Pipeline Integrity Management Systems
A Practical Approach

Rafael G. Mora
Phil Hopkins
Edgar I. Cote
Taylor Shie

ASME PRESS
This book is dedicated to the new generation of technicians, technologists, engineers, and professionals working in the pipeline industry and their mentors that guide them on their journey to achieve a safe and reliable pipeline operation protecting our environment.

The authors would also like to dedicate the book to their families, Cristal and Alexandra Shie, Marujita Sinning, Liliana Ortegon, David Esteban and Nicolas Mora, Benny Omaña and Josie Hopkins for accompanying us in the journey of writing the book for the next generation of pipeline industry professionals.
ACKNOWLEDGMENTS

ASME STAFF

The authors would like to acknowledge and thank the ASME staff specifically Ms. Mary Grace Stefanchik, Ms. Tara Smith, Ms. Kimberly Miceli, and Mr. Timothy Graves for their kind and professional support in the timely and quality preparation and publication of this book.

We would also like to acknowledge the contribution, guidance and support from the ASME Pipeline Systems Division (PSD).

BOOK REVIEWERS: ENCOURAGEMENT, KNOWLEDGE, AND EXPERIENCE

This book also benefited from many colleagues from multiple pipeline industry sectors such as pipeline operators, consultants, regulators, and services around the globe from their encouragement and knowledge and experience reflected in the technical review of the chapters of this book (alphabetical order by last name):

Nader Al-Otabi
Oswaldo Baron
Robert Basaraba
Colby Bell
Thomas Beuken
Tom Bubnik
Alex Cook
Graham Emmerson
James Ferguson
Colin Gagne
Adrian Luhowy
Robin Magelky
German Melendrez
Parimal More
Husain M. Muslim
Xavier Ortiz
Joe Paviglianiti
Jonathan Prescott
Debbie Price
Jerry Rau
Miguel Antonio Ramirez
Gabriela Rosca
Thushanthi Senadheera
Nauman Tehsin
Howard Wallace
Hong Wang
Adnan Zaheer
Dario Zapata

CONTRIBUTIONS TO INTEGRITY KNOWLEDGE AND EDUCATION

Following our distinguished Mo Mohitpour’s efforts in the Pipeline Integrity Assurance book, the authors would like to continue the list of professionals (not comprehensive) that, over the years, have relentlessly, through their professional dedication, made technical contributions to pipeline integrity knowledge and education (alphabetical order by last name):

Jose V. Amortegui
Tom Barlo
John Beavers
William R. Byrd
Iain Colquhoun
Aaron Dinovitzer
Ray Fessler
Manuel Garcia Lopez
Ron Hugo
Dave Jones
Shahani Kariyawasam
Roger King
Don Lefevre
BJ Lowe
Michael McManus
Jim Marr
Giancarlo Massucco
Oliver Moghissi
Alan Murray
Maher Nessim
Ken Paulson
Andrew Palmer
Moness Rizkalla
N. Daryl Ronsky
Wilson Santamaria
Bill Santos
William J. Shaw
Ed Seiders
Mark Stephens
John Tiratsoo
Carlos Vergara
Patrick Vieth
David Weir
Mike Yoon
PERMISSIONS

ASME and the authors would like to thank all the individuals and organizations who have granted their permission to use and reproduce figures, tables, data, and other material in this book. These are referenced along the book, accordingly.

We apologize in advance for any reference or attributions that we may have overlooked and will be pleased to remedy those brought to our attention as well as properly recognize them in any subsequent editions of the book.

