U.S. Department of
Transportation

**Federal Railroad
Administration**

LNG Safety Assessment Evaluation Methods

Office of Research,
Development,
and Technology
Washington, DC 20590

DOT/FRA/ORD-16/25

Final Report
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0			1		2			3		4			5
Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

Sandia National Laboratories evaluated published safety assessment methods across a variety of industries including Liquefied Natural Gas (LNG), hydrogen, land and marine transportation, as well as the US Department of Defense (DOD). All the methods were evaluated for their potential applicability for use in the LNG railroad application, and the Department of Energy (DOE) Hydrogen Safety Plan Checklist was thought to be the most suitable to be adapted to the LNG railroad application.

This report was developed from a survey of industries related to rail transportation for methodologies and tools that can be used by the FRA to review and evaluate safety assessments submitted by the railroad industry as a part of their implementation plans for liquefied or compressed natural gas storage (on-board or tender) and engine fueling delivery systems. The main sections of this report provide an overview of various methods found during this survey. In most cases, the reference document is quoted directly. The final section provides discussion and a recommendation for the most appropriate methodology that will allow efficient and consistent evaluations to be made. The DOE Hydrogen Safety Plan Checklist was then revised to make it suitable as a methodology for the Federal Railroad Administration's use in evaluating safety plans submitted by the railroad industry.

1. Introduction

Recently, restrictive emissions requirements and historically low natural gas prices have resulted in efforts to develop a fleet of dual-fueled Liquefied Natural Gas (LNG)/diesel hybrid locomotives. The Federal Railroad Administration (FRA) needs to make defensible regulatory decisions concerning the safety assessments of the proposed rail vehicles in a timely manner. As a result, the FRA has partnered with Sandia National Laboratories (Sandia) on research activities that will assess the safety of using natural gas as a locomotive fuel.

This report was developed from a survey of industries related to rail transportation for methodologies and tools that can be used by the FRA to review and evaluate safety assessments submitted by the railroad industry as a part of implementation plans for liquefied or compressed natural gas storage and delivery systems. The main sections of this report provide an overview of various methods found during this survey. In most cases, the reference document is quoted directly. The next section provides discussion and a recommendation for the most appropriate methodology that will allow efficient and consistent evaluations to be made. The Department of Energy (DOE) Hydrogen Safety Plan Checklist is most suitable to be adapted to the LNG rail application. The final section provides an adaptation of the DOE Hydrogen Safety Plan Checklist for the FRA to use in evaluating safety plans submitted by industry.

The term "safety assessment" refers to a broad class of assessments, ranging from qualitative methods (e.g., FMEA, HAZOP, and checklists) through quantitative methods like Probabilistic Risk Assessment (PRA). As a result, published sources were searched for these and similar additional terms to provide a comprehensive survey of relevant methodologies for reviewing and evaluating the quality and completeness of safety assessments. In many cases, the literature search revealed pertinent documents describing specific methodologies on how to **conduct** a safety assessment, but not specifics on how to **evaluate the quality** of an assessment. These, however, were deemed to be relevant to this task because evaluation criteria easily can be derived from the required components in an assessment methodology.

2. Safety Assessment Evaluation Checklists from Related Industries

Two safety assessment guidelines are discussed in this section. One is safety planning guidance for hydrogen and fuel cell projects, the purpose of which is to generate safety plans to identify and avoid potential incidents involving hydrogen, hazardous materials handling and fuel cell systems (DOE, 2010). The other is the International Atomic Energy Agency (IAEA) Safety Standards (2009), which provide guidance to protect people and the environment from harmful effects of ionizing radiation. Both guidelines recommend using a graded approach to ensure that the scope and level of detail of the safety assessment are consistent with the magnitude of possible risks and system complexity.

Although the two guidelines specifically focus on hydrogen facilities and activities that have radiation risks, their intent is to ensure that all safety assessment needs are conducted and all the safety relevant issues are considered. The overall philosophy and good practices specified in the guidelines have important implications for other industries.

2.1 Safety Planning Guidance for Hydrogen and Fuel Cell Projects

A safety plan addresses potential threats and impacts to personnel, equipment, business, and the environment. Its desired elements are summarized in Table 1, which is reproduced from DOE's Safety Planning Guidance document (DOE, 2010). [1] Quoting this reference:

> *"This guidance document provides information on safety requirements for hydrogen and fuel cell projects funded by the U. S. Department of Energy (DOE) Fuel Cell Technologies Program. Safe practices in the production, storage, distribution, and use of hydrogen are essential for the widespread acceptance of hydrogen and fuel cell technologies. A catastrophic failure in any project could damage the public's perception of hydrogen and fuel cells. The project safety plan is meant to help identify and avoid potential hydrogen and related incidents. This guidance document aims to assist recipients in generating their safety plan, which will serve as a guide for the safe conduct of all project work."* [1]

This methodology uses a checklist to ensure that all elements of the assessment are present and specifies the contents of each element. This basic methodology is very useful as a tool for rapid and consistent evaluations. Due to similarities between the application areas, this checklist readily can be adapted to the dual-fuel diesel and LNG locomotive tenders being implemented in the railroad industry.

