering practice according to relevant industry guidelines and codes of practice. This approach gives objective guidance while taking account of practical constraints. The drawback is that it does not allow for flexibility or for exemptions that usually coincide with the low-likelihood conditions.

Risk Improvement Approaches are those in which improvements that are gained by risk reduction measures are evaluated against a fixed “base case.” The overall objective in this approach is to reduce the risk by a pre-defined amount (e.g., cutting the risks in half or dropping the risk by at least one qualitative level). This approach tends to fit well into the qualitative matrix approach to risk where decisions would be made to drive risk from a higher risk level to a lower one. For quantitative studies, this approach places less emphasis on the absolute numbers in the risk analysis. Decisions can be made on a relative value of risk as opposed to an absolute value.

In the **Risk Criteria Approach**, the risk analyses are compared with a set of risk criteria. The criteria may be numerical for a quantitative system, or they may be associated with given levels of risk in a qualitative system. In their simplest form, these criteria indicate whether the activity is acceptable or not. If it is unacceptable, then risk reduction measures are typically adopted regardless of cost. If it is acceptable, then no further measures are needed. This has the advantage of giving clear guidance about when risk reduction is needed, but the level at which the criteria should be set is not well-established and varies throughout the world and across different industries.

Finally, in the **Cost-Benefit approach**, measures are selected if they have a favorable ratio of cost (e.g., expenditure and operating costs) to benefit (e.g., risk reduction). This approach is deemed the most powerful and rational of the various approaches and provides objective guidance on specific risk reduction measures, while accounting for economic constraints; however, this approach can be applied only to quantitative risk systems. The disadvantage is that this method may involve an explicit comparison between safety or environmental matters and mitigation economics. This comparison is usually cumbersome to explain to a public audience.

Refer to Section 8 for further discussion of the specific selection and screening processes used for risk mitigation.

SECTION 5—RISK MANAGEMENT PROGRAM OVERVIEW

A risk management program (RMP) is primarily a management tool that allows the user to identify, manage, and mitigate risks associated with petroleum terminal facilities. RMPs provide for management guidance and control; application of the technical analysis of risks; involvement of appropriate facility personnel in the program development, implementation, and maintenance; and the mitigation or management of high-risk items.

5.1 General

In developing this document for managing risks at terminal facilities, the authors followed certain guiding principles. These principles are reflected in many of the sections and are provided here to give the reader a sense of the need to view terminal integrity from a broad perspective.

Integrity management starts with the sound design and construction of the terminal. Equipment and operational integrity are typically built into the facility from the initial planning, design, and construction phases. A number of consensus standards, including API Std 2610, API Std 650, API Publ 340, NFPA 30, ASME B31.1, B31.3, and B31.4, provide guidance for new construction. API Std 2610 gives a more complete list of applicable codes, standards, and guidance. When these documents are applied to the design of a terminal, the designer usually considers the environmental setting of the facility, including the surrounding land use and the possible impacts on the surrounding environment and community. New construction is not a subject of this document, but the design specifications and as-built conditions of the facility provide important baseline information for an RMP.

Facility integrity depends on qualified people who use defined processes to operate and maintain facilities. The integrity of the physical facility is only part of the complete system that allows an owner to reduce both the number of incidents and the adverse effects of errors and incidents. The total system also takes into account the people who operate the facility and the work processes that the employees use and follow. Therefore, a comprehensive RMP typically addresses people, processes, and facilities.

Another significant aspect of an RMP is its flexibility as it is typically customized to support each facility's unique conditions. Furthermore, the program is typically evaluated continually and modified to accommodate changes in the facility design and operation, changes in the environment within which the facility operates, and changes in operating data and other integrity-related information. Continuous evaluation is essential to ensure that the program takes appropriate advantage of improved technology and that it remains integrated with the owner's business practices while effectively supporting the company's overall risk management goals.

Facilities have multiple options available for addressing risks. For example, components of the facility or system can be changed; additional training can be provided to the people who operate the system; processes or procedures can be modified; or a combination of actions can be taken that will have the greatest impact on reducing risk.

One of the key components of risk is the integration of available information, such as facility design and failure records, into the decision-making process. Since the information can come from a variety of sources, the owner of the facility is in the best position to gather and analyze the data. Once all of the relevant information is collected and integrated, the owner can begin to distinguish where the risks of an incident are the greatest and proceed to make prudent decisions to reduce the risk.

