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Jan-Erik Vinnem

Offshore Risk Assessment vol 2

Principles, Modelling and Applications
of QRA Studies

Third Edition

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Preface to 3rd Edition

This is the third edition of the book; the first edition was published in 1999 and the second edition in 2007. The author has since then returned to an adjunct professorship at University of Stavanger, Norway, teaching a course in applied offshore risk assessment. Starting from January 2013, the author is also adjunct professor at NTNU, Trondheim in marine operational risk. The author has been involved in several significant research projects during the last few years. Several major accidents worldwide have had considerable effect on the HES performance and awareness, not the least the Macondo accident in 2010. This prompted a need for a further update of the book.

Norwegian offshore regulations were profoundly revised around the beginning of the new century, with new regulation becoming law from 2002. A limited revision was implemented from 2011, mainly limited to the integration of onshore petroleum facilities. This edition of the book captures some of the experience and challenges from the application of the new regulations. The important aspects of the new regulations are also briefly discussed, see [Chap. 1](#).

About 30 major accidents and incidents are discussed at some length in [Chaps. 4](#) and [5](#) (Macondo accident), in order to demonstrate what problems have been experienced in the past. I have increased the emphasis on this subject in both the second and third editions, because it is essential that also new generations may learn from what occurred in the past. Where available, observations about barrier performance are discussed in addition to the sequence of events and lessons learned.

It is often claimed “what is measured will be focused upon”. This implies that even if QRA studies have several weaknesses and limitations, quantification is the best way to focus the attention in major hazard risk management. This is also one of the lessons from the Macondo accident, in the author’s view. It has therefore been surprising to realise how strong the opposition to QRA studies still is at the end of 2012 from many professionals in major international oil companies. This has to some extent given further inspiration to update this book, about a topic I consider crucial for improvement of major hazard risk management in the offshore petroleum industry.

Thanks are expressed to Springer London publishers, in particular Senior Editor Anthony Doyle and his staff, for agreeing to publish the third edition of this book,

and for providing inspiring and valuable advice and assistance throughout the process.

Appendix A presents an overview of some of the important software tools that are commonly used in offshore risk assessment. Thanks to all the consultancies and software suppliers who have provided the information required for the update of this appendix.

There are also several people who have kindly contributed with relevant information on various aspects; Torleif Husebø, PSA; Prof. Stein Haugen, NTNU; Celma Regina Hellebust, Hellebust International Consultants, Prof. Bernt Aadnøy, UiS and Dr. Haibo Chen, Scandpower Inc. China. Many thanks for valuable assistance to all of you.

Meihua Fang has been my assistant during the final stages of the revision work, during her stay in Norway as the wife of a student at UiS in an international M.Sc. program in offshore risk management. Meihua has a M.Sc. degree in safety technology and engineering from China University of Geosciences in Beijing and HES management experience from SINOPEC in China and Latin America, and has been an ideal assistant. The main task has been the updating of Appendix A, in addition to several other editorial tasks, which has been very helpful to finish the revision work in a timely manner. I am very grateful for the excellent assistance provided by Meihua.

Last, but not least, I am very grateful to those companies that responded positively when asked for a modest support in order to cover the expenses involved in the production of this third revision. My warmest and most sincere thanks go to these companies:

- Faroe Petroleum Norway
- Norwegian oil and gas association
- Total E&P Norway
- VNG Norway

Bryne, May 2013

Jan-Erik Vinnem
Adjunct Professor
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Preface to 2nd Edition

This is the second edition of the book; the first edition was published in 1999. The author has since then taken up a full professorship at University of Stavanger, Norway, teaching courses in offshore risk analysis and management. This prompted a need for an update of the book. The fact that several important developments have occurred since 1999 also implied that a major revision was required.

The oil price has reached its peak in 2006, at the highest level ever (nominally). But the economic climate is at the same time such that every effort is made to scrutinise how costs may be curtailed and profit maximised. This will in many circumstances call for careful consideration of risks, not just an 'off the shelf risk analysis', but a carefully planned and broad-ranging assessment of options and possibilities to reduce risk.

Norwegian offshore regulations were profoundly revised around the beginning of the new century, with new regulation becoming law from 2002. This second edition of the book captures some of the experience and challenges from the first 4-5 years of application of the new regulations. The important aspects of the new regulations are also briefly discussed, see Chapter 1.

The first Norwegian White Paper on HES management in the offshore industry was published in 2001, and the second in 2006. One of the needs identified in this paper was the need to perform more extensive R&D work in this field, and a significant programme has been running in the period 2002–2006. Some of the new results included in the second edition of the book result from that R&D initiative.

About 20 major accidents, mainly from the North Sea, are discussed at some length in Chapter 4, in order to demonstrate what problems have been experienced in the past. I have put more emphasis on this subject in the second edition, because it is essential that also new generations may learn from what occurred in the past. Where available, observations about barrier performance are discussed in addition to the sequence of events and lessons learned.

When it comes to management of risk and decision-making based upon results from risk analyses, this is discussed separately in a book published in parallel with my colleague at University of Stavanger, Professor Terje Aven, also published by

Springer in 2007. Interested readers are referred to this work, 'Risk Management, with Applications from the Offshore Petroleum Industry'.

Thanks are also expressed to Springer London publishers, in particular Professor Pham and Senior Editor Anthony Doyle, for agreeing to publish the second edition of this book, and for providing inspiring and valuable advice throughout the process. Simon Rees has given valuable assistance and support during production of the camera-ready manuscript.

Appendix A presents an overview of some of the important software tools that are commonly used. Thanks to all the consultancies and software suppliers who have provided the information required for this appendix.

In preparing the second edition of the book, I have been fortunate to have kind assistance from many colleagues and friends, who have provided invaluable support and assistance. First of all I want to express sincere thanks and gratitude to my friend David R Bayly, Crandon Consultants, who has also this time assisted with improvement of the English language, as well as providing technical comments and suggestions. I do not know how I could have reached the same result without David's kind assistance.

My colleague at UiS, Professor Terje Aven has contributed significantly to the discussion of statistical treatment of risk and uncertainty. I am very pleased that this important improvement has been made. Dr Haibo Chen, Scandpower Risk Management Beijing Inc has contributed valuable text regarding the analysis of DP systems on mobile installations.

Safetec Nordic AS has allowed use of several of their tools as input to the descriptions and cases. I want to express my gratitude for allowing this, and in particular express thanks to the following; Thomas Eriksen, Stein Haugen and Arnstein Skogset.

There are also several people who have contributed with relevant information on various technical details; Finn Wickstrøm, Aker Kvaerner and Graham Dalzell, TBS³. My daughter, Margrete, has assisted in the editing of the manuscript. Many thanks to all of you.

Bryne, January 2007

Professor Jan Erik Vinnem
University of Stavanger

Preface to 1st Edition

From a modest start in Norway as a research tool in the late 1970s, Quantified Risk Assessment (QRA) for offshore installations has become a key issue in the management of Safety, Health and Environment in the oil and gas industries throughout the entire North Sea. While the initiatives in the early stages often came from the authorities, the use is now mainly driven by the industry itself. The QRA is seen as a vehicle to gain extended flexibility with respect to achievement of an acceptable safety standard in offshore operations. The models may be weak in some areas and the knowledge is sometimes limited, but studies are nevertheless used effectively in the search for concept improvement and optimisation of design and operation.

This book results from working with offshore QRAs for more than 20 years. The author has, during this period, had the opportunity to practice and evaluate the use of such studies from different perspectives; the consultancy's, the operating company's, the researcher's and the educator's point of view.

The author has for several years taught a course in risk analysis of marine structures at the Faculty of Marine Technology, NTNU, Trondheim, Norway. The starting point for the manuscript was the need to update the lecture notes.

It is hoped that this book in the future also may be a useful reference source for a wider audience. There has been for some years a rapid expansion of the use of risk assessments for the offshore oil and gas activities. It is expected that the expansion is going to continue for some time, as the offshore petroleum industry expands into new regions and meets new challenges in old regions.

The oil price reached its lowest level for many years, during the first quarter of 1999. One might be tempted to think that the economic climate may prohibit further attention to risk assessment and safety improvement. The opposite is probably more correct. As a friend in Statoil expressed not so long ago: 'Whenever the margins are getting tighter, the need for risk assessments increases, as new and more optimised solutions are sought, each needing an assessment of risk'.