Table 1. Safety Plan Checklist (reproduced from [1])

Element	Description
Scope of Work	Nature of the work being performed
Organizational Policies and Procedures	Application of organizational safety-related policies and procedures to the work being performed
Hydrogen and Fuel Cell Experience	How previous organizational experience with hydrogen, fuel cell and related work is applied to this project
Identification of Safety Vulnerabilities (ISV)	What is the ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method Who leads and stewards the use of the ISV methodology Significant accident scenarios identified Significant vulnerabilities identified Safety critical equipment Storage and Handling of Hazardous Materials and related topics • ignition sources; explosion hazards • materials interactions • possible leakage and accumulation • detection Hydrogen Handling Systems • supply, storage and distribution systems • volumes, pressures, estimated use rates
Risk Reduction Plan	Prevention and mitigation measures for significant vulnerabilities
Operating Procedures	Operational procedures applicable for the location and performance of the work including sample handling and transport Operating steps that need to be written for the particular project: critical variables, their acceptable ranges and responses to deviations from them
Equipment and Mechanical Integrity	Initial testing and commissioning Preventative maintenance plan Calibration of sensors Test/inspection frequency basis Documentation
Management of Change Procedures	The system and/or procedures used to review proposed changes to materials, technology, equipment, procedures, personnel and facility operation for their effect on safety vulnerabilities
Project Safety Documentation	How needed safety information is communicated and made available to all project participants, including partners. Safety information includes the ISV documentation, procedures, references such as handbooks and standards, and safety review reports.

Element	Description
Employee Training	Required general safety training - initial and refresher Hydrogen-specific and hazardous material training - initial and refresher How the organization stewards training participation and verifies understanding
Safety Reviews	Applicable safety reviews beyond the ISV described above
Safety Events and Lessons Learned	The reporting procedure within the organization and to DOE The system and/or procedure used to investigate events How corrective measures will be implemented How lessons learned from incidents and near-misses are documented and disseminated
Emergency Response	The plan/procedures for responses to emergencies Communication and interaction with local emergency response officials
Self-Audits	How the project will verify that safety related procedures and practices are being followed throughout the life of the project
Safety Plan Approval	Safety plan review and approval process
Other Comments or Concerns	Any information on topics not covered above Issues that may require assistance from DOE

2.2 IAEA Safety Standards

The IAEA (2009) [2] establishes the following requirements to be fulfilled in safety assessment and safety analysis focused on the protection of people and the environment from harmful effects of ionizing radiation.

This methodology, presented as requirements in bullet form, could be useful in FRA application because it is similar to a checklist. The safety of radiological effects, however, has many conditions and elements that are not applicable to LNG transportation systems.

2.2.1 Overall Requirements (reproduced from [2])

- *Scope of the safety assessment*. A safety assessment shall be carried out for all applications of technology that give rise to radiation risks; that is, for all types of facilities and activities.
- *Responsibility for the safety assessment*. The responsibility for carrying out the safety assessment shall rest with the responsible legal person; that is, the person or organization responsible for the facility or activity.
- *Purpose of the safety assessment*. The primary purposes of the safety assessment shall be to determine whether an adequate level of safety has been achieved for a facility or activity and whether the basic safety objectives and safety criteria established by the designer, the operating organization and the regulatory body, in compliance with the requirements for protection and safety as established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, have been fulfilled.

2.2.2 Specific Requirements (reproduced from [2])

- *Preparation for the safety assessment.* The first stage of carrying out the safety assessment shall be to ensure that the necessary resources, information, data, analytical tools as well as safety criteria are identified and are available.
- *Assessment of the possible radiation risks.* The possible radiation risks associated with the facility or activity shall be identified and assessed.
- *Assessment of safety functions.* All safety functions associated with a facility or activity shall be specified and assessed.
- *Assessment of site characteristics*. An assessment of the site characteristics relating to the safety of the facility or activity shall be carried out.
- *Assessment of the provisions for radiation protection*. It shall be determined in the safety assessment for a facility or activity whether adequate measures are in place to protect people and the environment from harmful effects of ionizing radiation.
- *Assessment of engineering aspects.* It shall be determined in the safety assessment whether a facility or activity uses, to the extent practicable, structures, systems and components of robust and proven design.
- *Assessment of human factors.* Human interactions with the facility or activity shall be addressed in the safety assessment, and it shall be determined whether the procedures and safety measures that are provided for all normal operational activities, in particular those that are necessary for implementation of the operational limits and conditions, and those that are required in response to anticipated operational occurrences and accidents, ensure an adequate level of safety.
- *Assessment of safety over the lifetime of a facility or activity*. The safety assessment shall cover all the stages in the lifetime of a facility or activity in which there are possible radiation risks.

2.2.3 Defense in Depth and Safety Margins (reproduced from [2])

- *Assessment of defense in depth*. It shall be determined in the assessment of defense in depth whether adequate provisions have been made at each of the levels of defense in depth.

2.2.4 Safety Analysis (reproduced from [2])

- *Scope of the safety analysis.* The performance of a facility or activity in all operational states and, as necessary, in the post-operational phase shall be assessed in the safety analysis.
- *Deterministic and probabilistic approaches*. Both deterministic and probabilistic approaches shall be included in the safety analysis.
- *Criteria for judging safety.* Criteria for judging safety shall be defined for the safety analysis.

- *Uncertainty and sensitivity analysis*. Uncertainty and sensitivity analysis shall be performed and taken into account in the results of the safety analysis and the conclusions drawn from it.
- *Use of computer codes.* Any calculation methods and computer codes used in the safety analysis shall undergo verification and validation.
- *Use of operating experience data.* Data on operational safety performance shall be collected and assessed.

2.2.5 Documentation (reproduced from [2])

- *Documentation of the safety assessment.* The results and findings of the safety assessment shall be documented.

2.2.6 Independent Verification (reproduced from [2])

- *Independent verification.* The operating organization shall carry out an independent verification of the safety assessment before it is used by the operating organization or submitted to the regulatory body.

2.2.7 Management, Use and Maintenance of the Safety Assessment (reproduced from [2])

- *Management of the safety assessment.* The processes by which the safety assessment is produced shall be planned, organized, applied, audited and reviewed.
- *Use of the safety assessment.* The results of the safety assessment shall be used to specify the program for maintenance, surveillance and inspection; to specify the procedures to be put in place for all operational activities significant to safety and for responding to anticipated operational occurrences and accidents; to specify the necessary competences for the staff involved in the facility or activity and to make decisions in an integrated, risk informed approach.
- *Maintenance of the safety assessment.* The safety assessment shall be periodically reviewed and updated.

