## **Contents**

Foreword ---- V

Preface 2nd Ed ---- VII

About the Editors ---- XV

## List of Contributing Authors — XVII

## Barbara Foster

| 1      | The World of Nanotechnology —— 1                             |
|--------|--|
|        | Foreword —— 1  |
| 1.1    | Introduction —— 1  |
| 1.2    | What is Nanotechnology? —— 3                                 |
| 1.3    | The Growing World of Nanomaterials —— 4                      |
| 1.3.1  | Carbon-Based Nanomaterials —— 4                              |
| 1.3.2  | Colloidal-Based Nanomaterials — 5                            |
| 1.3.3  | Quantum Dots —— 7  |
| 1.3.4  | Biologically Based Nanomaterials — 7                         |
| 1.4    | Instrumentation for Investigating Nanotechnology —— 7        |
| 1.5    | Where is Nanotechnology Today? —— 11                         |
| 1.6    | Applications —— 12   |
| 1.7    | The Role of the Government in Promoting Nanotechnology —— 16 |
| 1.7.1  | US Funding —— 16   |
| 1.7.2  | Global Policy —— 17  |
| 1.7.3  | Impact of the UN —— 18                                       |
| 1.8    | The Nanotechnology Market —— 23                              |
| 1.8.1  | Is There Really a "Nanotechnology Market"? —— 23             |
| 1.8.2  | What Is the Size of the Nanotechnology Market? —— 27         |
| 1.8.3  | Nanotechnology Market Sectors —— 29                          |
| 1.9    | The Challenge of Nanotechnology Safety —— 33                 |
| 1.10   | The Crucial Need for Education and Certification —— 34       |
| 1.11   | The Future —— 38   |
| 1.11.1 | NNI's Signature Initiatives (as of 2021) —— 38               |
| 1.11.2 | Other Intriguing Future Initiatives —— 40                    |
| 1.11.3 | Energy Out of Thin Air —— 42                                 |
| 1.11.4 | Solar Cells —— 43  |
| 1.12   | Themes for Thought —— 44                                     |
|        | Bibliography —— 44   |



| Eylem A  | smatulu  |
|----------|--|
| 2        | The World of Engineering Nanomaterials —— 49                   |
| 2.1      | Introduction —— 49   |
| 2.1.1    | How Did Engineering Nanomaterials Evolve? —— 49                |
| 2.2      | Stabilization of Nanomaterial Shape —— <b>51</b>               |
| 2.2.1    | Surfactants —— <b>51</b>                                       |
| 2.2.2    | Nanomaterial Shape and Stabilization —— <b>51</b>              |
| 2.3      | Classification and Labeling of Nanomaterials —— <b>54</b>      |
| 2.3.1    | What Are Nanomaterials? —— <b>54</b>                           |
| 2.3.2    | Types of Nanoparticles —— <b>55</b>                            |
| 2.3.3    | Labeling of Nanomaterials —— <b>57</b>                         |
| 2.4      | Toxicity of Nanomaterials —— <b>59</b>                         |
| 2.4.1    | Particle Size <b>—— 59</b>                                     |
| 2.4.2    | Surface Chemistry —— <b>59</b>                                 |
| 2.4.3    | Surface Charges —— <b>60</b>                                   |
| 2.4.4    | Surface Area —— <b>60</b>                                      |
| 2.5      | Exposure Assessment —— <b>60</b>                               |
| 2.5.1    | Exposure Limit for Nanoparticles —— <b>60</b>                  |
| 2.5.2    | Exposure Monitoring —— 64                                      |
| 2.6      | Conclusions —— 65  |
|          | Bibliography —— <b>66</b>                                      |
| W. S. Kh | an and R. Asmatulu   |
| 3        | The Importance of Safety for Manufacturing Nanomaterials —— 69 |
| 3.1      | Introduction —— 69   |
| 3.2      | Nanotechnology Involvement —— 70                               |
| 3.2.1    | Scope of Nanotechnology —— <b>70</b>                           |
| 3.2.2    | Nanotechnology Education and Research Programs —— 72           |
| 3.3      | Nanostructured Materials —— <b>74</b>                          |
| 3.3.1    | Nanoparticles —— <b>75</b>                                     |
| 3.4      | Toxicity of Nanomaterials —— 78                                |
| 3.4.1    | Toxicity of Carbon-Based Nanomaterials —— <b>79</b>            |
| 3.4.2    | Toxicity of Metal-Based Nanomaterials —— <b>81</b>             |
| 3.5      | In Vitro Assessments of Nanomaterial Toxicity —— 83            |
| 3.5.1    | Detection of Surface Contamination —— 83                       |
| 3.5.2    | Particle Sizing and Aggregation —— <b>84</b>                   |
| 3.6      | Nano-safety —— <b>87</b>                                       |
| 3.6.1    | Potential Safety Issues —— <b>88</b>                           |
| 3.6.2    | Exposure Assessment and Characterization —— 88                 |
| 3.6.3    | Precautionary Measures —— <b>89</b>                            |
| 3.7      | Conclusions —— 90  |
|          | Bibliography —— 90   |