In Norway, the beginning of 1999 is also the time when the Norwegian Petroleum Directorate is preparing a major revision of the regulations for offshore installations and operations, anticipated to come into effect in 2001. It has obviously not been possible to capture the final requirements of the new regulations,

but an attempt has been made to capture the new trends in the regulations, to the extent they are known.

There have over the last 10-15 years been published a few textbooks on risk assessment, most of them are devoted to relatively generic topics. Some are also focused on the risk management aspects, in general and with offshore applicability. None are known to address the needs and topics of the use of QRA studies by the offshore industry in particular. The present work is trying to bridge this gap.

The use of QRA studies is somewhat special in Northern Europe, and particularly in Norway. The use of these techniques is dominated by offshore applications, with the main emphasis on quantification of risk to personnel. Furthermore, the risk to personnel is virtually never concerned with exposure of the public to hazards. Thus, the studies are rarely challenged from a methodology point of view. Most people will probably see this as an advantage, but it also has some drawbacks. Such challenges may namely also lead to improvements in the methodology. It may not be quite coincidental that the interest in modelling improvement and development sometimes has been rather low between the risk analysts working with North Sea applications.

This book attempts to describe the state of the art with respect to modelling in QRA studies for offshore installations and operations. It also identifies some of the weaknesses and areas where further development should be made. I hope that further improvement may be inspired through these descriptions.

About the Contents

A Quantified Risk Assessment of an offshore installation has the following main steps:

1. Hazard identification
2. Cause and probability analysis
3. Accidental scenarios analysis
4. Consequence, damage and impairment analysis
5. Escape, evacuation and rescue analysis
6. Fatality risk assessment
7. Analysis of risk reducing measures

This book is structured in much the same way. There is at least one chapter (sometimes more) devoted to each of the different steps, in mainly the same order as mentioned above. Quite a few additional chapters are included in the text, on risk analysis methodology, analytical approaches for escalation, escape, evacuation and rescue analysis of safety and emergency systems, as well as risk control.

It is important to learn from past experience, particularly from previous accidents. A dozen major accidents, mainly from the North Sea, are discussed at the end of Chapter 4, in order to demonstrate what problems that have been experienced in the past.

The main hazards to offshore structures are fire, explosion, collision and falling objects. These hazards and the analysis of them are discussed in separate chapters. Risk mitigation and control are discussed in two chapters, followed by an outline of an alternative approach to risk modelling, specially focused on risk relating to short duration activities. Applications to shipping are finally discussed, mainly relating to production and storage tankers, but also with a view to applications to shipping in general.

Acknowledgements

Parts of the material used in developing these chapters were initially prepared for a course conducted for PETRAD (Program for Petroleum Management and Administration), Stavanger, Norway. Many thanks to PETRAD for allowing the material to be used in other contexts.

Some of the studies that have formed the main input to the statistical overview sections were financed by Statoil, Norsk Hydro, Saga Petroleum, Elf Petroleum Norge and the Norwegian Petroleum Directorate. The author is grateful that these companies have allowed these studies to be made publically available.

Direct financial support was received from Faculty of Marine Technology, NTNU, this is gratefully acknowledged. My part time position as Professor at Faculty of Marine Technology, NTNU, has also given the opportunity to devote time to prepare lecture notes and illustrations over several years. The consultancy work in Preventor AS has nevertheless financed the majority of the work, including the external services.

Thanks are also expressed to Kluwer Academic Publishers, Dordrecht, The Netherlands, for agreeing to publish this book, and for providing inspiring and valuable advice throughout the process.

Appendix A presents an overview of some of the important software tools that are commonly used. Thanks to all the consultancies and software suppliers who have provided the information required for this appendix. Appendix B is a direct copy of the normative text in the NORSOK Guideline for Risk and Emergency Preparedness analysis, reproduced with kind permission from the NORSOK secretariat.

Some of the consultancies have kindly given permission to use some of their material, their kind assistance is hereby being gratefully acknowledged. DNV shall be thanked for allowing their database Worldwide Offshore Accident Databank (WOAD) to be used free of charge, as input to the statistics in the book. The Fire Research Laboratory at SINTEF has given kind permission to use illustrations from their fire on sea research, and Scandpower has granted permission to use an illustration of the risk assessment methodology. Safetec Nordic has given kind permission to use results and illustrations from their software Collide.

I am particularly indebted to several persons who have offered very valuable help in turning this into a final manuscript. My colleague Dr. David Bayly,

Crandon Consultants, has reviewed the raw manuscript and contributed with many valuable comments of both a technical and linguistic nature. The importance of providing clear and concise text can never be overestimated, the efforts made in this regard are therefore of utmost importance. This unique contribution has combined extensive linguistic improvements with pointed comments and additional thoughts on the technical subjects. I am very grateful to you, David, for your extensive efforts directed at improvement of the raw manuscript.

My oldest son, John Erling, has helped me with several of the case studies that are used in the text, plus quite a few of the illustrations. My part time secretary, Mrs Annbjørg Krogedal, has had to devote a lot effort to decipher a challenging handwriting, thank you for enthusiasm and patience. Assistance with the proof reading has been provided by Ms Kjersti G. Petersen, thanks also to Kjersti for enthusiastic and valuable assistance. Finally, M.Sc. Haibo Chen has also helped with the proof reading and checking of consistency in the text, your kind assistance is gratefully acknowledged.

Bryne, May 1999

Jan Erik Vinnem

Contents

Part I Background and Risk Assessment Process

1	Introduction	3
1.1	About QRA	3
1.2	QRA in Relation to Other Analysis Methods	5
1.3	Objectives	6
1.4	Relevant Regulations and Standards	7
1.5	Norwegian Regulations	8
1.5.1	Framework Regulations	8
1.5.2	HES Management Regulations	9
1.5.3	Facilities Regulations	12
1.5.4	Activities Regulations	13
1.5.5	NMD Risk Analysis Regulations	13
1.6	UK Regulations	14
1.6.1	Safety Case Regulations	14
1.6.2	PFEER Regulations	15
1.6.3	Management and Administration Regulations	16
1.6.4	Design and Construction Regulations	16
1.7	National and International Standards	16
1.8	Activity Levels	17
1.9	Limitations	17
1.9.1	Risk Management	18
1.9.2	Emergency Response	18
1.9.3	Subsea Production	19
1.9.4	Production Regularity	19
1.9.5	Resilience	19
1.9.6	High Reliability Organisations	20
1.9.7	STAMP	20
1.9.8	Inherently Safe	21
	References	21

- 2 Risk Picture: Definitions and Characteristics 23**
 - 2.1 Definition of Risk 23
 - 2.1.1 Risk Elements 23
 - 2.1.2 Basic Expressions of Risk 25
 - 2.1.3 Dimensions of Risk 26
 - 2.1.4 Fatality Risk 27
 - 2.1.5 Frequency of Impairment 35
 - 2.1.6 Environment Risk 36
 - 2.1.7 Asset Risk 37
 - 2.2 Risk Picture, North Sea 38
 - 2.2.1 Overview of Fatal Accidents 38
 - 2.2.2 Overview of Accidents to Personnel 39
 - 2.2.3 Fatal Accident Rates 41
 - 2.2.4 Trends in Fatality Rates 41
 - 2.2.5 Comparison Offshore: Onshore Activity 44
 - 2.3 Risk Presentation 45
 - 2.3.1 Fatality Risk 46
 - 2.3.2 Group Risk 52
 - 2.3.3 Impairment Risk 55
 - 2.3.4 Risk to Environment 55
 - 2.3.5 Asset Risk 56
 - 2.3.6 Load Distribution Functions 58
 - 2.4 Uncertainties 59
 - 2.4.1 Basis for Uncertainty Consideration 59
 - 2.4.2 Influence of Uncertainty 60
 - 2.4.3 Calculation Based on Observations 61
 - 2.5 Basic Risk Modelling Concepts 63
 - 2.5.1 Defence in Depth 64
 - 2.5.2 Barriers 65
 - 2.5.3 Root Causes 67
 - 2.5.4 Risk Influencing Factors 68
 - References 68