3. Risk Assessment Guidance from LNG Applications

3.1 International Association of Oil and Gas Producers (OGP)

"Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface," International Association of Oil and Gas Producers, Draft 116901, February 2013. [3]

This technical specification provides a common approach and guidance to those undertaking assessment of the major safety hazards as part of the planning, design, and operation of LNG facilities onshore and at shoreline using risk based methods and standards, to enable the a safe design and operation of LNG facilities. This document illustrates various methodologies for performing risk assessments, specifically for LNG installation, and could be used as a reference for the development of a safety analysis review guide. It covers qualitative and quantitative risk analysis. Various diagrams, plots, and tables are provided to illustrate the methodologies. [3]

3.2 LNG Risk Modeling and Consequence Analysis

Woodward, J.L., Pitblado, R.M., "*LNG Risk Based Safety: Modeling and Consequence Analysis*," John Wiley & Sons, Inc., 2010. [4]

This book reviews current scientific understanding of the predicted behavior of large accidental LNG spills. In this book, the full cycle of possible hazards and consequence mechanisms associated with loss of containment accidents or deliberate breaches is reviewed. Also presented are special hazards such as rapid phase transitions, boiling liquid expanding vapor explosion (BLEVE), and vapor cloud explosions that are only possible under certain special circumstances. The book seeks to review the technologies in use, particularly those relevant to marine transportation and reception terminal where the greater public exposure exists.

Chapter 4, Risk Analysis and Risk Reduction, covers the areas of risk analysis process and hazard identification, frequency, consequence modeling, ignition probability, risk results, terrorism, and risk reduction and mitigation measures for LNG.

Chapter 6, Risk Analysis for Onshore Terminal and Transport, cover topics such as U.S. guidelines and regulations for receiving terminals and LNG land transport risk. From Section 9 of this chapter: The risk in land transport systems is that of highway collisions, tuck rollover, spills upon loading the storage tanks, and storage tank leaks. The scale is smaller, but the event frequency is higher than for LNG import terminals and regasification systems. [4]

3.3 National Petroleum Council

Drube, T., Haukoos, B., Thompson, P., and Williams, G., "National Petroleum Council Future Transportation Fuels Study - An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation" Draft White Paper, May 22, 2012. [5]

As part of the National Petroleum Council's Future Transportation Fuels Study, the Natural Gas Subgroup has examined the potential expanded use of Liquefied Natural Gas (LNG) as an alternative to petroleum fuels. The purpose of this white paper is to supplement the study and discuss the history, risks and mitigating actions relating to deployment of LNG as a transport fuel from a safety perspective.

Assessing LNG safety as a transport fuel requires the identification of hazards and safeguards associated with each stage in the LNG supply chain. Since the public has accepted other fuel supply chains, a relative risk comparison between those and the LNG supply chain can be useful. In all examples provided, the relative assessment is qualitative only. [5]

This reference includes risk tables containing qualitative comparisons of LNG transport fuel with diesel, gasoline, CNG and LPG for a variety of different transportation activities.

3.4 California Energy Commission (CEC)

Phinney, S., "*International and National Efforts to Address the Safety and Security Risks of Importing Liquefied Natural Gas: A Compendium*," CEC-600-2005-002, Aspen Environmental Group, January 2005. [6]

This compendium summarizes the principal safety and security laws, regulations, and practices under which the LNG industry operates worldwide to prevent or respond to LNG-related emergencies. It also reviews information from recently conducted safety and risk assessment studies for LNG shipping and terminal construction projects. [6]

3.5 Risk Assessment Guidance from American Bureau of Shipping (ABS)

Guidance Notes on Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries, American Bureau of Shipping, June 2000. [7]

In its guidance document, the American Bureau of Shipping (ABS) describes risk assessment as covering four basic steps: hazard identification, frequency assessment, consequence assessment, and risk evaluation. The requirements for each of these steps is described in detail and could be used to develop an evaluation methodology for the LNG application, although it is very general in nature and better resources have been found in the survey.

ABS hazard identification methods include: hazard identification technique; what-if analysis, checklist analysis (e.g., evaluation against pre-established criteria); hazard and operability analysis; failure modes and effects analysis (considered best for reviews of mechanical and electrical hardware systems); and human factors analysis. Frequency assessment methods include: analysis of historical data, event tree analysis, fault tree analysis, common cause failure analysis, and human reliability analysis. Consequence assessment methods typically involve the use of analytical models. For LNG, these include dispersion models such as DEGADIS and LNGFIRE. Risk evaluation and presentation techniques include: subjective prioritization (e.g., high, medium, low risk); risk categorization/risk matrix, and risk sensitivity. ABS has identified which methods work best for different aspects of the industry. For example, event-tree analysis is often used for the analysis of vessel movement mishaps and propagation of fires, confined-space explosions, and toxic releases. [7]

3.6 Mexican Risk Assessment Requirements for LNG Terminals

Summarized in Phinney, S., "*International And National Efforts to Address the Safety and Security Risks of Importing Liquefied Natural Gas: A Compendium*," CEC-600-2005-002, Aspen Environmental Group, January 2005. [6]

The Mexican emergency LNG safety standards address risk assessment in depth. The risk assessment process must be performed during the initial design phase of a new LNG terminal and the location of the facilities and design of a new LNG plant must be based on the risk-analysis results. Furthermore, the risk assessment must be repeated when unacceptable risks are identified. Upon completion, a copy of the final analysis must be submitted to Mexican authorities for review. The risk-analysis methodology used for the LNG plant may be probabilistic, deterministic, or both. The risk assessment may be based on conventional methods such as hazard and operability study, failure mode effect and criticality analysis, event-tree analysis, or fault-tree analysis.

