

A Guide To Quantitative Risk Assessment for Offshore Installations

Principal Author

John Spouge

DNV Technica

Disclaimer

Every reasonable effort has been made to ensure that this Guide is based on the best knowledge available up to the time of finalising the text. However, no responsibility of any kind for any injury, delay, loss or damage, whatsoever, resulting from the use of the Guide can be accepted by CMPT, the sponsors or others involved in its publication.

Publication 99/100a

© CMPT 1999

ISBN I 870553 365

FOREWORD

The need for guidance on risk assessment was identified as an industry requirement as a result of regulations, initially promulgated in the UK and Norway, requiring quantitative risk assessments of new and existing installations as part of their safety case. At that time, no standard reference works existed, most expertise was held by individual operators and consultants and little reached the public domain.

The project leading to this Guide was initiated by MTD Ltd, and is now published by The Centre for Marine and Petroleum Technology (CMPT), in order to assist engineers involved in commissioning, performing and evaluating risk assessments specifically for the offshore industry.

The Guide was prepared under contract by Mr J R Spouge of DNV Technica (now part of Det Norske Veritas) as the primary contractor, with significant input from AEA Technology and Dovre Safetec. It was sponsored by 8 organisations (four oil operators and four regulatory bodies) and was managed for MTD, and latterly CMPT, by Mr R W Barrett.

Project Sponsors

Amoco (U.K.) Exploration Company
Chevron UK Ltd
Exxon Production Research Company
The Health and Safety Executive
Minerals Management Service (USA)
Mobil Technology Company
National Energy Board (Canada)
Norwegian Petroleum Directorate

Steering Group

A Steering Group comprising representatives of participants, MTD Ltd and CMPT, and the Technical Services Contractors provided the forum for both verbal and written discussion of the content of the Guide during its preparation. During the period of the project, the following individuals served on the Steering Group which was chaired by Mr W D Howells (Chevron UK Ltd) and Mr R W Barrett:

T Al-Hassan	Health and Safety Executive
RW Barrett	Centre for Marine and Petroleum Technology
DJ Bridge	Health and Safety Executive
FM Davies	Marine Technology Support Unit
K Gulati	Mobil Technology Company
S Harding	Exxon Production Research Company
WD Howells	Chevron UK Ltd
KL Nilsson	Norwegian Petroleum Directorate
ME Rodgers	Exxon Production Research Company
RJ Smith	National Energy Board (Canada)
JK Smith	Amoco (U.K.) Exploration Company
CE Smith	Minerals Management Service (USA)
JR Spouge	DNV Technica
A Wang	Exxon Production Research Company

Technical Services Contractors

The preparation of this Guide was undertaken by the following organisations and the individuals who worked on its various elements are listed below:

AEA Technology	KG Kinsella CG Morgan
DNV Technica	DJ Bridge JR Spouge EJ Smith
Dovre Safetec Ltd	S Haugen L Paterson F Vollen
Electrowatt Engineering Services UK Ltd	S Hall AJ Skudder
Four Elements Ltd	S Harris B Morgan

Acknowledgement

A further acknowledgement is due to the Health and Safety Executive's Offshore Safety Division who made additional contributions to the project. In particular we wish to acknowledge the input made by S Schofield, I Brearley, and T Norman during the latter stages of the project.

The principal author, JR Spouge, also wishes to acknowledge present and former colleagues, too numerous to list individually, whose assistance has been drawn upon extensively during the preparation of the Guide.