| Jitendra | S. Tate and Roger A. Hernandez                                       |
|----------|--|
| 4        | Safety Approaches to Handling Engineered Nanomaterials —— 93         |
| 4.1      | Introduction —— 93   |
| 4.2      | Potential Health Concerns —— 93                                      |
| 4.3      | Proactive Measures to Examine Precautions —— 94                      |
| 4.4      | Assessment of Engineered Nanomaterials —— 95                         |
| 4.4.1    | Hazard Assessment —— 95  |
| 4.4.2    | Hazardous Communication —— 96  |
| 4.4.3    | Exposure Assessment —— 96  |
| 4.5      | Characterization of Engineered Nanomaterials —— 98                   |
| 4.5.1    | Fullerenes 98  |
| 4.5.2    | Carbon Nanotubes —— 98   |
| 4.5.3    | Carbon Black —— 98   |
| 4.5.4    | Quantum Dots —— 99   |
| 4.5.5    | Metals and Metal Oxides —— 99  |
| 4.6      | Control Preferences —— 100   |
| 4.7      | Management of Engineered Nanomaterials —— 103                        |
| 4.7.1    | Waste Disposal —— 103  |
| 4.7.2    | Management of Spills —— 104  |
| 4.8      | Overview of National and International Associations that Adopted the |
|          | Handling and Use of Nanomaterials —— 105                             |
| 4.8.1    | British Standards Institution (BSI) —— 105                           |
| 4.8.2    | Health and Safety Executive (HSE) —— 106                             |
| 4.8.3    | International Organization for Standardization (ISO) —— 107          |
| 4.8.4    | Organization for Economic Cooperation and Development (OECD) —— 107  |
| 4.8.5    | U.S. National Institute for Occupational Safety and Health —— 108    |
| 4.8.6    | Safe Work Australia (SWA) —— 109                                     |
|          | Bibliography —— 110  |
| Christie | M. Sayes, James Y. Liu, and Matthew Gibb                             |
| 5        | Certification: Validating Workers' Competence in Nano-safety —— 115  |
| 5.1      | Introduction —— 115  |
| 5.2      | Definition of Nanotechnology for Training and Certification —— 116   |
| 5.3      | Occupational and Environmental Health and Safety Management —— 116   |
| 5.4      | Anticipating Hazards in Nanotechnology —— 119                        |
| 5.5      | Recognizing Hazards in Nanotechnology —— 120                         |
| 5.6      | Evaluating Hazards in Nanotechnology —— 121                          |
| 5.7      | Controlling Hazards in Nanotechnology —— 122                         |
| 5.8      | Confirming Hazards in Nanotechnology —— 124                          |
| 5.9      | Conclusions —— 125   |
| 5.10     | Time to Reflect Questions —— 125                                     |
|          | Bibliography —— 125  |