The probabilistic approach requires the following steps:

- Collect data regarding failure rates
- Define potential internal and external risks to the LNG plant
- Determine and classify the probability of these risks as one of the following:
  - Frequent
  - Possible
  - Rare
  - Extremely rare
  - Improbable
  - Probability is not quantifiable
- Determine and classify the potential effects of each risk and its location using one of the following types of effects:
  - Catastrophic
  - Serious
  - Significant
  - Reparable
  - Nil
- Classify accidents according to the effects and probability of the same in determining the level of risk involved:
  - Unacceptable
  - Must be improved
  - Normal
- Verify that no risk is classified as unacceptable, and
- Justify those measures necessary to limit risks.

The deterministic approach must follow these steps:

- Define potential internal and external risks to the LNG plant
- Identify credible risks
- Determine and quantify the effects of such risks
- Justify those measures necessary to improve safety and limit risks [6]

3.7 Canadian Risk Assessment Requirements for LNG Terminals

Summarized in Phinney, S., "*International And National Efforts to Address the Safety and Security Risks of Importing Liquefied Natural Gas: A Compendium*," CEC-600-2005-002, Aspen Environmental Group, January 2005. [6]

The Canadian Technical Review Process of Marine Terminal Systems and Transshipment Sites (TERMPOL) code was first published in 1977. It applied to navigational risks associated with the location and operation of marine terminals for large oil tankers. A second edition, published in 1982, was expanded to include, on a voluntary basis, bulk shipments of LNG. TERMPOL was recently updated to cover operational safety aspects of dedicated ships transporting pollutants or hazardous cargoes in bulk. The code states that the selection of appropriate risk assessment models depends on the nature of the project and the characteristics of the marine terminal location. The terminal proponent must analyze any risk or risks relating to uncontrolled releases, either in route to or at a terminal. Typical scenarios include a two-ship collision, ship grounding, a ship striking a fixed object, an improper cargo transfer incident, a fire, and an explosion.

Predictions are to be made on a worst-case, but credible-incident scenario in the terminal area and at selected positions along the coastal route. Perceived risks to populations within coastal zones along the intended route, the terminal berth and surrounding area, and the marine environment should be included.

The risk assessment should include:

- Probabilities of credible incidents which result in the breaching of the ship's cargo containment system
- Risks associated with navigational and operational procedures
- Probabilities of a major cargo transfer incident at the terminal dock
- Geographical boundaries and the resulting consequences of an uncontrolled release of cargo on the marine environment and, when applicable, in the close vicinity of adjacent coastal communities
- Risk of an incident becoming "uncontrollable"

Predictions of vapor clouds must be based on defined, worst-case, credible incidents involving LNG releases from one cargo tank. The quantification and evaluation of vapor clouds is complex and an acceptable approach would be to calculate the risk of fatalities in terms of exposed persons per unit of time. Two dozen measures that could mitigate risks are presented as examples. Sabotage is specifically identified as one situation that could be considered in a terminal-oriented contingency plan. [6]

3.8 United Kingdom (UK) Formal Safety Assessment (FSA)

Report on Safety and Environmental Assessment Methods. Thematic Network for Safety Assessment of Waterborne Transport. Deliverable No. D5.1. http://projects.dnv.com/themes/Deliverables/D5.1Final.pdf [8]

The Formal Safety Assessment (FSA) is the basis of the "Safety Case" regime, by which the UK Health and Safety Executive judges offshore activity. FSA is a structured and systematic methodology for enhancing maritime safety. It was originally developed, in part, as a response to the 1988 Piper Alpha offshore platform explosion. It is now being applied to the International Maritime Organization (IMO) rulemaking process. Interim guidelines were adopted in 1997 and IMO member states are carrying out trials. Steps involved in a FSA include:

- Identification of hazards
- Risk analysis
- Risk control options
- Cost-benefit assessment
- Recommendations for decision-making

Characterization of hazards and risks should be both qualitative and quantitative, and both descriptive and mathematical, consistent with the available data. [8]

3.9 US Coast Guard (USCG) Risk Assessments

United States Coast Guard, Liquefied Natural Gas and Liquefied Petroleum Gas – Views and Practices, Policy and Safety, Commandant Instruction (COMDTINST) M16616.4. [9]

This guide outlines USCG views and policies for transporting LNG and liquefied petroleum gas by water and presents generic spill scenarios. A USCG Captain of the Port applies the risk-management standards from COMDTINST M16616.4 to decide which USCG measures should be deployed at a port to safeguard an LNG facility. Risk mitigation measures reflect the geographic location of terminals relative to population centers. Terminals in urban settings employ more safety measures than terminals in rural settings. Examples of USCG risk mitigation measures are: USCG escort, daylight transit, full or partial transfer monitoring, pre-arrival carrier inspection, USCG sea marshals, tugs for docking, and safety and security zones.

The USCG officially adopted the Risk Based Decision Making (RBDM) program in 2001 and has recently re-emphasized the program to identify the greatest risks and to prioritize efforts that minimize or eliminate them. RBDM consists of five major components: Decision Structure, Risk Assessment, Risk Management, Impact Assessment, and Risk Communication. The USCG used RBDM in its review of the Cove Point LNG facility. (See discussion of the Cove Point risk assessment, below.)

The RBDM process encourages USCG decision makers to ask the following questions:

- What can go wrong?
- How likely are the potential problems to occur?
- How severe might the potential problems be?
- Can the risk of potential problems be tolerated?
- And, what can/should be done to lessen the risk?

Based on its work for Cove Point, the USCG developed a detailed risk-analysis process for determining the suitability of a waterway for LNG transport. The process will be made available for future and existing LNG operations.