- 3 Risk Assessment Process and Main Elements 71**
 - 3.1 Selection of Risk Assessment Approach 71
 - 3.2 Quantitative or Qualitative Risk Assessment? 71
 - 3.3 Risk Assessment Approach 73
 - 3.4 Establishing the Context 74
 - 3.5 Hazard Identification 75
 - 3.6 Risk Analysis 76
 - 3.7 Risk Evaluation 77
 - 3.8 Risk Treatment 78

3.9	Monitoring and Review	78
3.10	Communication and Consultation	79
3.11	Who Are These Requirements Applicable For?	79
3.12	Ethics in Risk Assessment	80
3.12.1	Case Study	80
3.12.2	Overview of Risk Studies and Risk-Informed Decision-Making	82
3.12.3	Choice Between Alternative Locations	82
3.12.4	Risk Analysis in Tolerability Evaluations	83
3.12.5	Risk Communication with the Public	84
3.12.6	Use of Risk Analysis in the Design Process	85
3.12.7	Cause of Deficiencies	87
3.12.8	Main Ethical Challenges	88
3.13	Misuse of Risk Analysis	89
3.14	Risk Reduction Priorities	90
3.15	Norwegian and UK Approaches Suitable as Models?	91
	References	92
4	Lessons from Major Accidents	95
4.1	Overview	95
4.2	Ekofisk B Blowout	97
4.2.1	Event Sequence	97
4.2.2	Barrier Performance	98
4.2.3	Lessons Learned for Design	99
4.2.4	Lessons Learned for Operation	99
4.3	Ixtoc Blowout	99
4.3.1	Event Sequence	99
4.3.2	Barrier Performance	101
4.3.3	Lessons Learned	102
4.4	Enchova Blowout	102
4.4.1	Event Sequence	102
4.4.2	Barrier Performance	102
4.4.3	Lessons Learned for Design	103
4.4.4	Lessons Learned for Operation	103
4.5	West Vanguard Gas Blowout	103
4.5.1	Event Sequence	103
4.5.2	Barrier Performance	105
4.5.3	Lessons Learned for Design	105
4.5.4	Lessons Learned for Operation	105
4.6	Ocean Odyssey Burning Blowout	106
4.6.1	Event Sequence	106
4.6.2	Barrier Performance	107
4.6.3	Lessons Learned for Design	108
4.6.4	Lessons Learned for Operation	108

- 4.7 Treasure Saga 2/4–14 Underground Blowout 108
 - 4.7.1 Event Sequence 109
 - 4.7.2 Barrier Performance 110
 - 4.7.3 Lessons Learned for Well Operations 110
- 4.8 Temsah Burning Blowout 111
- 4.9 Snorre Alpha Subsea Gas Blowout 111
 - 4.9.1 Event Sequence 111
 - 4.9.2 Barrier Performance 113
 - 4.9.3 Lessons Learned for Well Operations 114
- 4.10 Usumacinta Blowout 115
 - 4.10.1 Event Sequence 115
 - 4.10.2 Barrier Performance 116
 - 4.10.3 Lessons Learned for Design 117
 - 4.10.4 Lessons Learned for Operation 117
- 4.11 Montara Blowout 118
 - 4.11.1 Event Sequence 118
 - 4.11.2 Barrier Performance 119
 - 4.11.3 Lessons Learned for Well Drilling 120
- 4.12 Gullfaks C Well Incident 120
 - 4.12.1 Event Sequence 121
 - 4.12.2 Barrier Performance 121
 - 4.12.3 Lessons Learned for Well Operations 122
- 4.13 Frade Underground Blowout 122
 - 4.13.1 Event Sequence 123
 - 4.13.2 Barrier Performance 123
 - 4.13.3 Lessons Learned for Well Operations 124
- 4.14 Brent A Explosion 124
 - 4.14.1 Event Sequence 125
 - 4.14.2 Barrier Performance 125
 - 4.14.3 Lessons Learned for Design 126
 - 4.14.4 Lessons Learned for Operation 126
- 4.15 Piper A Explosion and Fire 127
 - 4.15.1 Event Sequence 127
 - 4.15.2 Barrier Performance 127
 - 4.15.3 Lessons Learned for Design 129
 - 4.15.4 Lessons Learned for Operation 129
- 4.16 Ekofisk A Riser Rupture 130
 - 4.16.1 Event Sequence 130
 - 4.16.2 Barrier Performance 131
 - 4.16.3 Lessons Learned for Design 131
 - 4.16.4 Lessons Learned for Operation 132
- 4.17 Jotun Pipeline Rupture 132
 - 4.17.1 Event Sequence 132
 - 4.17.2 Barrier Performance 133

4.17.3	Lessons Learned for Design	134
4.17.4	Lessons Learned for Operation	134
4.18	Mumbai High North Riser Rupture	134
4.18.1	Event Sequence	134
4.18.2	Barrier Performance	135
4.18.3	Lessons Learned for Design	136
4.18.4	Lessons Learned for Operation	136
4.19	Deep Sea Driller Capsize	137
4.19.1	Event Sequence	137
4.19.2	Barrier Performance	137
4.19.3	Lessons Learned for Design	138
4.19.4	Lessons Learned for Operation	139
4.20	Alexander L. Kielland Capsize	139
4.20.1	Event Sequence	139
4.20.2	Barrier Performance	140
4.20.3	Lessons Learned for Design	140
4.20.4	Lessons Learned for Operation	141
4.21	Ocean Ranger Capsize	141
4.21.1	Event Sequence	141
4.21.2	Barrier Failures	142
4.21.3	Lessons Learned for Design	142
4.21.4	Lessons Learned for Operation	142
4.22	Glomar Java Sea Capsize	143
4.22.1	Event Sequence	143
4.22.2	Barrier Failures	144
4.22.3	Lessons Learned for Design	144
4.22.4	Lessons Learned for Operation	144
4.23	Seacrest Capsize	145
4.23.1	Event Sequence	145
4.24	West Gamma Capsize	145
4.24.1	Event Sequence	145
4.24.2	Barrier Performance	146
4.24.3	Lessons Learned for Design	147
4.24.4	Lessons Learned for Operation	147
4.25	Norne Shuttle Tanker Collision	147
4.25.1	Event Sequence	147
4.25.2	Barrier Performance	148
4.25.3	Lessons Learned for Design	149
4.25.4	Lessons Learned for Operation	149
4.26	P-36 Capsize	149
4.26.1	Event Sequence	149
4.26.2	Barrier Performance	151
4.26.3	Lessons Learned for Design	152
4.26.4	Lessons Learned for Operation	152

- 4.27 P-34 Listing 152
 - 4.27.1 Event Sequence 152
- 4.28 Ocean Vanguard Anchor Line Failure 153
 - 4.28.1 Event Sequence 153
 - 4.28.2 Barrier Performance 154
 - 4.28.3 Lessons Learned for Design 155
 - 4.28.4 Lessons Learned for Operation 155
- 4.29 Gryphon Alpha FPSO Multiple Anchor Line Failure 156
 - 4.29.1 Event Sequence 156
 - 4.29.2 Barrier Performance 157
 - 4.29.3 Lessons Learned for Design 157
 - 4.29.4 Lessons Learned for Operation 158
- 4.30 Exxon Valdez Oil Spill 159
 - 4.30.1 Event Sequence 159
 - 4.30.2 Barrier Failures 160
- 4.31 Summary of Barrier Performance 161
- References 162

- 5 Lessons from Macondo Accident 165**
 - 5.1 The Deepwater Horizon and Macondo Well 165
 - 5.2 Organisations Involved 167
 - 5.3 Sequence of Events 168
 - 5.4 Investigations 169
 - 5.4.1 Technical Aspects 170
 - 5.4.2 Organisational Aspects 171
 - 5.5 Findings 173
 - 5.6 Lessons Learned 174
 - 5.6.1 Lessons Learned for Risk Management
in Association with Well Drilling 174
 - 5.6.2 Lessons Learned for Emergency Management 175
 - 5.7 Similarity Between Offshore and Nuclear Accidents 177
 - References 177

