

CONTENTS

ENVIRONMENTAL HEALTH CRITERIA FOR HUMAN EXPOSURE ASSESSMENT

PREAMBLE	xiii
ABBREVIATIONS	xxii
FOREWORD	xxiv
1. DEFINING EXPOSURE	1
1.1 Introduction	1
1.2 Defining exposure	1
1.2.1 Exposure and exposure concentration	2
1.2.2 Exposure estimation by integration and averaging	3
1.2.3 Exposure measurements and models	4
1.2.4 Exposure in the context of an environmental health paradigm	4
1.3 Elements of exposure assessment	10
1.4 Approaches to quantitative exposure assessment	12
1.5 Linking exposure events and dose events	13
1.6 Summary	14
2. USES OF HUMAN EXPOSURE INFORMATION	16
2.1 Introduction	16
2.2 Human exposure information in environmental epidemiology	16
2.3 Human exposure information in risk assessment	17
2.3.1 Risk allocation for population subgroups or activities	22
2.3.2 Population at higher or highest risk	25
2.4 Human exposure information in risk management	26
2.5 Human exposure information in status and trend analysis	29
2.6 Summary	31

3. STRATEGIES AND DESIGN FOR EXPOSURE STUDIES	35
3.1 Introduction	35
3.2 Study design	35
3.3 Sampling and generalization	37
3.4 Types of study design	37
3.4.1 Comprehensive samples	38
3.4.2 Probability samples	38
3.4.3 Other sample types	41
3.5 Exposure assessment approaches	42
3.5.1 Direct approaches to exposure assessment	42
3.5.1.1 Personal monitoring of inhalation exposures	43
3.5.1.2 Personal monitoring of dietary exposures	44
3.5.1.3 Personal monitoring of dermal absorption exposures	45
3.5.2 Indirect approaches to exposure assessment	46
3.5.2.1 Environmental monitoring	46
3.5.2.2 Models as an indirect approach to assessing exposure	50
3.5.2.3 Questionnaires as an indirect approach to assessing exposure	50
3.6 Summary	51
4. STATISTICAL METHODS IN EXPOSURE ASSESSMENT	53
4.1 Introduction	53
4.2 Descriptive statistics	55
4.2.1 Numerical summaries	55
4.2.2 Graphical summaries	58
4.2.2.1 Histograms	58
4.2.2.2 Cumulative frequency diagrams	58
4.2.2.3 Box plots	61
4.2.2.4 Quantile-quantile plots	62
4.2.2.5 Scatter plots	62
4.3 Probability distributions	64
4.3.1 Normal distribution	66

4.3.2	Lognormal distribution	67
4.3.3	Binomial distribution	69
4.3.4	Poisson distribution	73
4.4	Parametric inferential statistics	75
4.4.1	Estimation	75
4.4.2	Measurement error and reliability	76
4.4.3	Hypothesis testing and two-sample problems	77
4.4.4	Statistical models	80
4.4.4.1	Analysis of variance and linear regression	82
4.4.4.2	Logistic regression	84
4.4.5	Sample size determination	85
4.5	Non-parametric inferential statistics	86
4.6	Other topics	87
4.7	Summary	88
5.	HUMAN TIME-USE PATTERNS AND EXPOSURE ASSESSMENT	89
5.1	Introduction	89
5.2	Methods	96
5.2.1	Activity pattern concepts	96
5.2.1.1	Time allocation parameters	96
5.2.1.2	Microenvironment parameters	97
5.2.1.3	Intensity of contact	97
5.2.2	Surrogates of time-activity patterns	98
5.2.3	Data collection methods	99
5.3	Potential limitations	105
5.3.1	Activity representativeness	106
5.3.2	Validity and reliability	107
5.3.3	Inter- and intra-person variability	109
5.4	Summary	110
6.	HUMAN EXPOSURE AND DOSE MODELLING	112
6.1	Introduction	112
6.2	General types of exposure model	112
6.3	Environmental media and exposure media	114
6.4	Single-medium models	118