CONTENTS

PART I

1.	INTRODUCTION TO THE GUIDE	1
1.1	General Introduction to Offshore QRA	1
1.2	Objectives of the Guide	1
1.3	Structure of the Guide.....	1
1.4	Nature of the Guidance.....	3
1.5	Referencing.....	3
1.6	Definition of Terms	3
2.	A GENERAL OUTLINE OF QRA	3
2.1	Hazards, Risks and Safety	3
2.2	What is QRA?.....	5
2.3	The Key Components of QRA	6
2.4	QRA as Part of Risk Management.....	7
2.5	What is QRA Used For?.....	8
2.6	How to Set the Scope of a QRA	9
2.7	QRA in the Life of an Installation	10
2.8	Existing Guidance on Offshore QRA.....	11
2.9	Which Calculation Environment to Use	11
2.10	Strengths and Limitations of QRA	12
3.	HISTORY OF OFFSHORE QRA	15
3.1	Concept Safety Evaluations.....	15
3.2	Total Risk Analyses.....	15
3.3	Developments in the UK Sector	15
3.4	Mobile Platforms	16
3.5	Effects of <i>Piper Alpha</i>	16
3.6	Safety Cases.....	16
3.7	Risk Management	16
4.	REGULATORY REQUIREMENTS FOR OFFSHORE QRA.....	18
4.1	The United Kingdom.....	18
4.2	Norway	19
4.3	USA	21
4.4	Canada	21
4.5	Australia	22
4.6	Denmark	22
4.7	Netherlands.....	23
4.8	Indonesia.....	23
4.9	Malaysia.....	23
4.10	Brunei	23
4.11	Nigeria	23
4.12	Brazil	23
4.13	Venezuela	23
4.14	Trinidad & Tobago	23
4.15	China.....	24
5.	TYPES OF OFFSHORE QRA STUDIES.....	25
5.1	Fatality Risk Assessment.....	25
5.2	Concept Safety Evaluation	25
5.3	Total Risk Assessment.....	26
5.4	Lifetime Risk Assessment	27
5.5	Cullen Forthwith Studies	27
5.6	Fire and Explosion Analysis.....	27
5.7	Evacuation, Escape and Rescue Analysis.....	28
5.8	QRAs of Mobile Platforms.....	28

5.9	Other Offshore Risk Studies	29
6.	HAZARD ASSESSMENT	30
6.1	Definitions	30
6.2	The Importance Of Hazard Identification.....	30
6.3	Techniques For Hazard Identification	30
6.4	Hazard Review	31
6.5	Hazard Checklists	34
6.6	Hazard and Operability Study (HAZOP)	36
6.7	Procedural HAZOP.....	38
6.8	What-If Analysis.....	39
6.9	HAZID.....	40
6.10	Failure Modes, Effects and Criticality Analysis (FMECA).....	42
6.11	Emergency Systems Survivability Analysis	43
6.12	Safety Inspections and Audits	44
7.	FAILURE CASE SELECTION	45
7.1	Outline	45
7.2	Definitions	45
7.3	Requirements for Hazard Identification in QRA	45
7.4	How to Identify Hazards for a QRA.....	46
7.5	How to Distinguish Failure Cases from Accident Scenarios.....	47
7.6	How to Select Failure Cases	49
7.7	How to Select Leak Sizes	49
7.8	How to Rank and Screen Hazards	53
7.9	How to Define Accident Scenarios.....	53
8.	FREQUENCY ANALYSIS	57
8.1	Definitions	57
8.2	Approaches to Frequency Analysis	58
8.3	Sources of Historical Frequency Data	58
8.4	Calculation of Frequencies	59
8.5	Analysis of Historical Accident Data	61
8.6	Measures of Exposure	64
8.7	Effect of Human Factors and Safety Management on Accident Frequencies	65
8.8	Strengths and Weaknesses of Historical Accident Frequencies	66
8.9	Judgemental Frequency Estimation.....	67
8.10	Bayesian Analysis.....	68
9.	RELIABILITY ANALYSIS.....	71
9.1	Outline	71
9.2	Reliability Concepts.....	71
9.3	Techniques of Reliability Analysis.....	73
9.4	Fault Tree Analysis.....	73
9.5	Event Tree Analysis.....	77
9.6	Reliability Simulation	79
9.7	Sources of Reliability Data.....	80
9.8	Human Reliability Analysis.....	80
10.	CONSEQUENCE MODELLING FOR HYDROCARBON EVENTS	83
10.1	Definitions	83
10.2	Types of Hydrocarbons	83
10.3	Consequence Modelling Software.....	83
10.4	Discharge and Dispersion Modelling	85
10.5	Types of Outcome from Hydrocarbon Events.....	86
10.6	Fire Modelling	87
10.7	Explosion Modelling	90
10.8	Escalation of Hydrocarbon Events	91
10.9	Strengths and Weaknesses of Hydrocarbon Consequence Modelling.....	93
11.	IMPACT OF HYDROCARBON EVENTS.....	94