Baker Hughes Incorporated, www.bakerhughes.com
British Standards Institute, BSI
Chemical Institute of Canada, www.cheminst.ca
Colpet al Dia: Colombian Petroleum Company, La Historia de Coveñas in Facebook
Diakont Advanced Technologies, www.diakont.com
EnhanceCo, www.enhanceco.net
Gus Gonzalez-Franchi
Institution of Gas Engineers and Managers, IGEM, www.igem.org.uk
JW’s Pipeline Integrity Services, LLC, www.jwspiservices.com
Manuel Aguibre, Mexico Maxico, www.mexicomaxico.org
Mechling Bookbindery, www.mechlingbooks.com
Moness Rizkalla, Visitless Integrity Assessment Ltd, www.via-plus.net
Museum Rosneft, www.russianmuseums.info/M3115
New Century Integrity Plus, www.ncintegrityplus.com
Petroleum History Institute, www.petroleumhistory.org, Samuel T. Pees
Petrolia Heritage, www.petroliaheritage.com
Phil Hopkins, phil.hopkins.work@gmail.com
PII Pipeline Solutions, a GE Oil & Gas and Al Shaheen Joint Venture, www.geoilandgas.com/pipeline-storage/pipeline-integrity-services
Pipe Line Contractors Association of Canada, www.pipeline.ca
ROSEN Group, www.rosen-group.com
Russell NDE Systems, Inc. and PICA Corp, www.russelltech.com
Thinkstock, www.thinkstockphotos.ca
TRC Pipeline Services Sector, www.trcsolutions.com
USA National Transportation Safety Board, www.ntsb.gov
Wikimedia Commons, https://commons.wikimedia.org/wiki/Main_Page
World Oil, www.worldoil.com

---

1 Permission to reproduce extracts from PAS 551:2008 is granted by BSI. British Standards can be obtained in PDF or hard copy formats from the BSI online shop: www.bsigroup.com/Shop or by contacting BSI Customer Services for hardcopies only: Tel: +44 (0)20 8996 9001, Email: cservices@bsigroup.com.
CHAPTER 1 Pipeline Integrity Management (IM): History and Framework

1.1 Integrity Management (IM) Core Purpose 1
1.2 Key Integrity Management Terminology 1
1.3 First Hydrocarbon Transmission Pipelines, Reservoirs and Legislation 5
1.4 Pipeline Integrity Management Eras: History and Evolution 14
1.5 Pipeline Integrity Management Framework 23
1.6 References 29

CHAPTER 2 Engineering Concepts for Pipeline Integrity

2.1 Introduction 33
2.2 Design of Pipelines 33
2.3 Line Pipe 34
2.4 Pipeline Routing 39
2.5 The Design Process 42
2.6 Pipeline Design 44
2.7 Pipeline Construction 55
2.8 References 56

CHAPTER 3 Elements of a Pipeline Integrity Management System (PIMS)

3.1 Management Systems (MS) and Pipeline Integrity 59
3.2 Integrity Management Program (IMP) 62
3.3 PIMS: Management System and Integrity Management Program Linkage 62
3.4 PIMS Policy and Commitment [MS] 63
3.5 PIMS Planning: Purpose and High Level Processes [MS] 63
3.6 PIMS Implementation [MS] 70
3.7 Conformance and Compliance Verification and Action Plans [MS] 73
3.8 Management Review: Integrity Performance and KPIs [MS] 77
3.9 References 78

CHAPTER 4 Integrity Hazard and Threat Susceptibility and Assessment

4.1 Introduction 79
4.2 Threat Management Cycle 79
4.3 Pipeline Integrity Threat Assessment Process 81
4.4 Pipeline Integrity Hazards and Threats 81
4.5 Pipeline Integrity Hazard Identification 83
4.6 Threat Susceptibility Assessment 96
4.7 Pipeline Threat Assessment 102
4.8 References 111

CHAPTER 5 Consequence Assessment for Pipelines

5.1 Introduction 113
5.2 Pipeline Consequence Categories 113
5.3 Consequence Assessment Process 113
5.4 Consequence Analysis: Fluid Discharge and Dispersion 115
5.5 Consequence Classification along the Pipeline 129
5.6 Validation of the Consequence Classification 134
5.7 Consequence Assessment Results: Content and Format 134
5.8 References 134

CHAPTER 6 Risk Assessment for Pipelines

6.1 Introduction to Pipeline Risk Management 137
6.2 Risk Assessment Purpose, Applications, Functions, and Outcomes 143
6.3 Risk Assessment Types 144
6.4 Risk Assessment Process 147
6.5 Risk Analysis 150
6.6 Risk Estimation 152
6.7 Risk Evaluation and Sensitivity Analysis 153
6.8 References 157

CHAPTER 7 Pipeline Integrity Assessment Method Selection and Planning

7.1 Introduction 159
7.2 Selection of Pipeline Integrity Assessment Method Type 159
7.3 Integrity Assessment Planning: Process and Lessons Learned 165
7.4 References 168
By the end of 2000s, the idea of an integrity management book came about from students attending the University of Calgary’s Pipeline Integrity Management courses. An increasing need to develop combined engineering and management practices for the day-to-day became important for achieving integrity management effectiveness. Then, creating a resource or material with integrated and multi-disciplinary knowledge was one of many steps needed to contribute technicians, technologists, engineers and managers with knowledge and a practical approach for responding to the increasing society expectations for safe and reliable pipelines.