Preparing for and conducting a risk assessment is yet another key element in managing risk. Risk assessment is an analytical process through which an owner determines the types of adverse events or conditions that might impact system integrity; the likelihood that those events or conditions will lead to a loss of integrity; and the nature and severity of the consequences that might occur following a failure. This analytical process involves the integration and analysis of design, construction, operation,

5-1

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maintenance, testing, and other information about a terminal facility. Risk assessments can have varying scopes and levels of detail and use different methods; however, the ultimate goal of assessing risks is to identify and prioritize the most significant risks so that the owner can make informed decisions.

Assessing risks to terminal integrity is a continuous process where the owner will periodically gather additional information and operating experience that is then factored into the understanding of the risks associated with specific equipment or specific operations. As the significance and relevance of this additional information become understood, owners can adjust their integrity plan accordingly. This makes analyzing risks in a facility an iterative process. Adjustments in response to the data may lead to changes in inspection methods or frequency or additional modifications to the facility equipment or procedures. As changes are made, different companies and different facilities within a company will be at different places with regard to the goal of incident-free operation. Therefore, each facility and each company usually set specific goals and measures to monitor the improvements in integrity and to assess the need for additional changes.

Owners can act to address integrity issues that are raised from assessments and information analysis and then proceed to mitigate or eliminate injurious defects. Some of the high-risk events may require mitigation.

Owners can periodically assess the capabilities of new technologies and techniques that may provide improved understanding about the facility equipment condition or provide new opportunities to reduce risk. New technology can be evaluated and utilized as appropriate because it may enhance an owner's ability to assess, prevent, detect, or mitigate certain risks. Knowledge about what is available and effective will allow the owner to apply the most appropriate technologies or techniques to a specific risk. Owners are encouraged to perform internal reviews to ensure the effectiveness of their risk management program in achieving the goals stipulated by management.

5.2 Developing a Company Approach to Risk Management

Although individual terminals have unique design features and operating characteristics, an effective RMP typically comprises several key elements which are outlined in this section. The framework presented in this document provides recognized industry practices for developing these elements and a common structure upon which to establish a company-specific RMP.

In developing an RMP, owners can consider their unique risk management goals and objectives and then use existing approaches, or develop new processes, to achieve these goals. There are numerous approaches to implementing the different elements identified in this section, ranging from relatively simple to highly sophisticated and complex. There is no "best" approach that is applicable to all facilities for all situations. This publication recognizes the importance of flexibility in designing RMPs and provides guidance commensurate with this need.

It is important to recognize that an RMP is typically a highly integrated and iterative process. Although the elements detailed below are shown sequentially for ease in presentation, information flow and interaction between the different steps are significant. For example, the selection of a risk assessment approach depends in part on what facility-related data and information are available. Conversely, in the performance of a risk assessment, additional data needs are usually identified that better address potential equipment integrity issues; thus, the data-gathering and risk assessment elements are tightly coupled and may require several iterations until an owner is satisfied that the risk assessment appropriately characterizes the facility risks.

An RMP includes the following basic elements:

- Hazard Identification
- Risk Assessment

5-2

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- Risk Evaluation, Control, Management, and Mitigation
- Procedures
- Training
- Emergency Planning and Emergency Response
- Incident Investigation and Root Cause Determination
- Management of Change
- Compliance Audits
- Program Performance Measurement

Figure 5-1 provides a flow chart illustrating how one would integrate the basic elements of a risk management program.

5.2.1 Hazard Identification

The hazard identification element of an RMP provides the foundation for the risk assessment. It requires the facility to perform a rigorous and comprehensive review of the facility equipment, operational procedures, petroleum handling operations, and hazards specific to petroleum facilities. Part of the hazard identification process is to determine if a hazard is credible and whether the hazard poses a significant risk. The process incorporates the historical experience of the company and the knowledge base and intuition of personnel familiar with facility processes by taking into account what has gone wrong in the past and what can go wrong in the future. A formal analytical approach is critical to identify what could go wrong, and the results of the review are typically documented for future reference. This information can be used before an equipment or operational change is made at the facility. Hazard identification can be performed utilizing a variety of formal analytical processes often referred to as process hazard analysis (PHA). PHA involves the use of any one of a number of techniques, such as checklists, what-if/checklists, hazard and operability studies (HAZOPs), failure modes and effects analysis (FMEA), and fault-tree analysis.

The selection of the hazard identification method depends on the experience of the person or teams of people performing the analysis, the development stage (e.g., new equipment, modified process, experience with equipment or process), corporate philosophy, and the depth of the analysis to be performed. Hazard identification methods can be applied to new equipment or processes, modified equipment or processes, and periodically to ongoing operations.