Part II Analysis of Main Offshore Hazards

- 6 The Occurrence of Hydrocarbon Leaks: Process Systems 181**
 - 6.1 Statistical Sources 181
 - 6.2 Statistics from the UK Sector 181
 - 6.2.1 Classification of Releases 181
 - 6.2.2 Statistical Overview 182
 - 6.3 Statistics from the Norwegian Sector 184
 - 6.3.1 Classification of Releases 184
 - 6.3.2 Statistical Overview 185

- 6.3.3 Comparison of Installation Types 186
- 6.3.4 Installations with the Highest Leak Frequency
per Installation Years 187
- 6.3.5 Installations with the Highest Leak Frequency
per Number of Leak Sources 188
- 6.3.6 Installations with the Highest Leak Frequency
per Number of Operations 188
- 6.3.7 Installations with Highest Leak Frequency
with Combined Parameters 189
- 6.3.8 Comparison of Different Normalizations 190
- 6.4 Comparison of the UK and Norwegian Sectors 191
 - 6.4.1 Comparison of Unignited Leaks 191
 - 6.4.2 Detailed Comparison 192
 - 6.4.3 Comparison of Ignited Leaks 194
- 6.5 Comparison on a Worldwide Basis 195
- 6.6 Analysis of the Circumstances and Causes of HC Leaks 198
 - 6.6.1 MTO Perspective on Leaks 198
 - 6.6.2 Work Process Modelling 199
 - 6.6.3 Initiating Events Which May Cause Leaks 200
 - 6.6.4 Initiating Event Categories 202
 - 6.6.5 Activity Types Involved in Leaks 202
 - 6.6.6 Time When Leaks Occur 204
 - 6.6.7 Work Process Phases and Shift Distribution 205
 - 6.6.8 Design Weaknesses and Technical Degradation 206
 - 6.6.9 Major Hazard Risk Potential 207
- 6.7 HC Leaks Due to Technical Degradation 209
 - 6.7.1 Age of Installation with Degradation Failure 209
- 6.8 HC Leaks Due to Human Intervention 210
 - 6.8.1 Overview of Work Flow Phases 210
 - 6.8.2 Classification of Leaks During Work
Process Phases 210
 - 6.8.3 Personnel Groups Involved in Leaks 211
 - 6.8.4 Planning 211
 - 6.8.5 Isolation 212
 - 6.8.6 Execution of Intervention 214
 - 6.8.7 Reinstatement 214
 - 6.8.8 Phase when Leaks Occur 214
- 6.9 Causal Factors 214
 - 6.9.1 Risk Influencing Factors (RIFs)
from Investigations 215
 - 6.9.2 Management and Supervision 218
 - 6.9.3 Lack of Compliance with Steering
Documentation 219
- 6.10 HC Leaks Due to Design Errors 220

6.11	HC Leaks Due to External Impact	220
6.12	DNV Leak Frequency Model	220
6.12.1	Model Overview	220
6.12.2	Challenges with the Model	222
	References	222
7	Fire Risk Modelling	225
7.1	Overview	225
7.1.1	Cases with Opposite Results	225
7.1.2	Types of Fire Loads	226
7.1.3	Structural Fire Impact	226
7.1.4	Fire and Explosion Loads on People	227
7.2	Topside Fire Consequence Analysis	228
7.2.1	Mechanisms of Fire	228
7.2.2	Fire Balls	231
7.2.3	Gas Fires	231
7.2.4	Air Consumption in Fire	232
7.2.5	Choice of Calculation Models	232
7.2.6	Analysis of Topside Fire Events	233
7.2.7	Fire Simulations	233
7.3	Fire on Sea	235
7.3.1	Delayed Ignition of an Instantaneous Release	236
7.3.2	Ignition Probability of an Instantaneous Release	237
7.3.3	What Determines the Likelihood of Fire on Sea?	237
7.3.4	Loads from Sea Level Fire	240
7.4	Analysis of Smoke Effects	243
7.4.1	Methods for Prediction of Smoke Behaviour	243
7.4.2	Smoke Flow and Dispersion	245
7.5	Structural Response to Fire	246
7.5.1	Manual Methods	246
7.5.2	Uninsulated Steel	246
7.5.3	Insulated Steel	247
7.6	Risk Reducing Measures	250
7.6.1	Overview	250
7.6.2	Recent R&D Experience	251
7.7	Dimensioning of Structural Fire Protection	251
7.7.1	Case Illustration	251
7.7.2	Dimensioning Fire	252
7.7.3	Fire Duration Distribution	253
7.7.4	Definition of Dimensioning Fire	255
7.7.5	USFOS [®] Modelling	255
7.7.6	QRA Modelling	257
7.7.7	QRA Results	260
7.7.8	Observations	261

7.8	Blast and Fire Design Guidance	261
	References	262
8	Explosion Risk Modelling	263
8.1	Overview	263
8.1.1	Introduction	263
8.1.2	Explosion Loads on Structure	263
8.1.3	Explosion Loads on People	264
8.2	Explosion Frequency	264
8.2.1	Event Tree Analysis	264
8.2.2	Historical Frequencies	264
8.3	Explosion Consequence Analysis	269
8.3.1	Types of Explosion Loads	269
8.3.2	Gas Explosion	270
8.3.3	Blast Wave	271
8.3.4	Pressure	272
8.3.5	Formation of Explosive Cloud	273
8.3.6	Deflagration	275
8.3.7	Confined/Semi-confined Explosion	277
8.3.8	Calculation of Explosion Loads	278
8.3.9	Explosion Design of Facilities	279
8.4	Probabilistic Approach to Explosion Load Assessment	280
8.4.1	Basis	280
8.4.2	Approach to Probabilistic Evaluation	280
8.4.3	Probabilistic Evaluation	282
8.4.4	Example	287
8.4.5	Use of Load Function	287
8.4.6	Structural Response Calculations	288
8.4.7	Is a Probabilistic Approach the Best Way Forward?	289
8.5	Explosion Risk Reduction	289
8.5.1	Establishing Basis for Design	289
8.5.2	BFETS R&D Experience	290
8.5.3	Main Experience, Mitigation	292
8.5.4	Risk Reduction Possibilities	292
8.6	Example, Dimensioning Against Blast Load	296
8.6.1	Introduction	296
8.6.2	Basis for Dimensioning	299
8.6.3	Design Capability	299
8.6.4	Load Distributions	299
8.6.5	Gas Explosion Frequency	301
8.6.6	Reinforcement Costs	301
8.6.7	Optimisation	303

8.7	Case Study; Reduction of Blast Load	304
8.7.1	Layout and Geometry	305
8.7.2	Cases and Configurations Analysed.	306
8.7.3	Ventilation Results	306
8.7.4	Explosion Studies	307
8.7.5	FLACS Results.	308
8.7.6	Demonstration of Parameter Sensitivities.	308
8.7.7	Implications for QRA Modelling	310
8.7.8	QRA Sensitivity Results	310
8.7.9	Discussion and Evaluation	311
	References	312
9	Collision Risk Modelling.	313
9.1	Historical Collision Risk	313
9.1.1	Significant Collisions	313
9.1.2	Norwegian Platform Collisions.	314
9.1.3	Attendant Vessel Collisions	317
9.2	Modelling Overview	319
9.2.1	Introduction	319
9.2.2	Merchant Vessels	320
9.2.3	Naval Traffic	320
9.2.4	Fishing Vessels.	321
9.2.5	Offshore Traffic	321
9.2.6	Floating Units	323
9.3	Passing Traffic	323
9.3.1	Introduction	323
9.3.2	Powered Passing Vessel Collisions: Model Overview.	324
9.3.3	Traffic Pattern and Volume	327
9.3.4	Probability of Collision Course.	328
9.3.5	Probability of Failure of Ship Initiated Recovery . . .	334
9.3.6	Probability of Failure of Platform Initiated Recovery	337
9.3.7	Example Results.	338
9.3.8	Coast	338
9.3.9	Traffic Monitoring in the Norwegian Sector.	341
9.3.10	Model Validation	342
9.4	Collision Energy.	343
9.4.1	Impact Energy and Platform Energy Absorption Capacity	343
9.4.2	Mass of Colliding Vessels	344
9.4.3	Impact Velocity of Colliding Vessel	344
9.4.4	Critical Collisions	344