11.1	General Approach.....	94
11.2	Human Impact Criteria	94
11.3	Failure Criteria.....	96
11.4	Safety Function Impairment Criteria	97
11.5	Strengths and Weaknesses of Impact Criteria	99
12.	EVACUATION MODELLING.....	100
12.1	General Approach.....	100
12.2	Definitions	100
12.3	Evacuation Sequence.....	100
12.4	Mustering.....	101
12.5	The Evacuation Decision.....	101
12.6	Evacuation by Helicopter	101
12.7	Evacuation by Lifeboat.....	102
12.8	Escape to the Sea	103
12.9	Alternative Evacuation Methods	104
12.10	Including the QRA in Emergency Planning	104
12.11	Strengths and Weaknesses of Evacuation Modelling.....	104
13.	SUMMARY OF HYDROCARBON EVENT MODELLING.....	105
13.1	Procedure for Hydrocarbon Event Modelling	105
13.2	Fatality Estimates.....	105
13.3	Damage Estimates	107
13.4	Strengths and Weaknesses of Hydrocarbon Event Modelling.....	107
14.	BLOWOUTS.....	109
14.1	Definitions	109
14.2	Hazard Review	109
14.3	The Need for QRA of Blowouts.....	109
14.4	Data Sources	109
14.5	Causes of Blowouts	110
14.6	Blowout Frequencies	110
14.7	Blowout Scenarios.....	111
14.8	Blowout Consequences.....	112
14.9	Blowout Impacts.....	112
14.10	Strengths and Weaknesses of Blowout QRA	113
15.	RISER/PIPELINE LEAKS	114
15.1	Definitions	114
15.2	Hazard Review	114
15.3	Data Sources	114
15.4	Riser/Pipeline Leak Frequencies	114
15.5	Riser/Pipeline Leak Scenarios	115
15.6	Riser/Pipeline Leak Consequences.....	116
15.7	Effects of SSIVs	116
15.8	Riser/Pipeline Leak Impacts	116
15.9	Strengths and Weaknesses of Riser/Pipeline QRA.....	116
16.	PROCESS LEAKS.....	118
16.1	Definitions	118
16.2	Hazard Review	118
16.3	Data Sources	118
16.4	General Approach.....	118
16.5	Historical Process Fire Experience.....	119
16.6	Historical Process Leak Experience	119
16.7	Generic Process Equipment Leak Frequencies.....	119
16.8	Process Leak Development.....	120
16.9	Ignition of Process Leaks	120
16.10	Process Leak Consequences	121
16.11	Process Fire Impacts.....	121
16.12	Risk Reduction Measures	121

16.13	Strengths and Weaknesses of Process QRA	121
17.	COLLISIONS	122
17.1	Definitions	122
17.2	Hazard Review	122
17.3	Types of Colliding Vessel	122
17.4	Visiting Vessel Collisions.....	122
17.5	Passing Merchant Vessel Collisions	123
17.6	Fishing Vessel Collisions	123
17.7	Naval Vessel Collisions	123
17.8	Offshore Tanker Collisions	124
17.9	Collisions Between Fixed and Floating Platforms.....	124
17.10	Collision Consequences.....	124
17.11	Collision Impacts.....	124
17.12	Strengths and Weaknesses of Collision QRA.....	124
18.	STRUCTURAL AND MARINE EVENTS	126
18.1	Definitions	126
18.2	Hazard Review	126
18.3	Structural Reliability Analysis.....	126
18.4	Structural Failure of Steel Jacket Platforms	127
18.5	Structural Failure of Concrete Platforms	127
18.6	Structural Failure of Jack-Ups	128
18.7	Earthquakes	128
18.8	Structural Failure of Semi-Submersibles	128
18.9	Ballast System Failures.....	128
18.10	Structural Failure of Tankers	129
18.11	Fires/Explosions on Tankers.....	129
18.12	Dropped Objects	129
18.13	Bridge Failures	129
18.14	Oil Spills in Offshore Loading and Storage	130
18.15	Construction Failures.....	130
19.	NON-PROCESS FIRES.....	131
19.1	Definitions	131
19.2	Hazard Review	131
19.3	Fire Frequencies	131
19.4	Fatality Risks	131
20.	TRANSPORT ACCIDENTS	132
20.1	Hazard Review	132
20.2	Data Sources	132
20.3	Risk Measures Used	132
20.4	Helicopter Crash Risks	133
20.5	Helicopter Impact Risks	133
20.6	Crew Boat Accident Risks.....	133
21.	PERSONAL ACCIDENTS.....	134
21.1	Definitions	134
21.2	Data Sources	134
21.3	Risk Measures Used	134
21.4	UK Data.....	135
21.5	Other Data	135
21.6	Theoretical Methods	135
22.	FORMS OF RISK PRESENTATION	136
22.1	Risk Measures for Loss of Life	136
22.2	Individual Risks	136
22.3	Group Risks	138
22.4	Other Risk Measures	139
22.5	Calculation Methods.....	140