For API Publ 340, a group of experienced industry members assembled a list of causes for liquid releases and categorized the type and magnitude of the release from terminal equipment such as tanks, piping, loading/unloading operations, ancillary facility equipment, and system operating practices. Users can employ API Publ 340 as a base to identify hazards associated with terminal facilities; however, the hazard identification list in API Publ 340 does not include hazards associated with safety, vapor releases, or fire/explosion. Users may desire to expand their hazard identification process to include these hazards.

5.2.2 Risk Assessment Overview

Risk by definition is the evaluation of the likelihood of an event occurring and the consequences of that event occurring. The management of risks associated with identified hazards requires a thorough understanding of the likelihood of a hazard occurring and the projected consequences if the event does occur. Risk assessment is the process of taking an undesired credible event recognized in the hazard identification process (what can go wrong) and determining the likelihood (the probability or frequency of occurrence) and consequences (the impacts) of the undesired event. Risk assessment is an important part of an RMP because it quantifies the overall impact of an identified risk and provides the methodology for comparing risks.

The likelihood of an event occurring is a function of the type of equipment, specific site conditions, equipment age and maintenance, contained fluid, operating practices, weather, and several other factors. When the likelihood of an event is determined, the user estimates the likelihood (not the possibility) that a particular event will occur. The likelihood that an event will occur can be based on published information from the company data historian, regulatory information, industry available information, and manufacturer data. The likelihood that an event will occur can be reported in several different ways:

- In qualitative (relative) terms based upon experience, such as the event has a very low, low, medium, high, or very high likelihood of occurrence
- Quantitative terms, such as it occurs at 1 in 100 tanks, or 1 in 1000 fills
- A combination of qualitative and quantitative methods

As part of the development of this document, API assembled a group of experienced industry members who developed a model for the likelihood of occurrence of liquid releases for major terminal equipment, such as the risk of a tank bottom leak, a piping leak, an overflow, etc., and included the information in Appendix A. Users can implement this particular model, portions of this model, or develop their own model for determining the likelihood of an event occurring. Users can also base this model on historic data that they have gathered such as information on the success of installing high-level alarms in tanks to prevent overfills or on other probabilistic or empirical information to determine the likelihood of an identified hazard. The optional likelihood model presented in Appendix A does not address the hazards associated with safety, vapor releases, or fire/explosion.