9.5	Collision Consequences	346
9.5.1	Failure Criteria	346
9.5.2	Collision Geometry	347
9.5.3	Local Collision Damage	347
9.5.4	Global Damage	348
9.6	Risk Reducing Measures	348
9.6.1	Overview of Risk Reducing Measures	348
9.6.2	Passing Vessels	349
9.6.3	Effect of Risk Reducing Measures	350
9.6.4	Experience with Collision Avoidance	354
9.6.5	Illustration of Effect of Risk Reduction	355
9.7	Collision Risk Case Study	356
9.7.1	Installation	356
9.7.2	Routes	356
9.7.3	Results	359
9.7.4	Energy Distributions	360
9.7.5	Intervention Options	362
9.7.6	Collision Geometry	363
	References	366
10	Marine Systems Risk Modelling	369
10.1	Ballast System Failure	369
10.1.1	Background	369
10.1.2	Regulatory Requirements	369
10.1.3	Relevant Hazards	370
10.1.4	Previous Studies	371
10.1.5	Stability Incidents and Accidents	372
10.1.6	Observations from Incidents and Accidents	373
10.1.7	Evaluation of Typical QRA Studies	374
10.1.8	Proposed Approach to Analysis of Stability Hazards	375
10.1.9	Comparison of QRA Results with Experienced Events	380
10.1.10	Observations	381
10.2	Anchoring System Failure	381
10.2.1	Incidents Involving More than One Anchor Line	382
10.2.2	Release of Chains in Winches	383
10.2.3	Failures in Anchor Lines	383
10.2.4	Dragging of Anchors	385
10.2.5	Other Risks with Anchoring Systems	385
10.2.6	Risk Analysis of Anchoring Systems on MODUs on the NCS	385

10.2.7	Use of Fault Trees in QRA of Anchoring Systems	386
10.2.8	Summary	386
10.3	Failure of Drilling DP Systems	387
10.3.1	Barrier Function 1: Prevent Loss of Position	389
10.3.2	Barrier Function 2: Arrest Vessel Movement	390
10.3.3	Barrier Function 3: Prevent Loss of Well Integrity	390
10.4	Shuttle Tanker Collision Risk	391
10.4.1	Background	391
10.4.2	Tandem Off-Loading Configurations	393
10.4.3	Overview of Current Field Configurations	394
10.4.4	Characterisation of Shuttle Tanker Collision Hazard	395
10.4.5	Barrier Modelling	397
10.4.6	Analysis of Risk Aspects	397
10.4.7	Trends in Occurrence Frequencies	400
10.4.8	Collision Energy and Consequences	401
10.4.9	Accidents and Incidents for Taut Hawser Configurations	401
10.4.10	Main Contributors to Collision Frequency, in Drive-Off	402
10.4.11	Experience Data	403
10.4.12	Accident Frequencies: 1996–2003	405
10.4.13	Accident Frequencies: 1996–2011	408
10.5	Loss of Buoyancy Due to Gas Plume	408
10.6	Accidental Weight Condition	409
10.7	Tow-Out and Installation Risk	410
	References	410
11	Risk Due to Miscellaneous Hazards	413
11.1	Crane Accidents	413
11.1.1	Modelling of Dropped Object Impact	414
11.1.2	Physical Aspects of Falling Loads	415
11.1.3	Probability of Dropped Loads	417
11.1.4	Probability of Hitting Objects	418
11.1.5	Consequences of Impact	419
11.1.6	Impact Energy Distributions	421
11.2	Accidents During Tow	424
11.3	Man-Overboard Accidents	424
11.3.1	Frequency of MOB Accidents	425
11.3.2	Scenarios Involving MOB Accidents	427
11.4	Structural Failure	427
11.5	Subsea Gas Release	429
	References	431

12	Fatality Risk Assessment	433
12.1	Overview of Approaches	433
12.1.1	Why Fatality Risk?	433
12.1.2	Statistical Analysis	434
12.1.3	Phenomena Based Analysis	434
12.1.4	Averaging of FAR Values	437
12.1.5	Variations Between Installations	438
12.2	Occupational Fatality Risk	439
12.3	Immediate Fatality Risk	442
12.3.1	Overview	442
12.3.2	Subjective Modelling	442
12.3.3	Modelling Based on Physical Effects	444
12.3.4	Is There a Need for Benchmarking?	447
12.4	Analysis of Escape Risk	452
12.4.1	Overview	452
12.4.2	Escape Time Analysis	454
12.4.3	Impairment Analysis	455
12.4.4	Escape Fatality Analysis	458
12.5	Analysis of Evacuation Risk	460
12.5.1	Overview of Evacuation Means	460
12.5.2	Impairment Analysis	466
12.5.3	Evacuation Fatality Analysis	467
12.6	Analysis of Risk Associated with Rescue Operations	468
12.6.1	Rescue Time Analysis	470
12.6.2	Rescue Capacity	474
12.6.3	Rescue Fatality Analysis	477
12.7	Diving Fatality Risk	479
12.8	Fatality Risk During Cessation Work	480
	References	481
13	Helicopter Transportation Fatality Risk Assessment	483
13.1	Overview	483
13.2	Accidents and Incidents—Offshore Northwest Europe	484
13.3	Risk Modelling	488
13.3.1	Assumptions and Premises	488
13.3.2	Risk Model	489
13.4	Previous Predictions	491
13.5	Combined Prediction of Risk Levels: UK and Norwegian Sectors	492
13.6	Prediction of Risk Levels: UK Sector	494
13.7	Prediction of Risk Levels: Norwegian Sector	495

- 13.8 Other Risk Parameters. 498
 - 13.8.1 Fatality Distribution 498
 - 13.8.2 Comparison of Risk Associated with Shuttling. 498
- 13.9 Prediction of Risk Levels for an Individual Installation. 500
- References 500

Part III Risk Analysis, Presentation and Evaluation Process

- 14 Methodology for Quantified Risk Assessment 505**
 - 14.1 Analytical Steps and Elements 505
 - 14.1.1 Analytical Elements 505
 - 14.1.2 Identification of Initiating Events 507
 - 14.1.3 Cause Analysis. 507
 - 14.1.4 Modelling of Accident Sequences. 509
 - 14.1.5 Consequence Analysis. 510
 - 14.1.6 Risk Calculation, Analysis and Assessment 512
 - 14.2 Analysis Steps 514
 - 14.2.1 Requirements for Analytical Approach 515
 - 14.3 Hazard Modelling and Cause Analysis 516
 - 14.3.1 Blowout Hazard Study 516
 - 14.3.2 Process Hazard Study 517
 - 14.3.3 Riser/Pipeline Hazard Study. 518
 - 14.3.4 Fire Load and Smoke Assessment. 519
 - 14.3.5 Explosion Load Assessment. 520
 - 14.3.6 Collision Hazard Study 520
 - 14.3.7 Dropped Object Hazard Study 521
 - 14.3.8 Structural Failure Study. 521
 - 14.4 Analysis of Critical Risks 522
 - 14.4.1 Barrier Study 522
 - 14.4.2 Assessment of Safety Critical Systems 523
 - 14.4.3 Detailed Probability Study 523
 - 14.4.4 HOF Integration 524
 - 14.4.5 Detailed Consequence Study 524
 - 14.4.6 Revised Event Tree Study 525
 - 14.5 Analysis of Different Risk Dimensions 525
 - 14.5.1 Impairment Analysis 525
 - 14.5.2 Fatality Risk Analysis 525
 - 14.5.3 Analysis of Environmental Spill Risk 525
 - 14.5.4 Analysis of Asset Risk 526
 - 14.6 Sensitivity Analysis 526
 - 14.7 Limitations of Risk Analysis 527
 - 14.8 Use of Software 528
 - 14.9 Data Sources 529
 - 14.9.1 Types of Data Sources 529