In the summer of 2014, ASME Publishing Committee notified their approval for publication of the book. This initiated the authors journey to collectively share their engineering and management experiences from four (4) interlinked pipeline industry sectors (i.e., pipeline transmission, engineering integrity consulting, technology services, and regulatory oversight) and their multiple geographical exposures (i.e., Arctic, Canada, USA, South America, Europe, Asia Pacific, and Australia). However, the authors’ interest was focused on making the reader the “Hero of the Story” not the writers by engaging them with core, relevant, and attractive knowledge needed at work. Figures and real case examples were made generic for transferring knowledge and experience to the Hero for easier applicability and building-block innovation.

The book outline portrays a management system (MS) approach that enables management in providing direction, guidance, support, and evaluation to sustain continuous improvement, while it connects to and explains the Integrity Management Program (IMP) elements providing the engineering integrity core for sustaining pipeline risk reduction. The key for success resides in the linkage between MS and IMP, named hereafter as Pipeline Integrity Management System (PIMS). PIMS approach enables organizations to achieve state-of-the-art adequacy, timely implementation, and measured effectiveness of the relentless integrity goals, objectives, and targets toward the safety of employees and the public, the protection of the environment, and a reliable service.

The table of contents follows the PIMS structure detailing within each management system element the engineering elements; however, they can be read individually as each applicable chapter has a PLAN-DO-CHECK-ACT built-in process for enabling the reader to become the Hero.

During the 2015 winter, the review of the book chapters became an insightful experience for all authors discovering the richness and value added by 28 reviewers from multiple engineering and management backgrounds and experience levels located around the globe. The review was conducted relaxing the reviewers by not knowing whose materials they were commenting on and empowering them by applying their need for changes in the final book: their review guided the writers for reader’s benefit.

In the early 2016, when the time for writing the acknowledgments came, the authors realized that there were not enough pages and expressive words of gratitude for all individuals who reviewed the book and have contributed with pipeline integrity knowledge and education. In the Acknowledgments page, we continued the list initiated by Dr. Mo Mohitpour in the Pipeline Integrity Assurance book with the extent possible. We all know that our reward at the end of the day is enjoying that the people and environment along the pipeline are safe and protected.

With appreciation,

Rafael G. Mora, Taylor Shie, Edgar I. Cote, and Phil Hopkins

The Authors

If you had any questions, comments, clarifications or improvement for the next edition, please email us at asme.pims@outlook.com. Please indicate your phone number in the email, if you would like to be contacted as soon as possible.
LIST OF FIGURES

