

Contents

Foreword	xiii
List of Contributors	xvii

SECTION 1 PRECAUTION

CHAPTER 1 Nanotechnology Environmental Health and Safety—What We’ve Learned and Where We’re (Potentially) Heading 3

References	7
------------------	---

CHAPTER 2 What Are the Warning Signs That We Should Be Looking For? 9

2.1 Early warning signs	10
2.2 Cautionary tales, but is anyone listening?	13
2.3 Two steps forward and one step back? Or one step forward and two steps back?	14
2.3.1 Lessons 1–3: Heed the “warnings”	14
2.3.2 Lessons 4 and 11: Reduce obstacles to action	15
2.3.3 Lessons 5 and 8: Stay in the real world	16
2.3.4 Lessons 6 and 9: Consider wider issues	16
2.3.5 Lesson 7: Evaluate alternative solutions	17
2.3.6 Lesson 10: Maintain regulatory independence	18
2.3.7 Lesson 12: Avoid paralysis by analysis	18
2.4 But have we done enough?	19
References	20

CHAPTER 3 Are We Willing to Heed the Lessons of the Past? Nanomaterials and Australia’s Asbestos Legacy..... 25

3.1 Introduction	25
3.2 Lessons of the past	26
3.3 Big problems with small materials	31
3.4 Controls and risk assessment	34
3.5 What needs to be done?	39
3.6 Answering the call for precaution?—SWA approach to ENMs post 2009	41

3.7	Emerging from the shadow: 2009 SWA report	41
3.8	A big shift: 2010–2012.....	42
3.9	A move toward higher levels of control	46
3.10	Conclusions.....	48
	Acknowledgment	49
	References.....	49

SECTION 2 PROGRESS

CHAPTER 4 Characterization of Nanomaterials for NanoEHS Studies 55

4.1	Introduction.....	55
4.2	Morphology.....	56
4.3	Chemical composition.....	59
4.4	Standard reference materials and method standards	62
4.5	Incidental nanoparticles and nanoparticle cycles under relevant conditions	64
4.6	Advanced measurement techniques	69
4.7	Routine analysis	70
4.8	Reporting recommendations	71
4.9	Conclusions.....	72
	References.....	72

CHAPTER 5 Toxicological Issues to Consider When Evaluating the Safety of Consumer Products Containing Nanomaterials 77

5.1	Introduction.....	78
5.2	Types of consumer products that contain nanomaterials	79
5.3	Life cycle exposure to nanomaterials in consumer products	80
	5.3.1 Occupational exposure to nanomaterials	80
	5.3.2 Consumer exposure to nanomaterials	83
	5.3.3 Environmental exposure.....	83
5.4	Nanotoxicology	85
5.5	Safety evaluations of consumer products containing nanomaterials	92
5.6	Characterizing nanomaterials for toxicological evaluation.....	97
	5.6.1 TEM and SEM	99
	5.6.2 Energy dispersive spectroscopy	100
	5.6.3 Atomic force microscopy	100
	5.6.4 Electron diffraction	100

5.6.5 X-ray diffraction.....	101
5.6.6 Inductively coupled plasma mass spectroscopy	101
5.6.7 X-ray fluorescence	102
5.6.8 Dynamic light scattering	102
5.6.9 Nanoparticle tracking analysis	103
5.6.10 Field-flow fractionation.....	103
5.6.11 Brunauer, Emmett, and Teller (BET)	104
5.6.12 Raman and other spectroscopies	105
5.6.13 Summary of characterizing nanomaterials for toxicological studies.....	106
5.7 Recommendations for companies developing nano-containing consumer products	107
5.8 Conclusion.....	107
References	109