- 14.9.2 Blowout Frequency 529
- 14.9.3 Process System Leak Frequency 530
- 14.9.4 Riser/Pipeline Leak Frequency 531
- 14.9.5 Vessel Collision 531
- 14.9.6 Falling Objects 533
- 14.9.7 Marine Accidents 533
- 14.9.8 Utility Area Accidents 533
- 14.9.9 Helicopter Accidents 534
- 14.9.10 Occupational and Diving Accidents 534
- 14.9.11 Ignition Probability 534
- 14.9.12 Safety System Reliability 535
- 14.9.13 Data Sources for Reliability Analysis 535
- 14.9.14 Data for Fatality Modelling 535
- 14.10 Use of Installation Specific Data 536
 - 14.10.1 Generic versus Installation Specific Data 536
 - 14.10.2 Installation Specific Data from RNNP 536
 - 14.10.3 Combination of Specific and Generic Data 537
 - 14.10.4 Example, Combination of Data 539
 - 14.10.5 Data Sources for Installation Specific Data 541
- 14.11 Use of Risk Analysis Studies in Life Cycle Phases 543
 - 14.11.1 Analyses During Concept Development 543
 - 14.11.2 Analyses in Operations 543
- 14.12 Execution of Quantified Risk Analysis 544
 - 14.12.1 Quality Aspects 544
 - 14.12.2 Documentation of Assumptions and Premises 547
 - 14.12.3 Typical Study Definitions 547
- 14.13 Challenges Experienced with QRA Studies 549
 - 14.13.1 Ethical Failures 549
 - 14.13.2 Hazard Identification 549
 - 14.13.3 Analysis of Risk 549
 - 14.13.4 Presentation of Analysis Results 551
 - 14.13.5 Identification of Risk Reduction Measures 551
 - 14.13.6 Use of Study Results in Risk Management 551
- References 552

- 15 Analysis Techniques 555**
 - 15.1 Hazard Identification 555
 - 15.1.1 HAZOP 557
 - 15.1.2 PHA 558
 - 15.1.3 SAFOP 559
 - 15.1.4 Bow-Tie 560
 - 15.2 Cause, Probability and Frequency Analysis 561
 - 15.2.1 Fault Tree Analysis 561
 - 15.2.2 Event Tree Analysis 564

15.2.3	Failure Mode and Effect Analysis	564
15.2.4	Statistical Simulation Analysis	564
15.2.5	Analytical Methods	564
15.3	Operational Risk Analysis	564
15.3.1	BORA Methodology	565
15.3.2	Bayesian Belief Network	568
15.3.3	Risk_OMT Project	569
15.4	Event Tree Analysis	573
15.4.1	Basics of Event Tree	573
15.4.2	Major Hazard Scenarios	579
15.4.3	Initiating Event Frequency	579
15.4.4	Nodes in Event Trees	583
15.4.5	End Event Frequency	584
15.4.6	Gas Leak in Process Area	586
15.4.7	Blowout Event Tree	589
15.4.8	Gas Leak from Riser/Pipeline	592
15.5	Analysis of Barriers	595
15.5.1	Cause Analysis	595
15.5.2	Analysis of Dependencies Between Barriers	595
15.5.3	Analysis of SIL	596
15.6	Event Sequence Analysis	598
15.6.1	Time Dependency	598
15.6.2	Node Sequence in Event Tree Modelling	599
15.6.3	Directional Modelling	599
15.6.4	MTO	600
15.6.5	Integration of Investigation and QRA	602
15.6.6	Survey of the Extent of HOFs in QRA	602
15.7	HC Leak Modelling	604
15.7.1	Leak Statistics	606
15.7.2	Calculation of Leak Rates from Experience Data	607
15.7.3	Modelling of Leaks	608
15.8	Ignition Probability Modelling	608
15.8.1	Experience Data	609
15.8.2	Why is it Difficult to Develop an Ignition Model?	610
15.8.3	Cox Model	610
15.8.4	Platform Specific Modelling	610
15.8.5	Model Overview Time Dependent Modelling (TDIIM)	612
15.8.6	Revised JIP Model	618
15.9	Escalation Modelling	620
15.9.1	Functionality	620
15.9.2	Availability and Reliability	620
15.9.3	Survivability	622
15.9.4	Node Probability	622

15.10	Escalation Analysis	622
15.10.1	Modelling of Fire Escalation	623
15.10.2	Modelling of Explosion Escalation	625
15.10.3	Damage Limitation	626
15.10.4	Response of Equipment to Fire and Explosion	627
15.10.5	Tolerability Criteria for Personnel	630
15.10.6	Impairment Criteria for Safety Functions	631
15.10.7	Required Intactness Times for Safety Functions	633
	References	635
16	Presentation of Risk Results from QRA Studies	639
16.1	Requirements for Risk Presentation	639
16.1.1	Regulatory Requirements	639
16.1.2	NORSOK Requirements	639
16.1.3	Risk Result Presentation and Risk Tolerance Criteria	641
16.1.4	Proposed Presentation Format	641
16.2	Presentation of Risk According to Application Area	642
16.2.1	Life Cycle Phases	642
16.2.2	ALARP Evaluations	642
16.2.3	Risk Presentation for Different User Groups	642
16.2.4	Framework for Risk Presentations	643
16.3	Presentation of Overall Risk	643
16.3.1	Main Results	643
16.3.2	References for Risk Results	644
16.4	Presentation of Risk Contributions	646
16.4.1	FAR Contributions	646
16.4.2	Contributions for Leak Frequencies	648
16.4.3	Fire and Explosion Characteristics	650
16.5	Presentation of Significant Improvements	651
16.6	Presentation of Sensitivity Studies	652
16.6.1	Risk Reducing Measures	652
16.6.2	Risk Model Parameter Variations	655
16.7	Evaluation of Uncertainty	655
16.8	Presentation Format for Easy Understanding	657
	References	657
17	Evaluation of Personnel Risk Levels	659
17.1	Current Fatality Risk Levels	659
17.1.1	FAR in Norwegian Offshore Operations	659
17.1.2	FAR in Worldwide Offshore Operations	666
17.2	Prediction of Future Fatalities: Norwegian Sector	667
17.2.1	Important Assumptions and Evaluations	669
17.2.2	Occupational Accidents	670

17.2.3	Major Accidents on Installations	670
17.2.4	Helicopter Transportation Accidents	671
17.2.5	Summary of Predicted Fatalities	671
17.3	Major Accident and Evacuation Frequencies	673
17.3.1	Life Boat Evacuations on the NCS	673
17.3.2	Experience Data from Freefall Lifeboat Tests	675
17.3.3	Major Accident Frequency: Norwegian Sector	675
17.3.4	Major Accidents Worldwide.	676
17.3.5	Major Accident Probability: Norwegian Sector.	677
17.4	Risk Tolerance Criteria	678
17.4.1	Definition	678
17.4.2	Philosophical Dilemma	678
17.4.3	Norwegian Regulatory Requirements.	679
17.4.4	Risk Tolerance Criteria Requirements According to UK Regulations	680
17.4.5	General Requirements	682
17.5	Criteria Used for Personnel Risk by the Petroleum Industry	683
17.5.1	Group Average Risk	684
17.5.2	Risk Distribution	684
17.5.3	Potential Loss of Life	685
17.6	Use of Risk Tolerance Criteria in Personnel Risk Evaluation	685
17.7	Risk Tolerance Criteria for Environmental Spill Risk	687
17.7.1	Initial Approach	687
17.7.2	Current Approach	688
17.8	Risk of Material Damage/Production Delay	690
17.9	Risk Tolerance Criteria for Temporary Phases	690
	References	691
18	Environmental Risk Analysis	693
18.1	Overview of Environmental Risk—Norway	693
18.1.1	Acute Spill Statistics for the Offshore Industry.	693
18.1.2	RNNP Presentation of Environmental Risk in Norway	693
18.2	Regulatory Requirements Etc.	700
18.2.1	Norway	700
18.2.2	OGP Oil Spill Risk Assessment Standard	701
18.3	Modelling of Environmental Risk Analysis	702
18.3.1	General Aspects Relating to Environmental Risk Analysis	702
18.3.2	Event Trees	703
18.4	Overview of the MIRA Approach.	704
18.4.1	General Principles.	704
18.4.2	Environmental Damage Distribution	708