The approach follows elements of the Port and Waterways Safety Assessment (PAWSA) process that address risk identification and assessment steps. Example "what if" scenarios included: what if terrorists attempted to board and take control of an LNG carrier; and what if terrorists attempted to damage the LNG carrier from the shore. The goal is to begin risk assessments at as general a level as possible and to do more detailed studies only in areas where the additional risk assessment will help the decision maker. If the stakeholder team determines that a more formal assessment of risks is necessary, RBDM Guidelines provide detailed guidance on the various methods available for performing these assessments. [9]

This reference also includes details of the types of studies done by developers for many of the existing and proposed facilities, the models used to identify risks, and the general conclusions regarding risks.

4. Risk Assessment Guidelines from Related Industries

4.1 Land Transport: Department of Transportation (DOT)

United States Department of Transportation (DOT) Federal Transit Administration, Clean Air Program, "*Design Guidelines for Bus Transit Systems Using Compressed Natural Gas as an Alternative Fuel*", DOT-FTA-MA-26-7021-96-1, DOT-VNTSC-FTA-96-3, June 1996. [10]

The main purpose of this document is to provide guidance, information on safe industry practices, applicable national codes and standards, and reference data, where it is available, that the transit agencies need to review when considering modifications to their existing facilities or when planning new bus facilities to safely use CNG as an alternate fuel.

Hazard Identification: There are four basic methods of hazard identification that may be employed to identify hazards. These methods are:

- Data from previous accidents (case studies) or operating experience
- Scenario development and judgment of knowledgeable individuals
- Generic hazard checklists
- Formal hazard analysis techniques

Every effort should be made to identify and catalog the whole universe of potential hazards. There are several hazard analyses techniques that should be considered to assist in the evaluation of potential hazards and to document their resolution. These techniques include a Preliminary Hazard Analysis (PHA), Subsystem Hazard Analysis (SSHA), System Hazard Analysis (SHA) and Operational and Support Hazard Analysis (O&SHA). These analyses should be conducted in general accordance with MIL-STD-882C, Tasks 202 (PHA), 204 (SSHA), 205 (SHA) and 206 (O&SHA), or equivalent, respectively.

Hazard Assessment: The third step in the hazard resolution process is to assess the identified hazards in terms of the severity or consequence of the hazard and the probability of occurrence of each type of hazard. This should be accomplished in general conformity with the criteria outline in MIL-STD-882C, Paragraphs 4.5 and 4.6 or equivalent. [10]

4.2 Marine Transport: Dangerous Goods Transport in the Baltic Sea Region (DaGoB)

Mullai, A., "*Risk Management System–Risk Assessment Frameworks and Techniques*," DaGoB Publication Series 5.:2006. [11]

In the context of the DaGoB project objectives, the purpose of this report is to provide unified understanding of the field of risk management. Based on the review and study of many risk assessment frameworks and techniques employed in shipping and other industries and sectors, this report explores some of the best practices in the field. The main stages and steps of the risk analysis process are also explored, and are further developed for ready application in risk analysis of the maritime transport system of packaged dangerous goods.

Evaluation criteria for risk management strategy and measure: Due to the wide range of effects, risk management strategies and measures are often difficult to compare and evaluate. The best decision is the one that yields the greatest expected value. For example, the USCG (2001) has designed three general criteria (Table 2) for evaluation of risk management strategies and measures.

Table 2. Evaluation Criteria (USCG 2001) [12]

Criterion	Description
Efficacy	The degree to which the risk will either be eliminated or minimized by the proposed action.
Feasibility	The acceptability of implementing the proposed preventative action (economic, legal, physical, political, social, technical, etc.).
Efficiency	The cost-effectiveness of the proposed action in terms of potential dollars lost if no action is taken versus the cost of the action.

Risk assessment frameworks in shipping: In recent years, facing several challenges and increasing public concern about safety and health, the marine environment and property protection, numerous quantitative and qualitative risk assessment frameworks and techniques have been developed in the shipping industry. Detail is provided on state-of-the-art risk assessment frameworks and related practices in the shipping industry, namely:

- Formal Safety Assessment (FSA)
- Safety Case (SC)
- Quantitative Risk Assessment (QRA)
- Marine Accident Risk Calculation System (MARCS)
- USCG Risk-Based Decision-making (RBDM) Guidelines
- QRA and Risk-Effect Model (REM)
- Risk Assessment Framework for Maritime Safety Management System
- Other frameworks
- Marine accident/risk analysis procedures in the European Union
- Example: marine accident/risk analysis procedures [11]

4.3 Defense: Department of Defense (DOD) Military Safety Programs

United States Department of Defense, "*Military Standard System Safety Program Requirements*," MIL-STD-882C, January 1993. [13]

This standard provides uniform requirements for developing and implementing a system safety program of sufficient comprehensiveness to identify the hazards of a system and to impose design requirements and management controls to prevent mishaps.

The general requirement for a risk assessment is that decisions regarding resolution of identified hazards shall be based on assessment of the risk involved. To aid the achievement of the objectives of system safety, hazards shall be characterized as to hazard severity categories and hazard probability levels, when possible. Since the priority for system safety is eliminating hazards by design, a risk assessment procedure considering only hazard severity will generally suffice during the early design phase to minimize risk. When hazards are not eliminated during the early design phase, a risk assessment procedure based upon the hazard probability, hazard severity, as well as risk impact, shall be used to establish priorities for corrective action and resolution of identified hazards. [13]

5. Recommendation

As is evidenced by the variety of information in the excerpts from various industries, countries, and transport media, safety and risk assessments are not standardized or consistent. However, this lack of consistency is what enables risk analyses to conform to the nature of the system, the industry, and the available resources, all of which vary tremendously. After reviewing the documents, the DOE's Hydrogen Safety Plan Checklist (Section 2.1) is considered the most suitable to be adapted to the LNG rail application.