1.1 PIMS Conceptual: Connecting Management Systems and Integrity Management Programs 3
1.2 Timeline of the First Hydrocarbons Transmission Pipelines: 1862 to 1977 (Not Comprehensive) 5
1.3 Canadian Oil Fields of Oil Springs, Lambton County, Ontario (Source: Courtesy of Petrolia, Canada's Victoria Oil Town at www.petroliaheritage.com) 6
1.4 Early Construction Workers in Southern Ontario (Source: Courtesy of Pipe Line Contractors Association of Canada http://www.pipeline.ca/history.html) 6
1.5 Van Syckel (Top) and Steam Pump from the 5 Mile Van Syckel Pipeline, 1865 (Source: Samuel T. Pees, Petroleum History Institute http://www.petroleumhistory.org/Oilhistory/pages/pipelines/van_syclkel.html) [15] 8
1.7 Russia's Early Oil Pipeline Balakhani—Black City (Source: Wikimedia Commons http://museum.rosneft.ru/past/chrono/year/1879) 9
1.8 Cerro de la Pez, el Ebano, State of San Luis Potosi (Left) and Pipelines Going to Tampico (Right) (Source: Courtesy of Manuel Aguirre, http://mexicomaxico.org/Voto/pemex.htm) 10
1.9 323.85 MM (NPS 12) Petrolea—Coveñas Sagoc Pipeline (Left) and Petrolea Camp and Pump Station in 1938 (Right) (Source: Epoca de la Sagoc, La Historia de Coveñas, Gabriel Moré Sierra) 10
1.10 DAMMAM No. 7 Oil Well (Left) and Trans-Arabian Pipeline (Right) (Source: Wikimedia Commons) 11
1.11 Comodoro Rivadavia (Cr) Oil Wells on the Atlantic Coastline (Source: Wikimedia Commons) 12
1.12 Wietze Oil Wells (Source: Grantville Gazette, Volume 23, 1 May 2009 by Jeff Corwith https://grantvillegazette.com/wp/article/publish-303/) 12
1.14 Modes of Transportation for Oil and Gas (Source: Phil Hopkins) 14
1.15 Causes of Gas Pipeline Failures in Europe (Source: Phil Hopkins) 15
1.16 Chronology of SCC Events in Canada from 1976 to 1996 (Source: National Energy Board, 1996, Public Inquiry Concerning Stress Corrosion Cracking on Canadian Oil and Gas Pipelines: MH-2-95) 17
1.17 Canadian Natural Gas Pipeline SCC Failures by Location before 1996 (Source: National Energy Board, 1996, Public Inquiry Concerning Stress Corrosion Cracking on Canadian Oil and Gas Pipelines: MH-2-95) 17
1.18 Canadian Liquids Pipeline SCC Failures by Location before 1996 (Source: National Energy Board, 1996, Public Inquiry Concerning Stress Corrosion Cracking on Canadian Oil and Gas Pipelines: MH-2-95) 18
1.19 Risk-Based Land Use Planning Guidelines—Recommendation (Source: Chemical Institute of Canada/Canadian Society for Chemical Engineering—Process Safety Management) 19
1.20 The 406.40-MM (NPS 16) Products Pipeline Rupture and Fire in Bellingham, WA (Source: National Transportation Safety Board (NTSB), USA Report PAR-02/02) 20
1.21 The 762 MM (NPS 30) Gas Transmission Pipeline Rupture and Explosion in Carlsbad, NM (Source: National Transportation Safety Board (NTSB), USA Report PAR-03/01 Docket # 15291 NTSB Accident ID# DCA00MP009) 21
1.22 Pipeline Integrity Framework 23
1.23 ASME B31.8S-2014 Integrity Management Program Elements 26
1.24 ASME B31.8S-2014 Integrity Management Plan Process Flow Diagram 26
1.25 Structure of BSI PAS 55-1:2008 (Source: British Standard Institute and Institute of Asset Management, BSI Group) 27
2.1 Determining Yield and Ultimate Tensile Strengths 34
2.2 Ductility in the Stress-Strain Curve 35
2.3 Toughness 'Transition' Curve 35
2.4 Line Pipe Types 36
2.5 Corrosion Cell [20] 38
2.6 Examples of Pipeline External Coatings 39
2.7 “Cut-back” Areas on Line Pipe to be Coated in the Field 39
2.8 Example of a Cathodic Protection System 39
2.9 Routing Boundaries 41
2.10 Right of Way 41
2.11 Pipeline Construction’s ‘Working Width’ 41
2.12 Location and Distance Restrictions in Pipeline Standards for Gas Pipelines 42
2.13 The Design Process 44
**2.14** Wall Thickness and Diameter (OD) Used in the Barlow Equation 47

**2.15** Design Factor 48

**2.16** Over-Pressures in Pipelines [45] 49

**2.17** Area for Classification in ASME B31.8 50

**2.18** Proximity Distances for Natural Gas Pipelines 51

**2.19** Pipeline Bend Terminology 53

**2.20** Safety Factor 54

**2.21** Technology Developments in Pipeline Construction [13] 55

**2.22** The ‘Spread’ Method 56

**3.1** Pipeline Integrity Management System (PIMS) Elements 60

**3.2** Walter Shewhart’s Process 60

**3.3** The Japanese PDCA Cycle Evolved from Deming Wheel 60

**3.4** The 1993 PDSA Cycle Adapted from Deming 61

**3.5** Elements of an Asset Management System from BSI PAS 55-1:2008 (Source: British Standard Institute and Institute of Asset Management, BSI Group) 62