6.4.1	Outdoor and indoor air	118
6.4.2	Potable water	119
6.4.3	Surface waters	121
6.4.4	Groundwater	122
6.4.5	Soil	122
6.5	Multiple-media modelling	123
6.5.1	Inter-media transfer factors	124
6.5.1.1	Diffusive partition coefficients	125
6.5.1.2	Advective partition coefficients	125
6.5.2	Exposure factors	126
6.5.3	Multiple-media/multiple-pathway models	127
6.6	Probabilistic exposure models	127
6.6.1	Variability	129
6.6.2	Uncertainty	130
6.6.3	Implementing probabilistic exposure models	131
6.7	A generalized dose model	132
6.8	Physiologically based pharmacokinetic models	135
6.9	Validation and generalization	136
6.10	Summary	137
7.	MEASURING HUMAN EXPOSURES TO CHEMICALS IN AIR, WATER AND FOOD	138
7.1	Introduction	138
7.2	Air monitoring	139
7.2.1	Gases and vapours	162
7.2.1.1	Passive samplers	162
7.2.1.2	Active samplers	162
7.2.1.3	Direct-reading instruments	163
7.2.2	Aerosols	163
7.2.3	Semivolatile compounds	165
7.2.4	Reactive gas monitoring	165
7.3	Water	165
7.3.1	Factors influencing water quality	168
7.3.2	Water quality monitoring strategies	169
7.3.3	Sample collection	171
7.4	Assessing exposures through food	172
7.4.1	Duplicate diet surveys	173
7.4.2	Market basket or total diet surveys	174

7.4.3	Food consumption	175
7.4.3.1	Food diaries	176
7.4.3.2	24-h recall	177
7.4.3.3	Food frequency questionnaires	177
7.4.3.4	Meal-based diet history	179
7.4.3.5	Food habit questionnaires	179
7.4.4	Contaminants in food	180
7.5	Summary	180
8.	MEASURING HUMAN EXPOSURE TO CHEMICAL CONTAMINANTS IN SOIL AND SETTLED DUST	182
8.1	Introduction	182
8.2	Selected sampling methods	184
8.2.1	Soil	184
8.2.1.1	Surface soil collection	184
8.2.1.2	Soil contact and intake measurements	184
8.2.2	Settled dust	185
8.2.2.1	Wipe sampling methods	185
8.2.2.2	Vacuum methods	188
8.2.2.3	Sedimentation methods	190
8.3	Sampling design considerations	190
8.3.1	Concentration and loading	192
8.3.2	Collection efficiency	195
8.4	Sampling strategies	196
8.5	Summary	199
9.	MEASURING BIOLOGICAL HUMAN EXPOSURE AGENTS IN AIR AND DUST	200
9.1	Introduction	200
9.2	House dust mites	204
9.2.1	Air sampling for house dust mites	204
9.2.2	Dust sampling for house dust mites	206
9.2.3	Available methods of analysis for house dust mites	207
9.2.3.1	Mite counts	207
9.2.3.2	Immunochemical assays of dust mite allergens	207

9.2.3.3	Guanine determination	209
9.2.4	Mite allergens	209
9.3	Allergens from pets and cockroaches	211
9.3.1	Air sampling for allergens from pets and cockroaches	212
9.3.2	Dust sampling for allergens from pets and cockroaches	213
9.3.3	Available methods of analysis	213
9.3.4	Typical allergen concentrations	213
9.4	Fungi	214
9.4.1	Air sampling for fungi	214
9.4.2	Settled dust for fungi	218
9.4.3	Available methods of analysis for fungi in air	218
9.4.3.1	Total counts of viable and non-viable fungal particles	220
9.4.4	General considerations for fungi	220
9.5	Bacteria (including actinomycetes)	221
9.5.1	Air sampling for bacteria	222
9.5.2	Dust sampling for bacteria	222
9.5.3	Available methods of analysis for bacteria	223
9.5.3.1	Total count of viable and non-viable bacteria	223
9.5.3.2	Viable bacteria	223
9.5.3.3	Endotoxins	224
9.6	Pollen	225
9.6.1	Air sampling for pollen	225
9.6.2	Dust sampling for pollen	225
9.6.3	Available methods of analysis for pollen in air	227
9.6.4	General considerations for pollen sampling	227
9.7	Summary	228
10.	ASSESSING EXPOSURES WITH BIOLOGICAL MARKERS	230
10.1	Introduction	230
10.2	General characteristics	231