First, the format of a checklist enables the methodology to be easily applied and is concise in its requirements. Additionally, the Identification of Safety Vulnerabilities section allows the user (evaluator) to document which of the many assessment techniques were utilized as well as providing a list of significant components of the assessment that are important and applicable to the use of a flammable gas in a transportation mode. This assures a comprehensive analysis of the scenarios, vulnerabilities, hazards, material interactions, and storage and distribution issues of the complete system.

Beyond the traditional risk assessment contents, the checklist includes issues like Operating Procedures and Equipment Maintenance which will be important considerations for the rail system. This will cue the industry organizations preparing the assessments to consider the safety of the entire system, all operating states and all support equipment, which will have bearing on the safety of the LNG systems. The checklist goes further to include documentation, employee training, and emergency response.

This checklist also requires the least amount of editing to convert to a tool that can be used in the LNG rail application, due to the similarities between the two applications. In short, because of its comprehensive, concise and efficient handling of assessing safety risks, this checklist is recommended for FRA's use in evaluating safety assessments.

6. FRA Safety Assessment Evaluation Checklist

6.1 LNG Safety Analysis Evaluation Checklist for FRA

The DOE Safety Planning Guidance checklist (Section 2.1) was adapted to the dual-fuel diesel and LNG locomotive tenders being used in the railroad industry. The full checklist is shown in Table 3. Guidance for applying the checklist is contained in Section 6.2. A comprehensive safety analysis must include documentation of each element in Table 3.

Table 3. LNG Safety Assessment Checklist for FRA

Element	Description
Safety Assessment Description	• Purpose of the safety assessment • Boundary conditions and assumptions • The methodology applied to this project • Safety assessment team and reviewers • Safety plan review and approval process
System and Scope of Work	• Define system and components, their functions, and relationships • Describe site and facility characteristics • Nature of the work being performed
Information and Data Sources	• Previous LNG experience • Organizational policies and procedures • Operating policies and procedures • Safety policies and procedures
Identification of Safety Vulnerabilities (ISV)	• Hazards and consequences associated with storage, handling, and use of LNG • Risk and accident scenarios identified • Significant vulnerabilities identified • Safety critical equipment identified
Risk Management Plan	• Prevention and mitigation measures for significant vulnerabilities
Use of the Safety Assessment Results	• Process for implementing the results of the safety assessment • Equipment and mechanical Integrity • Employee training • Self-audits
Safety Events and Lessons Learned	• The reporting procedure within the organization and to the FRA • The system and procedure used to investigate events • How corrective measures will be implemented • How lessons learned from incidents and near-misses are documented and disseminated
Emergency Response	• The plan or procedures for responses to emergencies • Communication and interaction with local emergency response officials

Element	Description
Management of the Safety Assessment	• Process for periodic review and updating • Process for verifying continued implementation of safety recommendation throughout life of the system • Management of change procedures
Other Comments or Concerns	• Any information on topics not covered above • Issues that may require assistance from FRA

6.2 Checklist Guidance

The checklist is intended to be user-friendly and provide guidance at a high-level. A safety plan may have multiple sections under a single element heading to fully address the element. This section provides guidance for how to evaluate each element.

6.2.1 Safety Assessment Description

The safety assessment description section includes critical introductory elements defining the analysis framework. It should discuss the purpose of the safety assessment, the methodology used, the team conducting the analysis, and the reviewers evaluating the analysis.

This section should contain the methodology applied to the project. The methodology must be described in sufficient detail to permit verification or replication by other teams. Candidate methodologies include, but are not limited to, FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree or Probabilistic Risk Assessment methods. If a standard methodology is used, references to that methodology can be provided in lieu of detailed methodology description. The process of conducting the assessment should be included in the safety plan. This includes documentation that the methodology meets the requirements of the standard or other methodological documentation cited by the team conducting the analysis. Most importantly, this section should include documentation of assumptions and boundary conditions used in the analysis, as well as any topics or systems excluded from the analysis.

The team members and their qualifications should be documented in this section. Teams must contain at least three members, and generally should not exceed eight members. The team must be led by a safety analyst with experience in the methodology used. The team should contain at least one representative familiar with the design of the system and one familiar with the operation of the system. The safety plan should have a formal review and approval process, including peer review or another validation process.

6.2.2 System and Scope of Work

The system, facility, and operational environments must be described in sufficient detail to enable independent review of the assessment. This description should be as-built and as-operated. If the system is still at the design stages, the assessment should be reviewed and modified once the system is built.

This section should capture and define the system, and components, their functions, and their relationships and interfaces. Block diagrams or other figures may be included to facilitate efficient understanding of the boundaries of the system, components of the system, and functions of each component in each operational environment.

The scope of work must capture and define the work activities. If multiple operational environments are contained in one analysis, the work activities must be defined for each operational environment.

6.2.3 Information and Data Sources

This section should contain discussion of the data and information used to inform the analysis. Different safety assessment methodologies require different types of information and data. Selection of sources should be guided by the methodology implemented.

If any other safety reviews have been performed, they should be reviewed and discussed in the safety assessment.

In general, the required information and data includes organizational experience with the LNG technology, events in related industries or applications, organizational policies and procedures, data and statistics. If the organization has previous experience with LNG-related technology, this section should contain details about their experience with reference to safety. The safety assessment should document the key organizational policies and procedures that govern the storage, use, and handling of LNG. Operational procedures should be in place to protect workers, the system, the facility, and the equipment. The safety assessment should also document other policies and administrative controls applicable to the performance of the work. This may include policies that address access controls and any required training.

This section may include, but is not limited to assessment methodology documentation, references such as handbooks and standards, and safety review reports. A few standards that should be reviewed for applicability are listed below:

- National Fire Protection Association 59A: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG) and other local fire codes
- American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code
- ASME B 31.3 Process Piping
- ASME B 31.5 Refrigeration Piping
- ASME B 31.8 Gas Transmission and Distribution Piping Systems
- American Petroleum Institute (API) 625, Tank Systems for refrigerated Liquefied Gas Storage

6.2.4 Identification of Safety Vulnerabilities (ISV)

The chosen methodology should be used to identify hazards associated with handling and storing LNG, potentially significant risk scenarios and accident scenarios, significant vulnerabilities, and safety critical equipment.