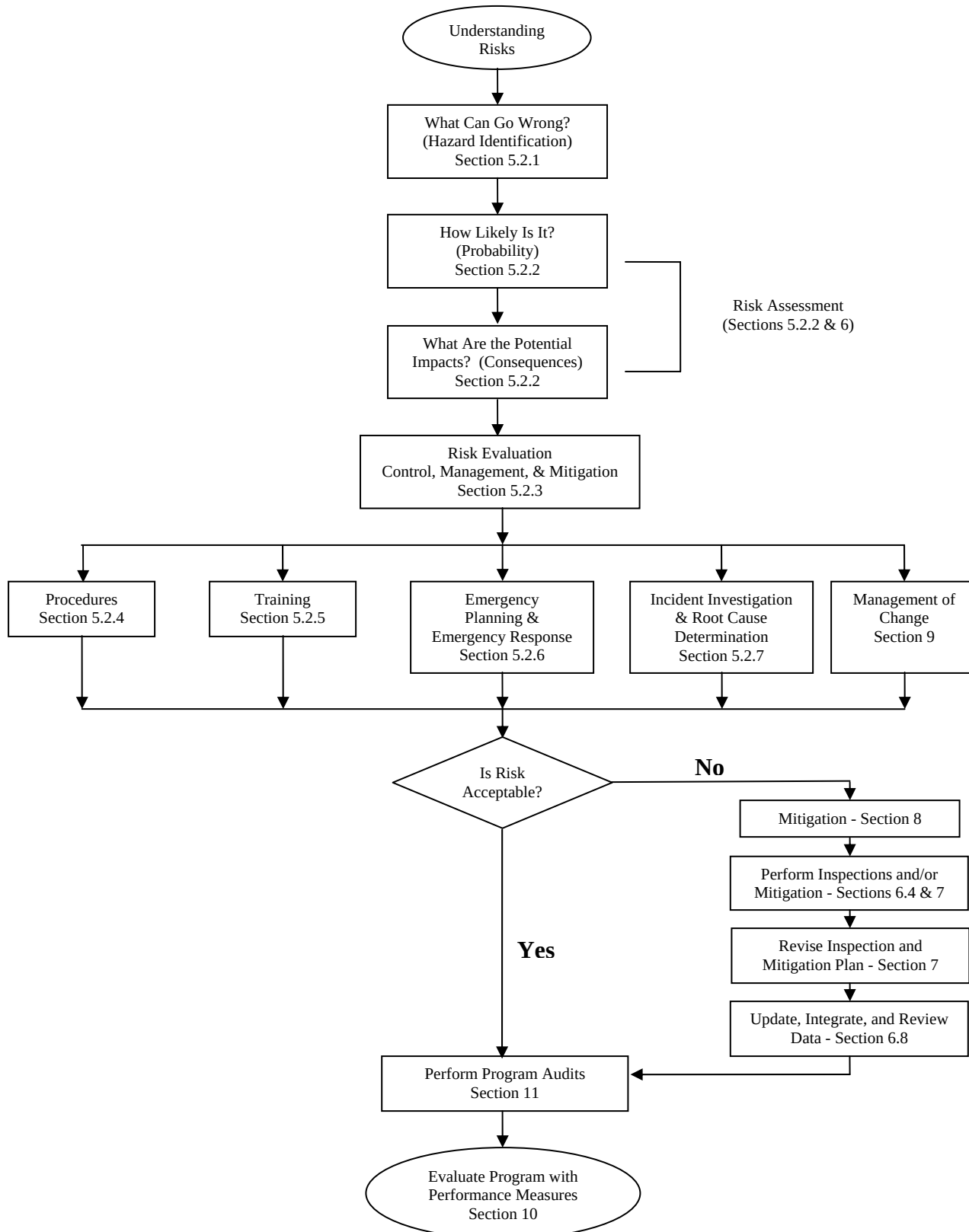


Figure 5-1: Risk Management Program

When the consequences of an event are calculated, environmental, economic, health, and safety issues, and items such as corporate reputation and philosophy, can be factored into the assessment. Furthermore, consequences are site specific and typically entail consideration of the type and magnitude of the hazard, site location, surrounding environment, land use, weather, population, regulatory environment, etc. The type and magnitude of consequences can be determined in several different ways:

- In qualitative (relative) terms such as a very small, small, medium, high, or very high spill; less than 1 gallon, 1 to 100 gallons; or other terms such as the spill is contained in the diked area, spill is contained on the property, offsite impact on groundwater, offsite impact on property, or offsite impact on surface water
- Quantitative terms such as dollars, volume spilled, environmental damage assessment
- A combination of qualitative and quantitative methods

As it did for the development of the model for the *likelihood* of occurrence, API assembled a group of experienced industry members who developed a model for the *consequences* of occurrence of liquid releases for major terminal equipment such as the risk of a tank bottom leak, a piping leak, an overflow, etc. This model is also included in Appendix A. Again, users can implement this model, portions of this model, or develop their own model for determining the consequences of an event. This model, like the one for likelihood of occurrence, can be based on historic data that the user has gathered such as information on the cost of cleaning up a spill in the containment area, or on other probabilistic or empirical information to determine the consequences of an identified hazard. The optional consequence model presented in Appendix A does not address the hazards associated with safety, vapor releases, or fire/explosion.

Section 6 covers the various types and approaches to risk assessment and includes an overview of the optional risk assessment methodology provided in the appendices.

5.2.2.1 Recognizing Changes That Affect a Risk Assessment Program. To keep the RMP current, the facility can identify the ways that changes to the facility, equipment, products, staffing, or procedures could impact the risk factors identified in the program. Examples of such changes are:

- Addition, deletion, or other modifications of the facility equipment
- Changes in the stored product
- Changes in operating conditions and spill control or other mitigation measures that are currently employed
- Changes to the piping system flow rate, operating pressure, or operating temperature
- Restart of equipment or systems that have been out of service for an extended time and/or systems that have not been maintained
- Changes to existing procedures or addition of new procedures

5.2.2.2 Planning the Risk Assessment. The purpose of this section is to help a user determine the scope and the priorities of a risk assessment. To focus the initial effort on the higher risk items, an initial screening can be performed of the equipment or systems at the facility. To further focus the effort, boundary limits can be identified to determine what is vital to include in the assessment and what constitutes a unit or equipment battery limit. Boundary limits are best set on process flow diagrams, piping and instrumentation diagrams (P&IDs), or site plans and can be established for sections of pipe, tanks, and loading/unloading areas. The boundary limits will then establish the discrete item, which will undergo the risk assessment. The organizing process of aligning priorities, screening risks, and identifying boundaries improves the efficiency and effectiveness of assessing and managing risk.

A risk assessment is typically undertaken with clear objectives and goals that are fully understood by all members of the team and by the facility management. An objective of the assessment may be to better understand the risks involved in the operation of the facility, or specific piece of equipment, and to

understand the effects that inspection, maintenance, and mitigation actions have on the risks. From the understanding of risks, an inspection program may be designed that optimizes the use of inspection and facility maintenance resources.