| Walt Try   | /bula and Deb Newberry   |
|------------|--|
| 6          | Understanding the Implications of Material Unknowns —— 127                   |
| 6.1        | Introduction —— 127  |
| 6.2        | Background on Nanotechnology Safety Programs —— 128                          |
| 6.3        | What Are Nanomaterial Unknowns? —— 131                                       |
| 6.4        | Impact to the Public —— 133  |
| 6.5        | Risk Avoidance —— 135  |
| 6.6        | Ethics —— 137  |
| 6.7        | Government Pressure to Create Facts —— 138                                   |
| 6.8        | There Is No Place for Politics or Opinions —— 140                            |
| 6.9        | Summary —— <b>142</b>  |
|            | Bibliography —— <b>143</b>   |
| Evelyn H   | l. Hirt and Walt Trybula   |
| 7          | What is Considered Reliable Information? —— 145                              |
| 7.1        | Introduction —— 145  |
| 7.2        | Background on the Use of "nano" —— 146                                       |
| 7.3        | Information 'Fact and Fiction' the Dangers —— 148                            |
| 7.3.1      | Questionable Correlations in Chinese Workers' Deaths —— 149                  |
| 7.3.2      | Questionable Identification of "Nano" Specific Dangers —— 149                |
| 7.3.3      | Questionable Correlation of Carbon Nanotubes to Asbestos —— 150              |
| 7.3.4      | Issues with NanoSilver Particles —— <b>150</b>                               |
| 7.3.5      | Over Generalization of Human Contact with Nanomaterials —— 151               |
| 7.3.6      | Impacts of Litigation on Fact Finding and Misleading Correlations —— 152     |
| 7.3.7      | Sources with Conflicting Information —— 152                                  |
| 7.3.8      | Separating 'Fact and Fiction' —— <b>153</b>                                  |
| 7.3.9      | Source of Generated Information —— 153                                       |
| 7.4        | Validity and Availability of Information Sources —— 154                      |
| 7.4.1      | Professional Societies Resources & Publications —— 155                       |
| 7.4.2      | Government Sponsored Publications & Recourses —— 156                         |
| 7.4.3      | Other Information Resources —— 156   |
| 7.5        | Summary Observations —— <b>157</b>   |
|            | Bibliography —— <b>157</b>   |
| J. Craig I | Hanks and Emily Kay Hanks  |
| 8          | Ethics and Communication: The Essence of Human Behavior —— 159               |
| 8.1        | Introduction —— 159  |
| 8.2        | The Challenge of Ethics for Emerging Technologies —— 160                     |
| 8.3        | What Does It Take to Be a Good Professional? —— 161                          |
| 8.4        | Technical and Procedural Knowledge and Skill Are Necessary, but not          |
|            | Enough <b>—— 162</b>   |
| 8.5        | Guidance from Rules Is Necessary, but Compliance Is not Enough —— <b>163</b> |

| 8.6      | Considering Ethical Frameworks —— 166                              |
|----------|--|
| 8.6.1    | Deontology and Kant: Autonomy and Respect for Persons —— 166       |
| 8.6.2    | The Pursuit of Happiness: Utilitarian Ethics —— 169                |
| 8.6.3    | Virtue: Character and Practice —— 171                              |
| 8.7      | Communication and Ethics — 174                                     |
| 8.8      | Final Remarks —— 176   |
| 8.9      | Questions —— 176   |
|          | Bibliography —— 177  |
| Christie | M. Sayes, James Y. Liu, and Matthew Gibb                           |
| 9        | Behavior-Based Worker Safety for Engineered Nanomaterials —— 183   |
| 9.1      | Introduction —— 183  |
| 9.2      | Traditional Behavior-Based Worker Safety —— 184                    |
| 9.3      | The ABC Model as Applied to Nanotechnology in the Workplace —— 185 |
| 9.4      | Exposure Scenarios Along the Nanomaterial Value Chain —— 186       |
| 9.4.1    | Stage 1: Production and Manufacturing —— 187                       |
| 9.4.2    | Stage 2: Distribution and Transportation —— 189                    |
| 9.4.3    | Stage 3: Formulators and Users —— 190                              |
| 9.4.4    | Stage 4: Disposal, Recycle, and Reuse —— 191                       |
| 9.5      | The Role of the Employer —— 192                                    |
| 9.6      | Time to Reflect Questions —— 193                                   |
|          | Bibliography —— 193  |
| Dominic  | k Fazarro  |
| 10       | The Future of Nanotechnology Safety —— 197                         |
|          | Bibliography —— 198  |

Index ---- 199