CHAPTER 6 Nanomaterials Ecotoxicology: A Case Study with Nanosilver..... 117

6.1 Introduction.....	117
6.2 Importance of comprehensive assessment of in-use applications	118
6.2.1 Incorporation into applications	118
6.3 General ecotoxicology	121
6.3.1 Toxicity.....	121
6.3.2 Bioaccumulation	125
6.3.3 Mechanism/mode of toxicity (MoA)	127
6.4 Environmental modifying factors.....	131
6.5 Dosimetry considerations.....	134
6.5.1 Mass standard.....	134
6.5.2 Particle size and shape	135
6.5.3 Particle number and number density	135
6.5.4 Total surface area.....	136
6.5.5 Dissolved fraction and kinetics	136
6.5.6 Corrected molar concentrations	138
6.5.7 Covariance between metrics and dose–response visualizations.....	138
6.6 Ecotoxicology related to modeled environmental concentrations	139
6.7 Conclusions and applicability of nanosilver to general nanotoxicology	140
References	142

CHAPTER 7 A Nanomaterial Registry.....	153
7.1 Introduction.....	153
7.1.1 Mission.....	154
7.1.2 Overview of the current Registry tool.....	155
7.2 Registry concepts	158
7.2.1 Data content: MIANs	158
7.2.2 Data content: IOC	159
7.2.3 Data quality: compliance to the MIAN.....	161
7.3 Data curation	163
7.3.1 Example of data curation: assigning IOCs.....	165
7.3.2 Example of data curation: PCC data	167
7.4 Leveraging initiatives in nanotechnology	167
7.5 Conclusions.....	170
Acknowledgments.....	170
References	170
CHAPTER 8 Nanoinformatics: Data-Driven Materials Design for Health and Environmental Needs	173
8.1 Overview	173
8.2 Introduction—the information challenge.....	174
8.3 Quantifying information complexity in nanoscience.....	180
8.4 Harnessing nanoinformatics: case studies.....	187
8.4.1 Data-driven design of nanoparticles: attribute selection methods	187
8.4.2 A data science framework for exploring beyond physics: mapping the property landscape with limited information	188
8.5 Big data for nanotechnology policy	190
References	195
SECTION 3 PERSPECTIVES	
CHAPTER 9 A Case Study of a Nanoscale-Research Facility: Safety Through Design and Operation.....	201
9.1 The BNC facility	202
9.2 Safety considerations	205
9.3 Designing in safety.....	208
9.4 Identification of hazard potentials in the BNC.....	215
9.5 Designing in safety—key examples.....	217
9.6 Gas hazard mitigation design	218
9.7 Summary	222

CHAPTER 10	Commercialization of Cellulose Nanocrystal (NCC™) Production: A Business Case Focusing on the Importance of Proactive EHS Management.....	225
10.1	Introduction.....	225
10.2	Regulatory framework in Canada.....	227
10.3	Physical–chemical characterization of NCC™	229
10.3.1	Characterization of NCC™ in aqueous solutions.....	229
10.3.2	Characterization of spray-dried NCC™	231
10.4	Ecotoxicological and toxicological test results for NCC™.....	233
10.5	Occupational and environmental testing at the NCC™ demonstration plant	236
10.5.1	Testing of spray-dried NCC™ in the laboratory.....	237
10.5.2	Testing for potential occupational exposure to NCC™ at the CelluForce demonstration plant.....	239
10.5.3	Fate of NCC™ released to the effluent treatment system	242
10.6	Conclusions.....	244
	References.....	245
CHAPTER 11	Nanotechnology Risk Management: An Insurance Industry Perspective	247
11.1	Introduction.....	247
11.2	Risk management strategies.....	248
11.2.1	Risk avoidance.....	248
11.2.2	Risk mitigation.....	249
11.2.3	Risk retention (self-insurance).....	249
11.2.4	Risk transfer (insurance).....	249
11.3	Which strategy to choose?	249
11.3.1	The role of insurance	250
11.3.2	Relationship between insurance and innovation.....	250
11.4	Insurance exposure and tools for risk management.....	251
11.4.1	Product liability	252
11.4.2	Environmental liability	253
11.4.3	Selecting the “Best” nanotechnology risk management option: MCDA as a tool	254
11.5	Potential risk management and regulatory issues for nanomaterials	258
11.6	Likely insurance scenarios.....	259
11.6.1	Stage I: The early study phase.....	259