10.3	Considerations for use in environmental exposure assessment	231
10.3.1	Toxicokinetics and toxicodynamics	233
10.3.2	Biological variability	235
10.3.3	Validation of biological markers	235
10.3.4	Normative data	236
10.4	Advantages of biological markers for exposure assessment	237
10.4.1	Characterizing inter-individual variability	237
10.4.2	Efficacy of use	238
10.4.3	Internal exposure sources	239
10.5	Limitations of biological markers for exposure assessment	240
10.5.1	Source identification	240
10.5.2	Biological variability and altered exposure response	240
10.5.3	Participant burden	241
10.5.4	Biosafety	242
10.6	Media available for use	242
10.6.1	Blood	243
10.6.2	Urine	247
10.6.3	Exhaled breath	248
10.6.4	Saliva	249
10.6.5	Keratinized tissue (hair and nails)	250
10.6.6	Ossified tissue	251
10.6.6.1	Teeth	251
10.6.6.2	Bone	251
10.6.7	Breast milk	252
10.6.8	Adipose tissue	253
10.6.9	Faeces	253
10.6.10	Other media	253
10.7	Summary	253
11.	QUALITY ASSURANCE IN EXPOSURE STUDIES	255
11.1	Introduction	255
11.2	Quality assurance and quality control	255
11.3	Elements of a quality assurance programme	256
11.4	Quality assurance programme	257
11.4.1	Organization and personnel	258

11.4.2	Record-keeping and data recording	258
11.4.3	Study plan and standard operating procedures	259
11.4.4	Collection of samples	259
11.4.5	Equipment maintenance and calibration	260
11.4.6	Internal audit and corrective action	260
11.5	Quality control/quality assurance for sample measurement	260
11.5.1	Method selection and validation	260
11.5.1.1	Accuracy	261
11.5.1.2	Precision	262
11.5.1.3	Sensitivity	263
11.5.1.4	Detection limits	263
11.5.2	Internal quality control	265
11.5.2.1	Control charts	265
11.5.3	External quality control	266
11.5.4	Reference materials	272
11.6	Quality assurance and control issues in population-based studies	273
11.7	Summary	274
12.	EXAMPLES AND CASE STUDIES OF EXPOSURE STUDIES	276
12.1	Introduction	276
12.2	Exposure studies	280
12.3	Air pollution exposure studies	280
12.3.1	Particle studies	280
12.3.2	Carbon monoxide	286
12.3.3	Nitrogen dioxide	288
12.3.4	Ozone	290
12.3.5	Combined exposure studies	291
12.3.6	Assessing ambient pollution impacts indoors	292
12.3.7	Volatile organic compounds	294
12.3.8	Commuter exposures	301
12.4	Exposures and biomarkers	303
12.4.1	Exposure to lead and cadmium	303
12.4.2	Exposure to furans, dioxins and polychlorinated biphenyls	306

12.4.3	Exposure to volatile organic compounds and urinary metabolites	308
12.5	Exposure to contaminants in drinking-water	309
12.6	Exposure to microbes	312
12.7	Exposure studies and risk assessment	315
12.7.1	The German Environmental Survey	315
12.7.2	The National Human Exposure Assessment Survey	315
12.7.3	Windsor, Canada exposure and risk study	317
12.7.4	Pesticide exposure study	318
12.7.5	Czech study of air pollution impact on human health	319
REFERENCES		320
RÉSUMÉ		358
RESUMEN		367