Since a risk assessment is a team-based process, it is important to define the following objectives at the beginning of the exercise:

- Why is the assessment being performed?
- How will the risk assessment be carried out?
- What knowledge and skills are required for the risk assessment personnel?
- What individuals will compose the risk assessment team?
- What are their roles in the process?
- Who is responsible and accountable for what actions?
- Which facilities, assets, and components will be included?
- What data are to be used in the assessment?
- What codes and standards are applicable?
- When will the assessment be completed?
- How long will the assessment remain in effect, and when will it be updated?
- How will the results be used?
- Are there event-based conditions that would necessitate an update?

Moreover, a risk assessment will determine the risk associated with the items assessed. The risk assessment team and management may wish to judge whether the individual equipment item and cumulative risks are acceptable. Establishing risk criteria to judge the acceptability of risk could be an objective of the assessment if such criteria do not exist already within the user's company (refer to Section 10).

Once the risks have been identified, mitigation strategies, such as inspections, procedures, and engineering or operating controls, that reduce risk to an acceptable level may be undertaken. The results of managing and reducing risk are improved safety, avoided losses of containment, and avoided commercial losses. Note that these actions may be significantly different from the actions undertaken during a statutory or certification type inspection of a mitigation program.

5.2.3 Risk Evaluation, Control, Management, and Mitigation

The process of identifying credible risks and assessing those risks is a necessary precursor to the evaluation, control, management, and where the owner deems appropriate, mitigation of those risks. The results from the hazard identification (section 5.2.1) and risk assessment (section 5.2.2) phases will provide the owner with the information necessary to evaluate a given risk. Management needs to realize that the potential for incidents always exists no matter how many engineered control measures are utilized, and therefore they can establish administrative controls. These controls can give personnel the decision-making tools to evaluate the risk, determine the appropriate method to control or manage the risk, refer specific risks to remediation via engineered and/or administrative controls, and select and implement the appropriate mitigation. After evaluating the risk assessment information, owners may appropriately decide that the risks are acceptable and no further action is required; that additional information, inspection, or evaluation is necessary to make a decision; or that they may mitigate the risk. Mitigation can be accomplished via change in operating conditions; removal from service of the high-risk unit; change in operating practices, procedures, or training; or implementation of engineered control measures.

Management typically provides the authority and resources to the facility and engineering personnel to ensure that the design, specification, and construction phases of new or replacement equipment or

facilities adhere to the appropriate company standards, industry standards, consensus codes, and applicable regulatory requirements. Section 4.2 explains the development of a risk scoring system, and Section 8 describes mitigation and control measure selection. Examples of risk mitigation strategies for environmental liquid release scenarios utilizing API Publ 340 are included in section 8.4.

5.2.4 Procedures

Facility operations require the use of instructions to plant personnel and/or contractors that take the form of written or verbal procedures. Procedures may be general in nature (e.g., housekeeping) or specific to a project task (e.g., gauging a tank), or they may address specific service conditions such as normal operations, maintenance, startup, safety, inspection, communications, or shutdown procedures.

Procedures are a necessary part of a facility's RMP and are typically not just a "paper" program. They are usually specific to a facility task or company and are kept current to reflect:

- Changes to the facility or equipment
- Feedback from incident investigations
- The results of the risk assessment evaluation
- Changes to employee training

The use of properly established procedures may be the primary method, or in some cases the only method, for managing a specific risk. Changes to facility operating procedures are inevitable, and a program can be in place that governs the review, modification, training, and updating of facility procedures. These items will become part of other elements of the RMP including training (section 5.2.5), emergency planning and emergency response (section 5.2.6), incident investigation and root cause determination (section 5.2.7), and management of change (Section 9).

5.2.5 Training

Training of employees and contractors in the facility operations, hazards, and job tasks is part of any company's basic corporate management program and is also an important element of a facility's RMP. Training refers to the activities associated with educating plant personnel or contractors in the operation and safe work practices at the facility. It forms the basis for ensuring that facility personnel are instructed in facility-specific hazards, that they understand the facility operations, and that they are adept at performing on-the-job training. This may involve having a junior operator or new hire work with a senior operator to observe and properly repeat an assigned task. In addition to standard job training and safe work practices, facility personnel are typically properly trained in the operation and maintenance of release prevention systems, release detection systems, facility alarms, and non-routine operating conditions.

Training programs are typically documented to ensure the effectiveness of training and to document that personnel have met the qualifying criteria established by the company. Training is a dynamic program that requires updates and, when appropriate, provides refresher training to onsite company personnel and contractors. Management review of the training program can occur based on changes in facility equipment after the completion of a management of change review (Section 9), emergency planning and emergency response updates (section 5.2.6), changes in procedures (section 5.2.4), or as a result of the findings from an incident investigation and root cause determination (section 5.2.7).

