Contents

Acknowledgments xi

Preface xiii

Chapter 1. Assessment and Perception of Nuclear Risk 1

1.1. Introduction. 1
1.2. Danger, exposure, radiotoxicity and risk. 4
1.2.1. Identification of radionuclide hazards 5
1.2.2. Contamination of the environment, including the anthroposphere, by radionuclides 7
1.2.3. Exposure to radiation. 11
1.2.4. Collective doses. 17
1.3. From dose to adverse effect in non-human organisms (flora and fauna) 17
1.3.1. The harmful effects of ionizing radiation 18
1.3.2. The dose–response relationship 20
1.3.3. Recommended threshold values 22
1.4. From dose to adverse effect in humans 24
1.4.1. Deterministic and stochastic effects 24
1.4.2. Dose–response relationships for average doses: epidemiological studies 25
1.4.3. Responses to low doses 26
1.5. Radiation protection and recommendations for human irradiation . . . 32
1.6. Risk perception 35
1.6.1. Probability of a future nuclear accident 36
1.6.2. Countries using or renouncing the use of nuclear energy 37
1.6.3. Opinion polls on nuclear power 38

1.6.4. Estimated risk and perceived risk 41
1.7. Conclusion 42

Chapter 2. Lessons from the Past in the Field of Nuclear Accidents 45

2.1. Early signals and late lessons 45
2.2. Structures for disseminating information on radioactive risk. 45
2.2.1. Situation from 1945 to 1990 46
2.2.2. Situation from the Chernobyl accident to the present day 47
2.2.3. The example of France. 48
2.2.4. Future change? 50
2.3. Feedback (REX) 51
2.3.1. Introduction: what is REX? 51
2.3.2. The overall REX process 52
2.3.3. Causes of REX failure 54
2.4. Lessons from the past 55
2.4.1. Lessons learned from military nuclear activities and accidents 55
2.4.2. Lessons from industrial accidents 57
2.4.3. Medical accidents. 72
2.5. Crisis exercises. 77
2.5.1. Transnational exercises 77
2.5.2. National exercises 78
2.6. Incident and accident reporting 80
2.6.1. A common severity scale 80
2.6.2. Management of declarations 81
2.6.3. Reporting systems 81
2.6.4. Websites 82
2.7. Conclusion 83

Chapter 3. Research for the Future 85

3.1. Introduction: safety and the main types of accidents. 85
3.1.1. Safety history 85
3.1.2. The main safety objectives 86
3.1.3. Defense in depth 87
3.1.4. New research in the field of nuclear safety 88
3.1.5. The aging of nuclear installations 90
3.2. International actions. 92
3.2.1. Improving the organization of security at the level of each state. 92
3.2.2. The IAEA 94
3.2.3. The NEA 95

3.2.4. The ICRP . . . 98
3.2.5. UNSCEAR . . . 99
3.2.6. The ICRU . . . 100
3.2.7. The IRSN at international level . . . 100
3.3. European actions . . . 101
3.3.1. Euratom . . . 101
3.3.2. Complementary safety assessments (ECS) process . . . 102
3.4. French actions . . . 103
3.5. Advances in nuclear safety . . . 106
3.5.1. Better knowledge of nuclear fuel . . . 107
3.5.2. Better preventing the risk of steam and hydrogen explosions . . . 110
3.5.3. Controlling radionuclide releases . . . 111
3.5.4. Consequences of a fire . . . 112
3.5.5. Knowing more about corium . . . 113
3.5.6. Controlling a water injection into a molten core . . . 115
3.5.7. Mastering electrical distribution systems . . . 115
3.5.8. Improving modeling . . . 116
3.6. Advances in radioecology . . . 118
3.6.1. Determination of the source term . . . 118
3.6.2. Modeling of radionuclide dispersion in the terrestrial environment . . . 119
3.6.3. Modeling of radionuclide dispersion in aquatic environments . . . 120
3.6.4. Modeling of trophic transfer of radionuclides in organisms . . . 121
3.7. Advances in radiation protection . . . 121
3.7.1. Improving the radiological protection system . . . 122
3.7.2. Improving the management of a nuclear accident . . . 125
3.8. Safety research in other types of nuclear installations . . . 128
3.8.1. Cooling pools . . . 128
3.8.2. Spent fuel reprocessing plants . . . 129
3.8.3. Sodium-cooled fast neutron reactors . . . 129
3.8.4. ITER (International Thermonuclear Experimental Reactor) fusion facility . . . 129
3.8.5. Better understanding of criticality . . . 130
3.9. Advances in the humanities and social sciences . . . 130
3.10. Conclusion . . . 131