6.2.4.1 Risk and Accident Scenarios

Scenarios leading to the release and ignition of LNG should be identified. These scenarios should be diverse enough to encompass a variety of possible failures, events and accidents that could lead to harm. Once scenarios have been identified, the methodology should be used to prioritize and identify the dominant scenarios. Depending on the methodology, this could occur through ranking risk (e.g., based on likelihood and consequence of failure events), or through comparison to a criteria defined in the method.

6.2.4.2 Significant Vulnerabilities

During the course of the safety analysis, particular situations, scenarios, or elements of the system operation will present more significant risks, from a consequence standpoint, than others. Even though these vulnerabilities may have a very low occurrence, the severity of the consequences is such that these must be considered in the safety plan and addressed.

6.2.4.3 Safety Critical Equipment

Safety critical equipment should be identified based on the criteria established in the methodology. Once identified, these may be used as part of the risk reduction plan section to show preventative and mitigation measures for vulnerabilities. Possible safety critical components include:

- Cryogenic electronic controller
- Accumulator, including the gas buffer tank
- Pressure or other sensors
- Pressure relief valves
- Shutoff valves

6.2.4.4 Storage and Handling Hazards of LNG

This section should include general hazards of LNG and hazards specific to this application of LNG. All components related to storage, delivery, and use of natural gas should be included in the analysis. The following hazards should be analyzed: cryogenic hazards, chemical hazards, LNG handling hazards and flammability hazards. The Idaho National Engineering Laboratory [14] provides detailed descriptions of LNG hazards as well as detailed case history narratives of LNG transportation incidents that illustrate how LNG properties and behavior contribute to the hazards of a system. Table 4 lists general hazards to be cognizant of during the evaluation of the safety plan.

Table 4. LNG Cryogenic, Chemical, Handling and Flammability Hazards

Cryogenic Hazards	Pressure increases of a trapped volume of LNG (between two valves in a pipe) as the heat transfer from the surrounding causes boiling of the LNG. If the temperature of an LNG system is not maintained, the system can become entirely high pressure vapor. For this reason, cryogenic systems have relief valves in all sections of the system with an enclosed volume.
	Odorants typically used in natural gas (ethyl mercaptan) is not suitable for cryogenic fluids such as LNG because the odorant compound freezes and is not carried with the gas.
	Contact with cryogenic liquid can cause burns.
	Breathing cold vapors can damage lung tissue by freezing the alveoli cells causing water crystals to pierce cell membranes.
	LNG contact with materials such as metals that undergo a ductile to brittle transition can cause cracking in the material due to contraction and embrittlement.
Chemical Hazards	Although natural gas is non-toxic, the rapid evaporation of LNG can cause oxygen in the immediate area to be displaced, resulting in untenable asphyxiating conditions. When the gas is at temperatures where it is heavier than air, it can pool in lower elevations within a facility such as maintenance pits and basements.
	The expansion ratio of LNG is 600 to 1, meaning a given volume of LNG liquid occupies a volume 600 times the size when it is a vapor at ambient temperature and pressure. This leads to obvious over pressurization hazards if not vented.
LNG Handling Hazards	Weathering of LNG occurs when the methane component of natural gas evaporates out of the mixture at greater rates than other compounds due to its lower vapor pressure. The ullage space in an LNG storage tank therefore is composed mainly of methane. Over time, the concentration of ethane in the remaining LNG will increase. This becomes a hazard because the energy content of ethane is higher than methane and the energy required to initiate a detonation is lowered.
	Rollover occurs when new LNG is added to a large tank and the composition of the LNG differs from the LNG already in the tank. The mixing in the tank due to density differences can cause a large rapid release of vapor within the tank which may challenge its venting capacity.
	Geysering and bumping occurs when localized heat transfer occurs along pipe pathways that penetrate into deep LNG storage tanks. These phenomena can also cause rapid generation of vapor within the tank that can overload the venting capacity leading to over pressurization of the tank. However, these phenomena typically occur in very large storage tanks, much larger than the LNG locomotive tender system.
	Static electricity is a hazard associated with the transfer of fluids without grounding. Electrical charge potential builds up due to friction of the flowing fluid and its discharge can lead to ignition of flammable concentrations of vapor.

Flammability Hazards	Pure methane has flammability limits of 5-15% (volume or mole) in air, but as LNG is composed of multiple light-ends including noncombustible nitrogen, its actual flammable range can vary somewhat from the range quoted for pure methane. The flammability limits are somewhat dependent on the initial temperature of the mixture. When the vapor is very cold, the flammability limits are narrower than at room temperature. The ignition likelihood is also affected by the ignition energy.

	An LNG spill on land or on water would result in a rapidly evaporating pool that produces a vapor cloud driven by the wind. If any point of a vapor cloud (with dimension defined to flammable concentrations) reaches an ignition source and ignites, a flash fire would burn downwind and possibly also upwind from the ignition point. A flash fire will burn faster along the premixed (diluted by air) edges.
	The energy necessary to ignite a deflagration is only about 0.3mJ (2.8 x 10^{-7}BTU) for methane. Such energy is easily available from a match, an open flame, or a spark. A detonation of the mixture consisting of $CH_4 + 2O_2 + xN_2$ can be initiated by 1g (0.002lb) of the high explosive Tetryl at x = 2, but 1000g (2.2lb) of Tetryl is required at x = 6. With extrapolation for a mixture of methane and air (x = 7.4), 22kg (49lb) of Tetryl, equivalent to 300MJ (2.8 x 10^5BTU), would be necessary to initiate a detonation. Ethane/air will detonate with about 50g (0.1lb) of Tetryl, propane/air with 90g (0.2lb) and butane/air with about 100g (0.22lb).
	A flash fire is inherently transient, and exposure normally lasts no more than a few tens of seconds. While fatal to people inside the fire, the total radiation reaching an object near a flash fire is substantially lower than that from a longer-lasting pool or jet fire the same distance away. A flash fire does not likely produce secondary ignition or burns to people outside of the flaming region.
	An outdoor vapor cloud explodes only under conditions of partial confinement or in congested regions, which refer to regions with a high density of obstacles such as piping, pumps, and other such equipment. A deflagration explosion from an outdoor spill of LNG is a low probability event. Detonation explosions are virtually ruled out by the low reactivity of natural gas.
	Explosions occur with noticeable frequency from a buildup of nature gas vapors indoors or inside any enclosed space. Commonly, such explosions result from leaking natural gas lines in a building.
	Boiling liquid expanding vapor explosions are not likely for LNG because LNG storage and transport tanks are well insulated from the external atmosphere.