5.2.6 Emergency Planning and Emergency Response

The goal of risk management is to identify the risks, evaluate the likelihood of occurrence of those risks, and reduce the likelihood of occurrence. However, since assuring zero risk is not practical or reasonable, effective risk management requires planning for, responding to, and mitigating reasonable release scenarios. This is the role of emergency planning and emergency response.

As part of the facility's hazard identification program (section 5.2.1) and risk assessment analysis (section 5.2.2), the facility has already evaluated the specific credible failure mechanisms, the likelihood of occurrence for these mechanisms, and the consequences of occurrence for each specific risk. The facility can then use this information to prepare response plans for specific release scenarios. The consequences of the risk can be mitigated or controlled through proper emergency planning and emergency response. Incorporating an emergency planning and emergency response program into an RMP requires that a facility:

- Develop written contingency plans for possible petroleum release scenarios
- Develop procedures (section 5.2.4) for implementing actions detailed in the plan
- Conduct appropriate training (section 5.2.5) and/or drills outlined in the plan
- Plan, procure, or retain the services, equipment, and personnel to implement the necessary emergency response as outlined in the plan
- Establish a program to conduct communication and coordination with a third party and local responders

It is important to develop response procedures and action plans that include:

- Definition of organizational lines of responsibility and notification for response to accidental releases
- Training of personnel responsible for accidental release events
- Rapid verification of releases, if necessary
- Isolation and control of the release source
- Control of the released product according to procedures developed for specific environmental impacts and release volumes

Emergency planning and emergency response is a dynamic program that requires periodic updating of the plans and program. A management review process can occur based on changes to facility equipment, the findings from an incident investigation and root cause determination (section 5.2.7), or completion of a Management of Change review (Section 9). As the emergency planning and emergency response program is modified, the facility typically reviews its training program (section 5.2.5) to determine if modifications are necessary.

5.2.7 Incident Investigation and Root Cause Determination

Incident investigation and root cause determination involve an organized approach to recording a loss or near-loss incident, investigating the sequence of events of what went wrong, determining the root cause of the incident, and developing and documenting remedial measures to prevent the same or similar incidents from occurring in the future. Incident investigation of losses or near losses helps to refocus the risk assessment (section 5.2.2), risk mitigation approach (Section 8), and emergency planning and emergency response (section 5.2.6) elements of the facility's overall RMP. This is accomplished by using actual incidents to refine the hazard identification process (section 5.2.1), the likelihood of occurrence, and consequences or potential consequences of occurrence.

Incident investigation and root cause determination require preparation of proper investigation procedures; use of properly trained and qualified investigators and personnel involved with, or knowledgeable about, the incident; determination of the root cause; development of recommendations to remediate the root cause; and implementation of the recommended remedial measures. The results of an incident investigation may require updating or modifying other RMP elements, such as training (section 5.2.5), procedures (section 5.2.4), management of change (Section 9), hazard identification (section 5.2.1), or risk assessment (section 5.2.2).

SECTION 6—RISK ASSESSMENT

As discussed in section 5.2.2, a risk assessment method typically collects and logically processes data to arrive at a risk result. Risk assessment methods are tools that define a relationship between the type and frequency of threats that can reduce facility or equipment integrity (e.g., corrosion, mechanical damage, equipment failure, procedural breakdown, etc.) and the consequences in the event of a release. The risk assessment typically deals with a variety of data and assumptions about how the facility and equipment are designed, constructed, operated, and maintained, and the environmental and external factors that can affect risk. Risk assessment methods “predict” the value of the output variable (i.e., risk) based on the input values of more easily measured or evaluated variables (e.g., tank bottom thickness, soil conditions, pipe wall thickness, coating condition, etc.). The quality of the prediction depends on the quality of the inputs and the soundness of the logical relationships inherent in the risk assessment method used to evaluate the input and output conditions.