**3.6** Pipeline Integrity Threat Assessment Process Using a MS Approach 66

**3.7** Pipeline Integrity Hazard and Threat Management Cycle 66

**3.8** Pipeline Consequence Assessment Process Using a Management System Approach 67

**3.9** Pipeline Risk Management Process within the Management System Framework 67

**3.10** Integrity Assessment Method Selection 69

**3.11** Mitigation, Prevention, and Monitoring Process Using a Management System Approach 73

**3.12** Fitness-For-Service Assessment Process Using a MS Approach 74

**3.13** Compliance and Conformance Verification Process with a Management System Approach 75

**3.14** Integrity Management Review with a Management System Approach 77

**3.15** Integrity Management Performance Cycle [MS] 78

**4.1** Examples of Robustness Levels of Hazard Identification and Evaluation Process 80

**4.2** Examples of Threat Management Cycle Process 80

**4.3** Hazard and Threat Management Road Map 81

**4.4** Pipeline Integrity Threat Management Process within Management System Approach 82

**4.5** Example of Hazard and Threat Identification Steps and Processes 90

**4.6** Example of Event Tree Analysis of a Natural Gas Pipeline Leakage 92

**4.7** Example of Event Tree Analysis of Overpressure Incident 92

**4.8** Example of Standard Symbols Used in Fault Tree Analysis (FTA) (Source: Microsoft Corporation, Microsoft Visio 2007) 93

**4.9** Example of Fault Tree Analysis for Pipeline Failure due to Equipment Impact 95

**4.10** Illustration of SCC Susceptibility Analysis Flow Chart 97

**4.11** Example for Determining the Integrity Assessment Selection in a Pipeline Susceptible to a Threat 98

**4.12** Example of Maximum Critical Flow Size for Leak and Rupture Failure Modes 101

**4.13** Example of Flow Stress-Dependent Equation Graph for Leak and Rupture Boundaries 102

**4.14** Example of Probability of Failure from a Fault-Tree Analysis 104

**4.15** Frequency Distribution: Differences Between ILI Reported and As-Found Depth 104

**4.16** ILI Probability Density Function Describing Different ILI Tolerance and Certainty 106

**4.17** Field versus ILI Predicted Depth and Probability of Exceedance for Leak 107

**4.18** Field versus ILI Predicted Burst Pressure and Probability of Exceedance for Rupture 108


**4.20** Cumulative POE Leak Based-Criteria for Selecting ILI Excavation Program Scenarios 110

**5.1** Pipeline Consequence Assessment Process with a Management System Approach 114

**5.2** Discharge or Release Volume Affected by Elevation (Source: New Century Integrity Plus) 116

**5.3** Example of Drain Down and Total Volume Factoring Automatic or Remotely Operated Valves (Source: New Century Integrity Plus) 117

**5.4** Phases of Liquid Pipeline Dispersion (No Ignition) 118

**5.5** Samples of Overland Flow and Tracing on Water Model Results (Source: New Century Integrity Plus) 119

**5.6** Dispersion Phases of an Underground Gas Release (No Ignition) 120

**5.7** Dispersion Phases of a Two-Phase Fluid (HVP) Release (No Ignition) 121

**5.8** Example of Vapor Cloud Model Results (Source: New Century Integrity Plus, Software: Canary by Quest Consultants) 122

**5.9** Example of a Pool Fire Consequence Extent (Source: New Century Integrity Plus) 123

**5.10** Momentum Jet Cloud and Flare (Source: New Century Integrity Plus, Software: Canary by Quest Consultants) 125

**5.11** Vapor Cloud ½ LFL (Red), Thermal Radiation (Orange), and Overpressure (Yellow) (Source: New Century Integrity Plus, Software: Canary by Quest Consultants) 127