Chapter 4. Management of the Emergency Phase of a Nuclear Accident . . . 133

4.1. Introduction . . . 133
4.2. The first actions of the threat and rejection periods . . . 134

4.2.1. Radioactive releases in the event of an accident from a nuclear reactor. . . . 135
4.2.2. Radioactivity measurements during a nuclear accident. . . . 136
4.3. Population management in the emergency phase. . . . 138
4.3.1. Containment or sheltering of the population . . . 140
4.3.2. Mass evacuation or evacuation of part of the population. . . . 141
4.3.3. Distribution of stable iodine tablets . . . 152
4.4. Food supply management . . . 156
4.4.1. Recommended values . . . 156
4.4.2. Regulatory values. . . . 158
4.5. Intervention levels for the protection of populations. . . . 160
4.5.1. International recommendations. . . . 160
4.5.2. The texts of the various states . . . 163
4.6. The organization of crisis management in France . . . 164
4.6.1. Documentation of the ORSEC plan . . . 165
4.6.2. The subdivisions of the ORSEC plan . . . 167
4.6.3. French actors in nuclear crisis management . . . 167
4.6.4. The internal emergency plan . . . 168
4.6.5. The plan particulier d'intervention (PPI, special intervention plans) . . . 170
4.6.6. Other complementary plans of the PPI . . . 180
4.7. Exiting the emergency phase . . . 182
4.8. Conclusion . . . 183

Chapter 5. Management of the Post-accident Phase . . . 185

5.1. Introduction. . . . 185
5.2. The actions to be taken . . . 186
5.2.1. Priority actions to be undertaken . . . 187
5.2.2. Actions during the transitional period . . . 188
5.2.3. Long-term actions . . . 189
5.2.4. Radioactivity measurements following a nuclear accident. . . . 190
5.3. Environmental management . . . 191
5.3.1. Management of aquatic environments. . . . 191
5.3.2. Management of terrestrial environments . . . 193
5.4. Managing the anthroposphere . . . 195
5.4.1. Decontamination of living areas . . . 196
5.4.2. Nuclear waste management . . . 196
5.4.3. Agricultural management . . . 197
5.4.4. Managing the economy . . . 202
5.4.5. Food supply management . . . 203
5.5. Management of exposed populations. . . . 204
5.5.1. Limiting people's exposure to radiation . . . 204

5.5.2. Radiological monitoring of exposed populations 206
5.5.3. Radiological and health monitoring of nuclear workers 208
5.5.4. Health monitoring of exposed populations 208
5.5.5. The return of evacuated populations 209
5.5.6. The experience of local populations in contaminated environments 211
5.5.7. Human dignity 211
5.6. The organization of post-accident management 212
5.6.1. International and European recommendations 212
5.6.2. French doctrine 215
5.7. Conclusion 221

Chapter 6. Terrorist Attacks and Nuclear Security 223

6.1. Introduction 223
6.2. Malicious acts 224
6.2.1. Attempts at radiation aggression 225
6.2.2. The assassination of Alexander Litvinenko 225
6.2.3. Arafat's death 226
6.2.4. Overflights and intrusions into nuclear facilities 228
6.3. Possible terrorist attacks 228
6.3.1. The use of a nuclear weapon 229
6.3.2. The use of a "dirty" bomb 229
6.3.3. Attack on a nuclear installation or transport 231
6.3.4. The release of radioactive material 231
6.3.5. Cyber-attacks 232
6.4. The consequences of a terrorist act in the nuclear field 233
6.4.1. The health consequences 234
6.4.2. The psychological consequences 236
6.4.3. Countermeasures in the event of terrorist attacks 237
6.5. Organizational preparation for a terrorist threat 240
6.6. Prevention of terrorist risk in the nuclear field 242
6.6.1. Nuclear non-proliferation 242
6.6.2. Trafficking in military weapons and radionuclides 245
6.6.3. The actions to be taken 247
6.6.4. The limitation of nuclear materials 248
6.7. Conclusion 249

Chapter 7. General Conclusions 253

7.1. The probability of military and civil accidents 253
7.1.1. Nuclear risks and probabilities 253
7.1.2. The causes of accidents 254
7.2. The environmental consequences of accidents 255

7.3. The health consequences of accidents 256
7.4. The economic consequences of accidents 260
7.5. Prevention of nuclear accidents 262
7.6. Management of the emergency and post-accident phases. 264
7.7. Perception of nuclear risk 264
7.8. Public information. 265

References 269

Acronyms and Abbreviations 339

Index 355