22.6	Time Period Analysed	144
22.7	Formats for Risk Presentation	144
23.	RISK RESULTS	146
23.1	Results for Individual Installations	146
23.2	Results for Hypothetical Platform	146
23.3	Results for Generic Platforms	149
23.4	Results for UK Sector Overall	152
24.	UNCERTAINTIES	156
24.1	The Importance of Uncertainty	156
24.2	Definitions	156
24.3	Presentation of Uncertainties	157
24.4	Worst Cases and Best-Estimates	158
24.5	The Level of Uncertainty in QRAs	159
24.6	Approaches to Uncertainty Analysis	159
24.7	Sources of Uncertainty	160
24.8	Quantification of Uncertainties	161
24.9	Uses of Uncertainty Analysis	165
25.	RISK CRITERIA	167
25.1	QRA in Decision-Making	167
25.2	Definitions	168
25.3	Frameworks for Risk Criteria	168
25.4	Individual Risk Criteria	169
25.5	Group Risk Criteria	172
25.6	Impairment Frequency Criteria	174
25.7	Damage Risk Criteria	176
25.8	Cost-Benefit Analysis	176
26.	RISK REDUCTION MEASURES	185
26.1	How to Use QRA to Identify Risk Reduction Measures	185
26.2	How to Use QRA to Model Risk Reduction Measures	185
26.3	Analysis of Concept Selection Options	185
26.4	Analysis of Fire and Blast Protection Measures	186
26.5	Analysis of Evacuation Measures	188
26.6	Analysis of Collision Risk Reduction Measures	188
27.	SIMULTANEOUS OPERATIONS	190
27.1	Definition	190
27.2	The Need for Simultaneous Operations	190
27.3	Accident Experience	190
27.4	Legislation	190
27.5	Hazards of SD&P	191
27.6	QRA of SD&P	191
27.7	Comparison of SD&P with Sequential Operations	192
27.8	Safety Measures for SD&P Operations	192
27.9	Safety Management for SD&P	193
28.	SAFETY MANAGEMENT	194
28.1	The Importance of Safety Management	194
28.2	Elements of a Safety Management System	194
28.3	The Effect of Safety Management on Risks	194
28.4	Including Safety Management in a QRA	195
28.5	Including the QRA in Safety Management	195
28.6	Performance Standards	195
29.	QUALITY MANAGEMENT OF A QRA	197
29.1	The Need for Quality Management in QRA	197
29.2	Key Issues in Quality Management of QRAs	197
29.3	How to Check a QRA	199

29.4 How to Evaluate the Quality of a QRA	200
GLOSSARY	202
ABBREVIATIONS	208
REFERENCES	210

PART II

APPENDIX I	AN OUTLINE OF OFFSHORE ACTIVITIES
APPENDIX II	SOURCES OF OFFSHORE ACCIDENT DATA
APPENDIX III	ACCIDENT DESCRIPTIONS
APPENDIX IV	HYDROCARBON EVENT CONSEQUENCE MODELLING
APPENDIX V	IMPACT CRITERIA
APPENDIX VI	EVACUATION, ESCAPE AND RESCUE
APPENDIX VII	RISK ANALYSIS OF BLOWOUTS
APPENDIX VIII	RISK ANALYSIS OF RISER/PIPELINE LEAKS
APPENDIX IX	RISK ANALYSIS OF PROCESS LEAKS
APPENDIX X	RISK ANALYSIS OF COLLISIONS
APPENDIX XI	RISK ANALYSIS OF STRUCTURAL AND MARINE EVENTS
APPENDIX XII	RISK ANALYSIS OF NON-PROCESS FIRES
APPENDIX XIII	RISK ANALYSIS OF TRANSPORT ACCIDENTS
APPENDIX XIV	RISK ANALYSIS OF PERSONAL ACCIDENTS
APPENDIX XV	SAFETY MANAGEMENT SYSTEMS
APPENDIX XVI	DIRECTORY OF SOFTWARE FOR OFFSHORE QRA

1. INTRODUCTION TO THE GUIDE

1.1 General Introduction to Offshore QRA

Offshore production of oil and gas involves some of the most ambitious engineering projects of the modern world, and is a prime source of revenue for many companies and countries. It also involves risks of major accidents, which have been demonstrated by disasters such as the explosion and fire on the UK production platform *Piper Alpha*, the capsizes of the Norwegian accommodation platform *Alexander Kielland* and the Canadian semi-submersible drilling rig *Ocean Ranger*, and the sinking of the Norwegian gravity base structure *Sleipner A*.