**5.12** Fireball Dimensions and Distance to Receptor 128

**5.13** Toxic Dose and Percentage of Affected Individuals 129

**5.14** Class Location versus Consequence of a Pipeline Failure (Source: National Transportation Safety Board, USA) 132

**5.15** Proposed HCA Radius versus Actual Pipeline Failures in the USA and Canada (Source: Stephens, M.J., Leewis, K., Moore, Daron K., 2002, A Model for Sizing High Consequence Areas Associated with Natural Gas Pipelines, ASME International Pipeline
8.10 MFL Eddy Current—Remote Field Technology (Source: Russell NDE Systems) 180
8.11 Differential GPS or Tie Point to the Inertial Data at a Selected Location (Source: Rosen Group) 183
8.12 Example of the Possible Combination of Geometry, IMU, and AMFL Tools (Source: Rosen Group) 184
8.13 Schematic View of a High Performance Cleaning Tool with a Data Logger (Source: Rosen Group) 186
8.14 Photo of a Robotic Inspection Tool (Source: Diakont) 194
8.15 EMAT Scan of a Robotic Tool (Left) of Internal Corrosion (Right) (Source: Diakont) 194
8.16 Laser Scanning and Scan Results (Source: Diakont) 194
8.17 Robotic Vehicle Utilizing PEMAT Scanner (Source: Rosen Group) 195
8.18 Crack and Signal Obtained from PEMAT (Source: Rosen Group) 195
9.1 Pressure Testing of Pipelines 198
9.2 Hoop Stress Caused by Internal Pressure 198
9.3 Energy in a Pressure Test 199
9.4 Condition Assessment Methods for Pipelines 199
9.5 Pipelines are Made from Sections of Line Pipe 199
9.6 Mill Testing Sequence 200
9.7 Pressure and Hold Periods in the Pressure Test 201
9.8 Pressure Testing Pipelines in the Field 202
9.9 Safety Margin Following a Successful Pressure Test 203
9.10 ASME B31.4 Testing Requirements 203
9.11 Anomaly Profile and Hoop Stress at Failure 205
9.12 The ‘High Level’ Test and ‘Test to Yield’ 206
9.13 Biaxial Stressing during a Pressure Test [15, 28] 206
9.14 The Strength ("Proof") Test 207
9.15 The Leak Test 208
9.16 Problem with Short, Deep Defects 209
9.17 Defect Growth (Δd) during a Pressure Test 209
9.18 Pressure Reversal during a Pressure Test 209
9.19 The Spike Test 210
9.20 Defects Surviving the Pressure Test and Maximum Operating Pressure (MOP) 212
9.21 Time of Test Failures [48] 213
9.22 UK Experience of Pressure Test Failures in Natural Gas Pipelines (up to 1974) [21] 213
9.23 Plan-Do-Check-Act for Pressure Testing 215
10.1 Graphical Illustration of the NACE Direct Assessment Methodology (Source: NACE International) 220
10.2 Pipeline Integrity Management System Diagram for Direct Assessment 220
10.3 Illustration of an External Corrosion Direct Assessment Process 221
10.4 ACVG (Left) and CIS (Right) Being Performed (Source: JW’s Pipeline Integrity Services) 223
10.5 CIS Being Performed (Source: JW’s Pipeline Integrity Services) 224
10.6 DCVG Being Performed (Source: JW’s Pipeline Integrity Services) 224
10.7 Examples of Linear Polarization Resistance (LPR) Probes (Source: EnhanceCo) 226
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Evolution of Line Pipe Used in Pipelines [13]</td>
<td>37</td>
</tr>
<tr>
<td>2.2</td>
<td>Size Increases in Pipelines over the Past Century [14]</td>
<td>37</td>
</tr>
<tr>
<td>2.3</td>