18.5	Presentation of MIRA Results	709
18.6	Discussion of the Current Practice	710
18.7	New Approach to Environmental Risk Analysis	713
18.8	Need for Alternative Ways to Assess and Communicate Risk	714
	References	716
19	Approach to Risk Based Design	717
19.1	Overview	717
19.1.1	About the Need for Risk Based Design	717
19.1.2	Scope for Risk Based Design	718
19.1.3	Challenges for Design	719
19.2	Authority Regulations and Requirements	721
19.2.1	Norwegian Installations	721
19.2.2	UK Regulations	723
19.3	Relationship with Risk Analysis	723
19.3.1	Suitable Risk Analysis	724
19.3.2	Use of Event Trees	726
19.3.3	Use of Consequence Models	728
19.3.4	Sensitivity to Changes in Active Safety Systems	729
19.4	Approach to Risk Based Design of Topside Systems	731
19.4.1	Basis for Approach	731
19.4.2	Fundamentals of Proposed Approach	732
19.4.3	Overview of Sensitivities	733
19.4.4	What Should be the Target Protection Level	733
19.5	Risk Based Design of Structural and Passive Safety Systems	735
19.6	Practical Considerations	735
19.6.1	Design Against Fire Loads	735
19.6.2	Design Against Explosion Loads	741
19.6.3	Design Against Collision Impacts	742
19.6.4	Design Against Dropped Load Impact	743
19.7	Safety Integrity Levels	744
	References	744
20	Risk Based Emergency Response Planning	745
20.1	Philosophy of Emergency Response	745
20.2	Risk Based Emergency Response Times and Capacity	746
20.3	Risk-Based Rescue Capacity After Evacuation	746
20.3.1	Assumptions in QRA Studies	747
20.3.2	Escape and Evacuation Robustness	748
20.3.3	Principles for Probabilistic Pick-Up Calculations	750
20.3.4	Probability Limit for Determining Dimensioning Scenarios	751

- 20.3.5 Simplified Rules for Dimensioning
 - Pick-Up Capacity 752
- 20.4 Risk Based External Fire Fighting 753
- 20.5 Rescue of Personnel in Helicopter Accidents 753
- 20.6 External Medical Assistance to Injured and Ill Persons 754
- 20.7 Area Based Emergency Response Planning: Results 754
- 20.8 External Emergency Response Planning
 - in Arctic Conditions 755
- References 756

Part IV Risk Assessment and Monitoring in Operations Phase

- 21 Use of Risk Analysis During the Operations Phase 759**
 - 21.1 Study Updating 759
 - 21.1.1 Overview 759
 - 21.1.2 Scope of Updating 760
 - 21.1.3 Frequency of Updating 760
 - 21.2 Risk Analysis of Operational Improvement 761
 - 21.2.1 Overview of BORA Case Studies 761
 - 21.2.2 Risk_OMT Case Studies 763
 - 21.2.3 HRA in QRA 763
 - 21.3 Risk Analysis in Operational Decision-Making 764
 - 21.4 Living Risk Analysis (Risk Monitors) in Operational Phase. . . 765
 - 21.5 Use of Sensitivity Studies for Safety Systems
 - Improvement 766
 - 21.5.1 Risk Management Objectives 767
 - 21.5.2 Case Study: Effect of Improved Blowdown 768
 - 21.6 Acceptable Internal Leak Rates of Isolation Valves 771
 - 21.7 Case Study: Cost Benefit Analysis 773
 - 21.7.1 Field Data 773
 - 21.7.2 Definition of Risk Reducing Measure 774
 - 21.7.3 Risk Reducing Potentials 774
 - 21.7.4 Overall Approach to Comparison of Costs
 - and Benefits 775
 - 21.7.5 Modelling of Benefits 776
 - 21.7.6 Modelling of Costs 778
 - 21.7.7 Results 778
 - 21.7.8 Sensitivity Study 780
 - 21.7.9 Discussion and Evaluation 781
 - 21.7.10 Conclusions 782
 - 21.8 Analysis of Maintenance Activities 783
 - 21.9 Investigation of Precursor Events 783
 - 21.9.1 Authority Requirements 783

21.9.2	Authority Investigations in the Norwegian Petroleum Sector	784
21.9.3	Company Investigation Practices	785
21.9.4	Improvements in Investigation Practices Relating to Hydrocarbon Leaks	786
21.10	Overall Analysis of Modifications	786
21.10.1	Overview	786
21.10.2	Modification Risk in a Life Cycle Perspective	787
21.11	Tie-in of New Facilities	789
	References	790
22	Use of Risk Indicators for Major Hazard Risk	791
22.1	Background	791
22.1.1	Historical Development	791
22.1.2	The PFEER Approach to Risk Monitoring	792
22.1.3	Objectives	794
22.2	Need for Specific Indicators for Major Hazard Risk	795
22.2.1	Indicator Concepts and Definitions	796
22.2.2	Criteria for the Assessment of Major Hazard Risk Indicators	798
22.3	Major Hazard Risk Indicators at a National Level	800
22.3.1	Objectives, Scope of the Work and Stakeholders	800
22.3.2	Scope of the Work	801
22.3.3	Stakeholder Interest	801
22.3.4	Basic Concepts and Overall Approach	802
22.3.5	Major Hazard Risk	803
22.3.6	Other Indicators	803
22.3.7	Data Sources	804
22.3.8	Precursor-Based Indicators for Major Hazard Risk	806
22.4	Barrier Indicators for Major Hazard Risk in RNNP	808
22.4.1	Barrier Concepts and Performance	808
22.4.2	Barrier Indicators in RNNP	809
22.4.3	Availability Data for Individual Barrier Elements	810
22.4.4	Causal Factors	811
22.5	Lessons Learned from RNNP	812
22.5.1	Approach to Risk Projection	812
22.5.2	Relevance of Precursor Indicators	813
22.5.3	Suitability of Barrier Indicators	813
22.5.4	Normalisation of Precursor-Based Indicators	814
22.5.5	Ability to Distinguish Between Companies and Installations	814
22.6	Precursor Events as Major Hazard Indicators	815
22.6.1	Proposed Approach to the Selection of Individual Indicators	815

- 22.6.2 Weights for Individual Indicators 820
- 22.7 Barrier Indicators for Major Hazard Risk 820
 - 22.7.1 Suitability of Leading Barrier Indicators 820
 - 22.7.2 Suitability of Barrier Indicators 824
 - 22.7.3 Extended Suitability of Indicators 824
- 22.8 Barrier Indicators at an Installations Level. 825
 - 22.8.1 Technical Systems 825
 - 22.8.2 Indicators: HOFs. 828
- 22.9 Proposed Major Hazard Indicators for Companies 832
 - 22.9.1 Precursor Based Indicators 833
 - 22.9.2 Barrier Indicators 834
 - 22.9.3 Proposal: Barrier Indicators 834
 - 22.9.4 Proposal: Precursor-Based Indicators. 837
- References 837

- 23 Barrier Management for Major Hazard Risk 841**
 - 23.1 Background 841
 - 23.2 Regulatory Requirements. 842
 - 23.3 Barrier Concepts. 843
 - 23.4 Barrier Management in Life Cycle Phases. 844
 - 23.4.1 Planning Phases 844
 - 23.4.2 Establishing Barrier Strategy 844
 - 23.4.3 Overview of Barrier Functions and Systems. 846
 - 23.4.4 Structure of Barrier Functions 847
 - 23.4.5 Establishing PRs. 849
 - 23.5 Barrier Management in Operations Phase 852
 - 23.6 Challenges for Implementation. 852
 - References 854

- Appendix A: Overview of Software 855**

- Appendix B: Overview of Fatalities in Norwegian Sector 889**

- Appendix C: Network Resources 897**

- Glossary 901**

- Index 911**

Abbreviations

AIBN	Accident Investigation Board Norway
AIR	Average Individual Risk
AIS	Automatic Identification System
ALARP	As Low As Reasonably Practicable
ANP	National Petroleum Agency
AR	Accident Rate
ARCS	Admiralty Raster Chart Services
ARPA	Automated Radar Plotting Aid
ATM	Air Traffic Management
bara	Bar absolute
barg	Bar gauge (overpressure)
BAST	Best Available and Safety Technology
BBD	Barrier Block Diagram
bbls	Barrels
BD	Blowdown
BDV	Blowdown Valves
BF	Barrier Function
BFETS	Blast and Fire Engineering for Topside Systems
BHP	Broken Hill Proprietary Company Limited
BLEVE	Boiling Liquid Expanding Vapour Explosion
BOE	Barrels of Oil Equivalent
BOEMRE	Bureau of Offshore Energy Management, Regulation and Enforcement
BOP	Blowout Preventer
BORA	Barrier and Operational Risk Analysis
BP	British Petroleum
BSEE	Bureau of Safety and Environmental Enforcement
CAA	Civil Aviation Authority
CAD	Computer Aided Design
CBA	Cost Benefit Analysis
CCA	Cause-Consequence Analysis
CCR	Central Control Room
CFD	Computational Fluid Dynamics