6.2.5 Risk Management Plan

Once all the significant vulnerabilities are identified in the ISV portion of the safety report, prevention and mitigation measures for these vulnerabilities should be identified. For example, a discussion on safety critical equipment or an explanation as to why the vulnerability is unlikely may be included. All vulnerabilities should have a corresponding prevention or mitigation measure. These prevention and mitigation measures may include: design changes, administrative controls, physical barriers or additional testing.

6.2.6 Use of the Safety Assessment Results

The safety assessment documentation should also contain discussion of how the results will be implemented. Self-audits are intended for organizations to assess the effectiveness of their risk management and safety processes. As part of the safety plan, a procedure should be developed to conduct self-audits at a regular frequency and address corrective actions, as needed.

6.2.6.1 Equipment and Mechanical Integrity

The safety plan should include a strategy for ensuring equipment and mechanical integrity. The following should be documented:

- Initial testing and commissioning
- Preventative maintenance procedures
- Calibration of sensors

- Test and inspection frequencies

This is especially important for safety critical equipment. All testing, calibration, maintenance and inspections should be performed to industry or manufacturer standards.

6.2.6.2 Employee Training

The safety plan should include how applicable safety information is communicated and made available to all employees. The safety plan should include both general safety training and LNG-specific training courses. These courses may be internal courses or external courses, in a classroom or online. The safety plan should include a brief description of each course and the frequency at which employees have to take the courses. Finally, a brief description of the organization's plan to manage training and ensure compliance should be included.

6.2.6.3 Self-Audits

Self-audits are intended for organizations to assess the effectiveness of their risk management and safety processes. As part of the safety plan, a procedure should be developed to conduct self-audits at a regular frequency and address corrective actions, as needed.

6.2.7 Safety Events and Lessons Learned

If a safety event was to occur, a documented reporting procedure should be used to inform the organization and the FRA of the event. This reporting procedure, the procedure used to investigate the event and the procedure to manage corrective actions should be included as part of the safety plan. The objective of reporting all safety events is to generate lessons learned and near-misses that can be documented and disseminated to prevent similar events throughout the industry.

6.2.8 Emergency Response

An emergency plan must be created and included as part of the safety plan. The emergency plan should analyze difference emergency scenarios and provide procedures to address them as needed. This may include but is not limited to:

- Fires
- Harm resulting from exposure to LNG
- Natural disasters, such as earthquakes or tornados

Since an LNG-fueled locomotive will be novel, a plan should be developed to communicate the hazard to local emergency responders. The locomotive will be traversing through multiple jurisdictions, all of which should be made aware of the hazard and its inherent dangers.

6.2.9 Management of the Safety Assessment

The assessment should discuss the process for verifying the implementation of safety recommendations throughout life of the system. A process for periodic review and updates should be established to ensure the safety assessment is relevant to the as-built, as-operated system. This includes discussion of a process for management of change. In every system, issues arise and materials, technology, equipment, procedures, personnel or facility operations need to be updated or changed. These changes need to be reviewed to determine if they have any effect on the safety vulnerabilities. This system, including documented procedures, should be included in the safety plan.

6.2.10 Other Comments or Concerns

The safety plan may include any additional information deemed pertinent to LNG or LNG-fueled locomotive safety.

7. References

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Abbreviations and Acronyms

ABS	American Bureau of Shipping
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BLEVE	Boiling Liquid Expanding Vapor Explosion
CEC	California Energy Commission
CNG	Compressed Natural Gas
COMDTINST	Commandant Instruction
DaGoB	Dangerous Goods Transport in the Baltic Sea Region
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
FMEA	Failure Modes and Effects Analysis
FRA	Federal Railroad Administration
FSA	Formal Safety Assessment
FTA	Federal Transit Administration
HAZOP	Hazard and Operability Analysis
IAEA	International Atomic Energy Agency
IMO	International Maritime Organization
ISV	Identification of Safety Vulnerabilities
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MARCS	Marine Accident Risk Calculation System
MIL-STD	Military Standard
O&SHA	Operational and Support Hazard Analysis
OGP	Oil and Gas Producers
PAWSA	Port and Waterways Safety Assessment
PHA	Preliminary Hazard Analysis
PRA	Probability Risk Assessment
QRA	Quantitative Risk Assessment
RBDM	Risk Based Decision Making

REM	Risk-Effect Model
SC	Safety Case
SHA	System Hazard Analysis
SSHA	Subsystem Hazard Analysis
TERMPOL	Technical Review Process of Marine Terminal Systems and Transshipment Sites [Canada]
THEMES	THEMES was a Thematic Network (TN) funded by the European Commission under the 5th Framework Programme for Research, Technological Development and Demonstration. The overall goal of THEMES was to improve industrial safety and environmental protection in shipping through support to and development of a pro-active safety culture.
UK	United Kingdom
US	United States
USCG	United States Coast Guard