<td>Increase in Line Pipe Strengths by Decade [14]</td>
<td>37</td>
</tr>
<tr>
<td>2.4</td>
<td>Increase in Toughness by Decade [19]</td>
<td>38</td>
</tr>
<tr>
<td>2.5</td>
<td>Typical Outline of an Environmental Assessment [22]</td>
<td>40</td>
</tr>
<tr>
<td>2.6</td>
<td>ASME B31.8’s Four Location Classes</td>
<td>42</td>
</tr>
<tr>
<td>2.7</td>
<td>High Consequence Areas in the USA as Defined by PHMSA in 2011</td>
<td>42</td>
</tr>
<tr>
<td>2.8</td>
<td>The Business Process</td>
<td>43</td>
</tr>
<tr>
<td>2.9</td>
<td>Hazard Potential of Some Pipeline Substances</td>
<td>45</td>
</tr>
<tr>
<td>2.10</td>
<td>Classification of Pipeline Substances in ISO 13623 [3]</td>
<td>45</td>
</tr>
<tr>
<td>2.11</td>
<td>Key Parameters Affecting Flow Rate</td>
<td>46</td>
</tr>
<tr>
<td>2.12</td>
<td>Hoop Stress Design Factors in Standards</td>
<td>48</td>
</tr>
<tr>
<td>2.13</td>
<td>Over-Pressure Allowances in Standards</td>
<td>49</td>
</tr>
<tr>
<td>2.14</td>
<td>Location Classifications in ASME B31.8</td>
<td>50</td>
</tr>
<tr>
<td>2.15</td>
<td>Protecting Pipelines against Damage</td>
<td>51</td>
</tr>
<tr>
<td>2.16</td>
<td>Examples of Awareness Methods</td>
<td>51</td>
</tr>
<tr>
<td>3.1</td>
<td>Correlation of Pipeline Integrity Threat Names from Industry Standards</td>
<td>65</td>
</tr>
<tr>
<td>4.1</td>
<td>Correlation of Pipeline Integrity Threat Names from Industry Standards</td>
<td>83</td>
</tr>
<tr>
<td>4.2</td>
<td>Example of Failure Mechanisms, Integrity Threat, and Its Associated Integrity Hazards</td>
<td>83</td>
</tr>
<tr>
<td>4.3</td>
<td>Cases of Susceptibility, Identification and Assessment Levels</td>
<td>98</td>
</tr>
<tr>
<td>4.4</td>
<td>Example of Qualitative Matrix of Interactive Threat Combination</td>
<td>99</td>
</tr>
<tr>
<td>5.1</td>
<td>Coefficients for Potential Impact Radius Formulae for Some Gases (Source: Courtesy of USA Department of Transportation)</td>
<td>134</td>
</tr>
<tr>
<td>6.1</td>
<td>Example of Societal Risk Estimation with and without Aversion</td>
<td>143</td>
</tr>
<tr>
<td>6.2</td>
<td>Differentiating Scenario-Based, Index/Relative and Probabilistic/Quantitative Risk Assessment Methods</td>
<td>148</td>
</tr>
<tr>
<td>6.3</td>
<td>Example of Failure Mechanisms</td>
<td>152</td>
</tr>
<tr>
<td>7.1</td>
<td>Integrity Threat Type and In-Line Inspection Technology Principle</td>
<td>160</td>
</tr>
<tr>
<td>7.2</td>
<td>Pressure Testing Types and Purpose</td>
<td>160</td>
</tr>
<tr>
<td>7.3</td>
<td>Direct Assessment Types and Purpose</td>
<td>160</td>
</tr>
<tr>
<td>7.4</td>
<td>Example of Adding Integrity Assessment Methods</td>
<td>164</td>
</tr>
<tr>
<td>8.1</td>
<td>ILI MFL, Caliper, and Ultrasonic Technology Capability for Detection and Sizing (2016)</td>
<td>172</td>
</tr>
<tr>
<td>9.1</td>
<td>Energy in a Pressure Test [8]</td>
<td>199</td>
</tr>
<tr>
<td>9.3</td>
<td>Historical Testing Requirements in API 5L of Line Pipe Prior to 1942 [14]</td>
<td>201</td>
</tr>
<tr>
<td>9.4</td>
<td>Historical Testing Requirements in API 5L of Line Pipe After 1941 [14]</td>
<td>202</td>
</tr>
<tr>
<td>9.5</td>
<td>ASME B31.8 Pressure Test Requirements</td>
<td>203</td>
</tr>
<tr>
<td>9.8</td>