CNH	National Hydrocarbons Commission
CNLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CNSOPB	Canada-Nova Scotia Offshore Petroleum Board
CPA	Closest Point of Approach
CPP	Controllable Pitch Propeller
CSE	Concept Safety Evaluation
DAE	Design Accidental Events
DAL	Design Accidental Loads
DEA	Danish Energy Agency
DFU	Defined situations of hazard and accident
DHJIT	Deepwater Horizon Joint Investigation Team
DHSG	Deepwater Horizon Study Group
DHSV	DownHole Safety Valve
DNV	Det Norske Veritas
DOL	Department of Labor
DP	Dynamic Positioning
DSB	Directorate for Civil Protection and Emergency Planning (Direktoratet for samfunnssikkerhet og beredskap)
DWT	Dead Weight Tonnes
E&P	Exploration and Production
E&P Forum	Previous name of organisation now called OGPEER
EERS	Escape, Evacuation and Rescue
EESLR	Evacuation, Escape and Rescue Strategy
EGPWS	Risk due to explosion escalation by small leaks
EFSLR	Enhanced Group Proximity Warning System
EIA	Risk due to fire escalation by small leaks
EIF	Environmental Impact Assessment
EQDC	Environmental Impact Factor
ESD	Emergency Quick DisConnector
ESV	Emergency Shut Down
ETA	Emergency Shutdown Valve
Ex	Event Tree Analysis
FAR	Explosion [protected]
FCC	Fatal Accident Rate
FEM	Frigg Central Complex
FES	Finite Element Method
Fi-Fi	Fire and Explosion Strategy
FLAR	Fire Fighting
FLACS	Flight Accident Rate
FMEA	Flame Accelerator Software
FPS	Failure Mode and Effect Analysis
FPSO	Floating Production System
FPU	Floating Production, Storage and Off-loading unit
	Floating Production Unit

FRC	Fast Rescue Craft
FSU	Floating Storage Unit
FTA	Fault Tree Analysis
GBS	Gravity Base Structure
GIR	Group Individual Risk
GIS	Geographical Information System
GoM	Gulf of Mexico
GPS	Global Positioning System
GR	Group Risk
GRP	Glass fibre Reinforced Plastic
GRT	Gross Register Tons
HAZID	Hazard Identification
HAZOP	Hazard And Operability Study
HC	Hydrocarbon
HCL	Hybrid Causal Logic
HCLIP	Hydrocarbon Leak and Inventory Project
HCR	Hydrocarbon Release
HES	Health, Environment and Safety
HIPPS	High Integrity Pressure Protection System
HOF	Human and Organisational Factors
HR	Human Reliability
HRA	Human Reliability Analysis
HSE	Health and Safety Executive
HSS	Helicopter Safety Studies
IAEA	International Atomic Energy Agency
IEC	International Electro-technical Commission
IMEMS	International Marine Environmental Modeling Seminar
IMO	International Maritime Organization
IR	Individual Risk
IRIS	International Research Institute of Stavanger
IRF	International Regulators' Forum
IRPA	Individual Risk per Annum
ISO	International Organisation for Standardisation
JIP	Joint Industry Project
KPIs	Key Performance Indicators
LCC	Life Cycle Cost
LEL	Lower Explosion Level
LFL	Lower Flammability Level
LNG	Liquefied Natural Gas
MIRA	Environmental risk analysis (>Miljørettet risikoanalyse =)
MGB	Main Gearbox
MMI	Man-Machine Interface
MMS	Minerals Management Service
MNOK	Million Norwegian kroner

M&O	Management and Operation
MOB	Man Over Board
MOC	Management of Change
MODU	Mobile Offshore Drilling Unit
MOEX	Mitsui Oil EXploration
MP	Main (propulsion) Power
MSF	Module Support Frame
MTO	Man, Technology and Organisation
MUSD	Million US Dollar
NCS	Norwegian Continental Shelf
NEA	National Environment Agency
NORSOK	Norwegian Offshore standardisation organisation (>Norsk Sokkels Konkurransesepisjon =)
NM	Nautical Mile
NGOs	Non-governmental organizations
NMD	Norwegian Maritime Directorate
NOPSA	National Offshore Petroleum Safety authority (Australia)
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NOU	Norwegian Offshore Report (Norges Offentlige Utredninger)
NPD	Norwegian Petroleum Directorate
NPPs	Nuclear Power Plants
NPV	Net Present Value
NTNU	Norwegian University of Science and Technology
NTS	Norwegian Technology Standards Institution
OCS	Outer Continental Shelf
OGP	International Oil and Gas Producers Association
OIM	Offshore Installation Manager
OLF	The Norwegian Oil Industry Association (Oljeindustriens Landsforening)
OMT	Organisational, Human & Technology
ONGC	Oil and Natural Gas Corporation
OR	Overall risk
OSD	Offshore Division
OSPAR	Oslo and Paris Convention
OSRA	Oil Spill Risk Analysis
OTS	Operational Condition Safety ('Operasjonell Tilstand Sikkerhet')
PDQ	Production, Drilling and Quarters
P&ID	Piping and Instrumentation Drawing
PETRAD	Program for Petroleum Management and Administration
PFEER	Prevention of Fire and Explosion and Emergency Response
PFP	Passive Fire Protection

PGS	Petroleum Geo-Services ASA
PHA	Preliminary Hazard Analysis
PLATO	Software for dynamic event tree analysis
PLL	Potential Loss of Life
PLS	Progressive Limit State
POB	Personnel On Board
PR	Performance Requirements
PRS	Position Reference System
PS	Performance Standards
PSA	Petroleum Safety Authority [Norway]
PSD	Process Shut Down
PSV	Pressure Safety Valves
QA	Quality Assurance
QC	Quality Control
QM	Quality Management
QP	(Frigg) Quarters Platform
QRA	Quantified Risk Assessment
R&D	Research and Development
RABL	Risk Assessment of Buoyancy Loss
RAC	Risk Acceptance Criteria
RACON	Radar signal amplification
RAE	Residual Accidental Events
RAMS	Reliability, Availability, Maintainability, Safety
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations
RIF	Risk Influencing Factor
RNN	Risk Level [project] ('Risiko Nivå Norsk Sokkel')
RNNP	Risk level in the Norwegian petroleum activity (Risikonivå i norsk petroleumsvirksomhet)
ROS	Risiko-og sårbarhetsstudier
ROV	Remote Operated Vehicle
RRM	Risk Reducing Measure
SAFOP	Safety and Operability Study
SAR	Search and Rescue
SBV	Standby Vessel
SCR	Safety Case Regulations
SIL	Safety Integrity Level
SJA	Safe Job Analysis
SLR	Risk due to small leaks
SOLAS	Safety of Life at Sea
SSIV	SubSea Isolation Valve
SSM	State Supervision of Mines
ST	Shuttle tanker
SUPER-TEMPCALC	Software for 2D temperature analysis
TASEF-2	Software for 2D temperature analysis

TCAS	Traffic Collision Avoidance System
TCP2	(Frigg) Treatment Platform 2
TH	Thruster
TLP	Tension Leg Platform
TP1	(Frigg) Treatment Platform 1
TR	Temporary Refuge
TRA	Total Risk Analysis
TST	Technical Safety Condition (‘Teknisk SikkerhetsTilstand’)
TTS	Technical Condition Safety (‘Teknisk Tilstand Sikkerhet’)
UEL	Upper Explosive Limit
UFL	Upper Flammability Limit
UKCS	UK Continental Shelf
UPS	Underwater Production System
USFOS	Software for non-linear and dynamic analysis of structures
VEC	Valued Ecological Component
VHF	Very High Frequency
VOC	Volatile Organic Compounds
VTS	Vessel Traffic System
WOAD	Worldwide Offshore Accident Database (ref. DNV)
WP	Work Permit