11.6.2 Stage II: The fear phase	260
11.6.3 Stage III: The mature phase	261
11.7 Conclusions.....	262
References.....	262

CHAPTER 12 A Nanotechnology Legal Framework..... 265

12.1 Nano-product legal life cycle.....	266
12.1.1 Supply stage.....	267
12.1.2 Manufacturing stage	268
12.1.3 Intermediate use stage.....	268
12.1.4 Consumer stage.....	268
12.1.5 Disposal stage	270
12.2 Legal issues.....	270
12.2.1 Intellectual property	270
12.2.2 Workplace and occupational liability.....	276
12.2.3 Worker's compensation.....	279
12.2.4 Intentional workplace torts	280
12.2.5 Commercial and contractual liability.....	281
12.2.6 Government regulation	282
12.2.7 Product and tort liability in the US	300
12.2.8 Product and tort liability in the EU	305
12.3 Conclusion	307
References.....	308

CHAPTER 13 Two Steps Forward, One Step Back: Shaping the Nanotechnologies Landscape Through Regulatory Choice..... 313

13.1 Shaping behavior through regulation: subtle and not so subtle approaches.....	315
13.1.1 State-based regulation.....	316
13.1.2 Civil-based regulation.....	317
13.1.3 Co-regulation	319
13.2 Key lessons and recommendations of regulatory reviews to date.....	320
13.3 Multilateral and multiparty initiatives: the story so far	324
13.4 Moving forward amidst uncertainty	327
References.....	329

SECTION 4 SUSTAINABILITY

CHAPTER 14	Exploring Boundaries Around the Safe Use of Advanced Materials: A Prospective Product-Based Case Studies Approach	339
14.1	Introduction.....	340
14.2	Defining advanced materials.....	341
14.3	Advanced material risks and safe use—a prospective product-based case study approach	344
14.4	Testing the prospective product case study methodology—an example using a hypothetical dynamic food product label.....	351
14.5	A prospective product case study—a graphene-based dynamic labels for food products	352
14.5.1	Product description	352
14.5.2	Material generation.....	354
14.5.3	Intermediary production	354
14.5.4	Final production.....	355
14.5.5	Product storage and transportation	355
14.5.6	Product use.....	355
14.5.7	Product disposal.....	356
14.5.8	Exposure potential	356
14.5.9	Risk red flags	359
14.5.10	Summary	360
14.6	Utility of the prospective product case study methodology.....	360
	Acknowledgments	361
	References.....	362
CHAPTER 15	Nanomaterial Governance, Planetary Health, and the Sustainocene Transition	365
15.1	Introduction.....	365
15.2	Nanotechnology safety in global context.....	366
15.3	Regulatory uncertainty and nano-sunscreens	368
15.4	Regulatory uncertainty and nanosilver	369
15.5	Paths to greater nanoregulatory certainty	372
15.6	Reorienting global regulation so nanotechnology assists the Sustainocene	376
15.7	Reorienting the scientific quest toward nanotechnology's role with the Sustainocene	377

15.8	Rethinking the ethics of corporate globalization	379
15.9	Reorienting international law to nanotechnology's role with the Sustainocene	381
15.10	The moral culmination of nanoregulation in globalized artificial photosynthesis	386
	References.....	389
CHAPTER 16 Sustainable Nanotechnology: A Regional Perspective		395
16.1	Introduction.....	395
16.2	Environmental considerations.....	400
16.2.1	Introduction.....	400
16.2.2	Nanomaterials and health	401
16.2.3	Nanomaterials and the environment	402
16.2.4	Sustainable nanomanufacturing and green nanotechnology.....	403
16.2.5	Conclusions.....	404
16.3	Societal considerations	406
16.3.1	Introduction.....	406
16.3.2	Societal and ethical considerations.....	407
16.3.3	Spiral-theory-based undergraduate engineering curriculum.....	410
16.3.4	Work in progress	414
16.3.5	A student's perspective on sustainable technologies	414
16.4	Economic considerations of nanotechnology and sustainability	415
16.4.1	Introduction.....	415
16.4.2	Virginia's New River Valley.....	416
16.4.3	Conclusions about the NRV nanotech economy.....	418
16.5	Summary	419
	Acknowledgments	420
	References.....	420
Index		425