Major accidents represent the ultimate, most disastrous way in which an offshore engineering project can go wrong. Accidents cause death, suffering, pollution of the environment and disruption of business. Being so dramatic, they attract attention from the news media and linger in the public memory, causing concern about safety offshore. Are offshore platforms safe enough? Can major accidents be prevented? How should the offshore industry achieve an appropriate balance between the interests of safety and the economics of oil and gas production?

Quantitative risk assessment (QRA) is a technique that can be used to help achieve this balance. In the UK and Norway, the use of risk assessment is a legislative requirement for all new and existing installations, and several other countries are implementing similar regulations. As a result, QRA is now being used world-wide by designers, operators, and consultants in the offshore industry.

QRA is a relatively new technique. It cuts across traditional divisions of engineers such as civil, mechanical, chemical, aeronautical - it applies to all of them and belongs to none. Most of the textbooks on it relate to the fields of chemical and nuclear engineering, and there are no standard reference works on how to perform an offshore risk assessment. Most information and expertise is held by individual operators and consultants, and very little has reached the public domain. The UK and Norwegian regulations state what is required from a risk assessment, but do not say exactly how to do it.

As a result, the pool of expertise in risk assessment is very small. Many workers in the field are only recently acquainted with it. Few have experience in more than one or two applications. Risk assessment remains to a large extent a do-it-yourself activity.

In order to fill this gap, the Centre for Marine and Petroleum Technology (CMPT) has organised a multi-sponsor project to prepare a guide to offshore QRA. The sponsors include offshore operators and regulatory authorities in the UK, Norway, USA and Canada. DNV Technica has been the main contractor for the work.