It is important to distinguish between a risk management process and a risk assessment method. Risk assessment is the estimation of risk for the purposes of decision-making. Risk management is the overall process that includes the risk assessment, maintenance activity, and reintegration of data into subsequent risk assessments. Risk assessment methods can be powerful analytical tools to integrate data and information and to help identify the nature and locations of risks associated with terminal facilities. However, risk assessment methods alone are typically not relied on to establish risk or determine decisions about how risks can be addressed. Risk assessment methods can be used as part of a process that involves knowledgeable, experienced personnel who critically review the input, assumptions, and results. This review can integrate the risk assessment output with other factors not initially considered in the assessment, such as the impact of key assumptions and uncertainties created by the absence of data or the variability in assessment inputs. This can be completed before management makes decisions concerning risks and actions to reduce risk. The various approaches to risk assessment fall into three broad areas:

- The relative value of knowledge and data and their logical relationships within the risk assessment method
- The complexity and detail of the risk assessment method
- The nature of the output (probabilistic vs. relative measures of risk)

Independent of the risk assessment method used, all techniques incorporate the same basic components:

1. Identify potential events or conditions that threaten the facility or equipment’s integrity
2. Determine the risk represented by these events or conditions by determining the likelihood of a release and the consequences of a release
3. Rank the risk assessment results
4. Identify and evaluate risk mitigation options (i.e., both net risk reduction and benefit/cost analyses)
5. Integrate maintenance project data (i.e., a feedback loop)
6. Reassess risk

Ultimately, it is up to the facility to develop, select, and apply the risk assessment method that best meets its specific requirements. It is in the best interest of the facility to develop a thorough understanding of the various risk assessment methods available and in use, including the respective strengths and limitations of the different methods, before determining a long-term risk assessment method strategy.

This section presents information on the different types and approaches to risk assessment. The optional risk assessment methodologies, which are included in Appendices A and B, are briefly discussed and presented to illustrate how a risk assessment process would be performed. The user may choose to develop a risk assessment methodology that addresses the approach, concepts, and equipment detailed in

the appendices of this document. The user-developed risk assessment method does not have to address all the elements outlined in the optional Appendices A and B, and in some instances, the user-defined risk assessment program may extend beyond the equipment and scenarios outlined in this document. For example, Appendix A addresses the risk of liquid releases only, and the user may want to expand the risk to include vapor, safety, and other items that are important to the company.

6.1 Company Risk Assessment Program

Although individual liquid petroleum storage facilities have unique design features and operating characteristics, an effective risk management program (RMP) typically comprises several key elements outlined in this section. The framework presented in this document provides recognized industry practices for developing these elements and a common structure upon which to develop a company-specific RMP.

In developing this program, owners usually consider their unique risk management goals and objectives and then use existing approaches or develop new processes to ensure that these goals are achieved. Typical characteristics of a risk assessment program are listed below.

Structured: The underlying methodology is structured to provide a thorough analysis. Some methodologies employ a more rigid structure than others. More flexible structures may be easier to use; however, they generally require more input from subject matter experts. All risk assessment methods identify and use logic to determine how the data considered contribute to risk in terms of affecting the likelihood and/or consequences of potential incidents.

Given adequate resources: Appropriate personnel and adequate time should be allotted to fit the detail level of the analysis.

Experience-based: The frequency and severity of past events (in the subject or a similar system) are typically considered. The risk assessment can account for any corrective actions that have been made to prevent similar mishaps and consider the facility or company-specific operating history and other knowledge about the individual system that has been acquired by field operations and engineering personnel.

Predictive: A risk assessment is typically investigative in nature, seeking to identify previously unrecognized threats to equipment integrity. While it can make use of previous events, its focus should be on the potential for future mishaps, including credible scenarios that may never have occurred in the past.

Based on appropriate data: Some risk analysis decisions are judgment calls; however, relevant data and particularly data about the equipment or system under review, usually affect the confidence level placed in the decisions.

Able to provide for and identify means of feedback: Risk analysis is an iterative process. Actual field events and data collection efforts are typically used to validate (or invalidate) assumptions made during the risk assessment process.

6.2 Types of Risk Assessment

Detailed below are types of risk assessment approaches available to the user. These risk assessment approaches are based on those developed as part of API RP 580, API Publ 581, and API Std 1160. The user should note that API Publ 581 is primarily for scheduling inspections at refineries, while this document deals with managing and evaluating risks at liquid terminal facilities. Users can develop a qualitative, quantitative, or semi-quantitative risk assessment approach. The risk assessment approach presented in the optional Appendix A of this document is one method for performing a *quantitative approach* to risk assessment. The risk assessment approach presented in the optional Appendix B of this

document is one method for performing a *qualitative approach* to risk assessment. Other models for risk assessment approaches are available but are beyond the scope of this document.

6.2.1 Qualitative Risk Assessment

The qualitative approach typically does not require all of the data required of a quantitative risk assessment method. Further, items required are typically categorized only into broad ranges or classified vis a vis a reference point. It is important to establish a set of rules to assure consistency in categorization or classification. One way in which risk can be represented is in qualitative terms, such as low, medium, or high. The qualitative assessments of likelihood and consequence can be assigned to categories. For instance, a low likelihood might be placed in Category 1, and a medium consequence might be assigned to Category C. These values can then be displayed in a matrix similar to that discussed in Section 4 where risk increases from the lower left corner to the upper right corner of the matrix.