<td>Assessment Intervals from ASME B31.8S-2014 [43]</td>
<td>211</td>
</tr>
<tr>
<td>9.9</td>
<td>Location of Pressure Test Failures</td>
<td>213</td>
</tr>
<tr>
<td>11.1</td>
<td>Correlation of Pipeline Integrity Threat Names from Industry Standards</td>
<td>234</td>
</tr>
<tr>
<td>11.2</td>
<td>Pipeline Integrity Threat Prevention Examples</td>
<td>235</td>
</tr>
<tr>
<td>11.3</td>
<td>Pipeline Integrity Consequence Prevention Examples</td>
<td>235</td>
</tr>
<tr>
<td>11.4</td>
<td>Pipeline Integrity Threat Prevention Exercise</td>
<td>236</td>
</tr>
<tr>
<td>11.5</td>
<td>Pipeline Integrity Threat Mitigation Examples</td>
<td>236</td>
</tr>
<tr>
<td>11.6</td>
<td>Pipeline Integrity Consequence Mitigation Examples</td>
<td>237</td>
</tr>
<tr>
<td>11.7</td>
<td>Pipeline Integrity Threat Monitoring Examples</td>
<td>237</td>
</tr>
<tr>
<td>11.8</td>
<td>Pipeline Integrity Consequence Monitoring Examples</td>
<td>238</td>
</tr>
<tr>
<td>12.1</td>
<td>Definitions [14]</td>
<td>253</td>
</tr>
<tr>
<td>12.2</td>
<td>Crack Growth Calculation</td>
<td>260</td>
</tr>
<tr>
<td>12.3</td>
<td>Crack Growth Calculations with Y Varying</td>
<td>260</td>
</tr>
<tr>
<td>12.4</td>
<td>Metal Loss Assessment Levels in ASME B31G [59]</td>
<td>262</td>
</tr>
<tr>
<td>12.5</td>
<td>Choice of Flow Stress in ASME B31G</td>
<td>262</td>
</tr>
<tr>
<td>12.6</td>
<td>Input for Worked Example (Level 1, ASME B31G)</td>
<td>264</td>
</tr>
<tr>
<td>12.7</td>
<td>Typical Charpy (CVN) Toughness in Line Pipe over Seven Decades</td>
<td>266</td>
</tr>
<tr>
<td>12.8</td>
<td>Comparison of Corrosion Assessment Methods [58]</td>
<td>266</td>
</tr>
<tr>
<td>12.9</td>
<td>Interaction Criteria for Corrosion Defects</td>
<td>268</td>
</tr>
<tr>
<td>12.10</td>
<td>Corrosion Growth Rates in Soils</td>
<td>268</td>
</tr>
<tr>
<td>12.11</td>
<td>Growth Rates for Differing Types of Corrosion</td>
<td>268</td>
</tr>
<tr>
<td>12.12</td>
<td>Assessment Methods for Cracks in Pipelines</td>
<td>269</td>
</tr>
<tr>
<td>12.13</td>
<td>Example of a Crack Assessment Using a FAD (Inputs)</td>
<td>270</td>
</tr>
<tr>
<td>12.14</td>
<td>Failures in ERW Line Pipe</td>
<td>272</td>
</tr>
<tr>
<td>12.15</td>
<td>Pipeline Failures and Casualties (USA, 1993–2012) [116]</td>
<td>275</td>
</tr>
<tr>
<td>12.16</td>
<td>Dent Acceptance Levels</td>
<td>278</td>
</tr>
<tr>
<td>12.17</td>
<td>Dent Fatigue Models</td>
<td>279</td>
</tr>
<tr>
<td>12.18</td>
<td>Effect of Dents Containing Defects [54]</td>
<td>280</td>
</tr>
<tr>
<td>12.19</td>
<td>Ripple Acceptance Criteria in ASME B31.4</td>
<td>280</td>
</tr>
<tr>
<td>13.1</td>
<td>Example of Corrective and Preventive Action Plans from a Screening Verification</td>
<td>293</td>
</tr>
<tr>
<td>13.2</td>
<td>Example of Corrective and Preventive Action Plans from a Inspection</td>
<td>294</td>
</tr>
<tr>
<td>13.3</td>
<td>Example of Pipeline Integrity Immediate or Technical Causes</td>
<td>303</td>
</tr>
<tr>
<td>13.4</td>
<td>Example of Integrity Management System Basic or Root Causes</td>
<td>304</td>
</tr>
<tr>
<td>13.5</td>
<td>Example of Basic Causes Related to the People, Material, Equipment, Operation, and Environment</td>
<td>304</td>
</tr>
</tbody>
</table>