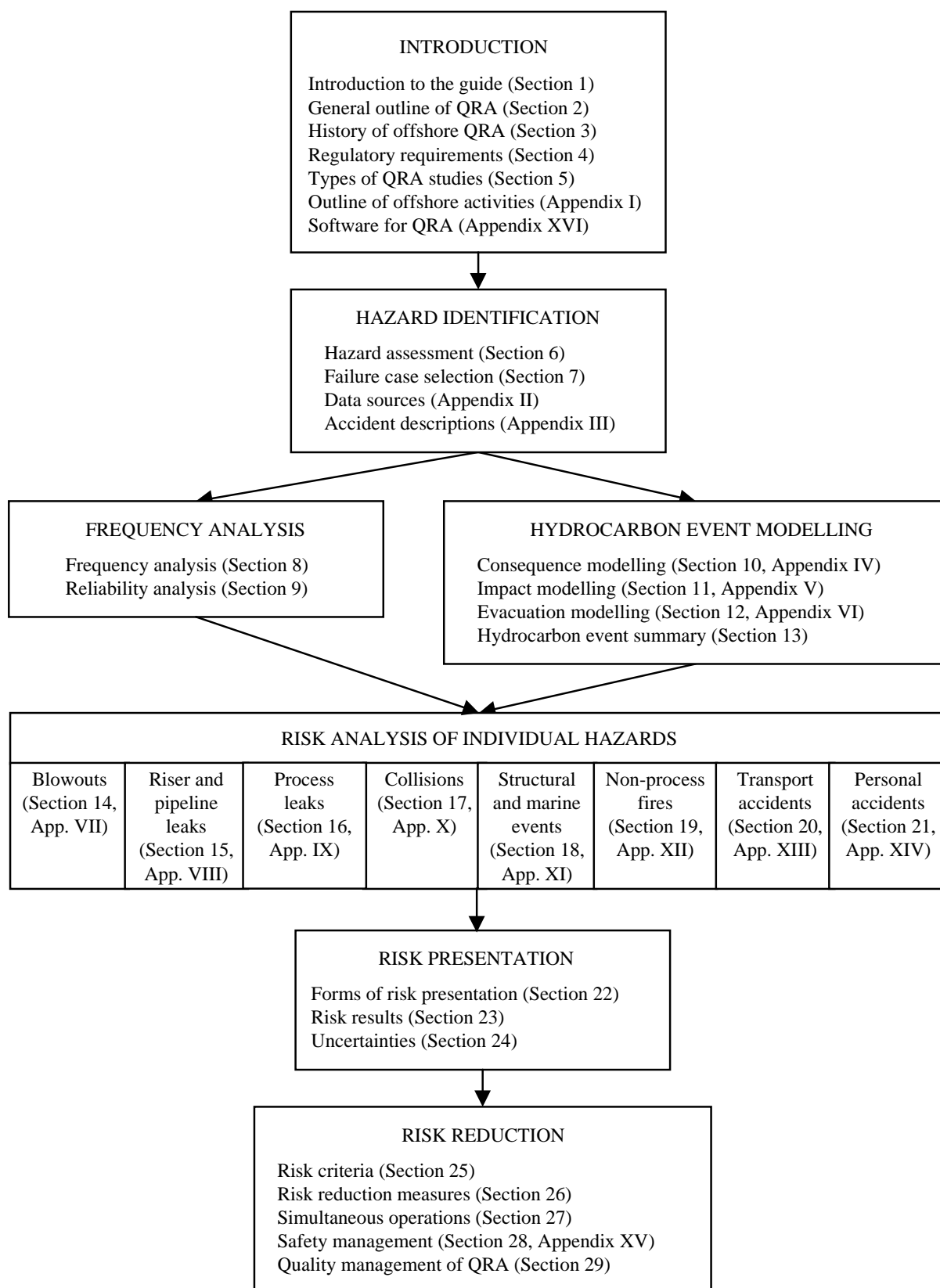
1.2 Objectives of the Guide

The intention of the guide is to provide an introduction to QRA specifically for the offshore industry. It aims to introduce all the major aspects of the subject and to describe good modern practice in offshore QRA. It includes a selection of data and relatively simple analytical techniques that may be used in performing QRAs, and gives references to more sophisticated databases and computational methods. It also presents some example risk results. It is intended to serve partly as a training manual and partly as a reference book, and should be useful for engineers involved in commissioning, performing and evaluating risk assessments.

1.3 Structure of the Guide

Figure 1.1 illustrates the arrangement of material in the guide.

Figure 1.1 Structure Of The Guide



Part I of the guide describes the subject as a whole and gives general guidance and example results. It follows the broad structure of a QRA study, divided into the following main areas:

1. Background material (Sections 1-5)
2. Hazard identification (Sections 6-7)
3. Frequency analysis (Sections 8-9)
4. General modelling of hydrocarbon releases (Sections 10-13)
5. Risk analysis of individual hazards (Sections 14-21)
6. Presentation of risks (Sections 22-24)
7. Risk reduction (Sections 25-29)

Part II of the guide includes 16 appendices containing more detailed information that may be useful when conducting an offshore QRA:

- Appendix I gives an introduction to offshore activities suitable for analysts with no prior knowledge of the industry.
- Appendix II outlines the main sources of data on offshore risks.
- Appendix III describes a selection of major offshore accidents.
- Appendices IV, V and VI give details on hydrocarbon release modelling issues covered in Sections 10-13 of Part I.
- Appendices VII to XIV give data on the individual hazards covered in Sections 14-21 of Part I.
- Appendix XV gives a more detailed discussion of safety management systems, which is summarised in Section 28 of Part I.
- Appendix XVI consists of a directory of computer software currently available for offshore QRA.

The information in Part II is necessarily only a small sample, and should if possible be supplemented with more relevant or more up-to-date data.

1.4 Nature of the Guidance

The guide does not attempt to specify a single approach to QRA. As far as possible, it presents a range of approaches from which readers can choose the ones appropriate to their study. Where specific guidance is given, it represents a view on reasonable approaches to QRA, balancing the need for accuracy against the need for economy, or else a judgement of what is typically done. The guidance should not be considered as mandatory, or as recommended by DNV Technica except where stated.

1.5 Referencing

References are given at the end of Part I and at the end of each Appendix.

As far as possible, this guide is based on public-domain sources, and all the references are either openly published or are expected to be published in the near future. In a few cases it references documents that are confidential but widely circulated within the offshore industry.

In many cases there are no public-domain sources for the data needed in a QRA, and therefore Part II of the guide draws extensively on sources that are confidential and cannot be acknowledged in full.

1.6 Definition of Terms

Terms such as ‘hazard’, ‘risk’ and ‘risk assessment’ have been given many different meanings. The definitions which are used in this guide are based on an authoritative multi-disciplinary review by the Royal Society (1983 and 1992), as extended for the chemical process industry (I.Chem.E 1992) and for quality assurance and reliability by ISO (1986) and its national implementations (e.g. BSI 1991). There is by no means universal agreement on the definitions given, but these are reasonably well used and are becoming standard by virtue of being adopted by the above sources.

Definitions of terms used are given at appropriate points in the guide. Definitions of the most commonly used terms and abbreviations are provided in a glossary at the end of Part I.