This qualitative type of approach requires data inputs based on descriptive information using engineering judgment and experience as the basis for the analysis of likelihood and consequence of failure. As previously mentioned, inputs are often given in data ranges rather than discrete values; however, numerical values may be associated with these categories. The value of this type of analysis is that it enables completion of a risk assessment in the absence of detailed quantitative data. Generally, a qualitative analysis using broad ranges requires a higher level of judgment, skill, and understanding from the user than a quantitative approach. Ranges and summary fields may be evaluated for circumstances with widely varying conditions that require the user to carefully consider the impact of input on risk results.

The accuracy of results from a qualitative analysis depends on the background and expertise of the analyst, so, despite the approach's simplicity, it is important to have knowledgeable and skilled persons perform the qualitative risk assessment analysis.

6.2.2 Quantitative Risk Assessment

Quantitative risk assessment analysis integrates into a uniform methodology the relevant information about facility design, operating practices, operating history, component reliability, human actions, the physical progression of incidents that could result in a release, release quantities, and the potential environmental effects.

Quantitative risk analysis uses logic models depicting combinations of events that could result in severe accidents and physical models depicting the cause of releases, the progression of incidents resulting in a release, and the transport of liquid petroleum products to the environment. The models are evaluated probabilistically to provide both qualitative and quantitative insights about the level of risk and to identify the design, site, or operations characteristics that are the most important to risk; hence, more detailed information and data are needed for quantitative risk assessment in order to provide input for the models. Quantitative risk analysis is distinguished from the qualitative approach by the analysis depth and the integration of detailed assessments.

Quantitative risk assessment logic models generally consist of an organized methodological approach such as *event tree* and *fault tree* types of analysis. Event trees delineate initiating events and combinations of system successes and failures, while fault trees depict ways in which the system failures represented in the event trees can occur. These models are analyzed to estimate the likelihood of each accident sequence. Results using the approach are typically presented as risk numbers (e.g., cost per year) and are either plotted on a risk matrix or risk curve or a single value is found by utilizing a scoring system.

The traditional quantitative risk assessment is composed of five tasks:

1. Systems identification
2. Hazards identification
3. Likelihood assessment
4. Consequence analysis
5. Risk results

The system definition, hazard identification, and consequence analysis are integrally linked. A quantitative analysis deals with total risk, not just a risk associated with equipment failure, leakage, or overfills.

The quantitative assessment also involves a much more detailed evaluation of the following types of data:

- Existing hazard and operability study (HAZOP) or process hazards analysis results
- Dike, piping, tank design, and inspection information
- Hazard detection systems
- Release statistics
- Environmental factors
- Local site conditions
- Land use

Personnel experienced in the specific methodology (risk analysts) generally perform the analysis due to the extensive and detailed nature of the evaluation; however, the risk analyst also requires input from engineers and operations personnel.

6.2.3 Semi-Quantitative Risk Assessment

The semi-quantitative analysis typically requires the same data as a quantitative analysis but generally is not as detailed. For example, the fluid volumes may be estimated or grouped into ranges of low, medium, and high. Since the analysis may be less precise, the time required for data-gathering and analysis will also be less.

6.3 Precision vs. Accuracy

Risk assessment values can be represented in several different ways: a single numeric value (e.g., 102); a range of values (e.g., 100 to 200); a letter (e.g., “A”, “B”, “C”, “D”) where each letter represents a different risk criteria; an order of magnitude; a descriptive word (e.g., “low”, “medium,” “high,” “very high”); or any way that is meaningful and helpful to the user. It is important to remember that precise numeric values, although implying a greater level of accuracy, do not mean a more thorough or complete analysis. Numeric values provide the air of precision, but not necessarily better accuracy. The element of uncertainty that is inherent in the probabilities and consequences model limits the accuracy of any given method. The accuracy of the output is a function of the methodology used and the quantity and quality of the data. In practice, there are often many factors that will affect the estimated likelihood of failure and the magnitude of the failure (consequences) that cannot be fully taken into account with a fixed model. It may be beneficial to use quantitative and qualitative methods in a complementary fashion to produce the most effective and efficient assessment. Risk assessment results (quantitative or qualitative) do not indicate whether the assessment type was qualitative or quantitative.

6.4 The Role of Inspection in Risk Assessment

Reducing inspection costs is not the primary objective of risk assessment, and the analysis may actually lead to increased inspection. Inspection optimization is frequently a side-effect of performing a risk assessment. The risk assessment review allows an owner to optimize the inspection quality and frequency