

CONTENTS

ENVIRONMENTAL HEALTH CRITERIA FOR ZINC

PREAMBLE	xi
ABBREVIATIONS	xxii
1. SUMMARY AND CONCLUSIONS	1
1.1 Identity, and physical and chemical properties.....	1
1.2 Analytical methods.....	1
1.3 Sources of human and environmental exposure	1
1.4 Environmental transport, distribution and transformation.....	2
1.5 Environmental concentrations	3
1.5.1 Human intakes	4
1.6 Kinetics and metabolism in laboratory animals and humans.....	4
1.7 Effects on laboratory animals	5
1.8 Effects on humans	6
1.9 Effects on other organisms in the laboratory and field.....	8
1.10 Conclusions	9
1.10.1 Human health.....	9
1.10.2 Environment	10
2. IDENTITY, PHYSICAL AND CHEMICAL PROPERTY, AND ANALYTICAL METHODS	11
2.1 Identity	11
2.2 Physical and chemical properties.....	11
2.2.1 Zinc metal.....	11
2.2.2 Zinc compounds	14
2.3 Analytical methods.....	18
2.3.1 Introduction	18
2.3.2 Sampling and sample preparation.....	18
2.3.3 Separation and concentration.....	21

2.3.4	Detection and measurement.....	22
3.	SOURCES OF HUMAN AND ENVIRONMENTAL EXPOSURE	29
3.1	Natural occurrence.....	29
3.2	Anthropogenic sources	31
3.2.1	Production levels and processes	31
3.2.1.1	Production levels.....	31
3.2.1.2	Production processes.....	32
3.2.2	Uses	33
3.2.3	Emissions during production and use.....	36
3.2.3.1	Emissions to atmosphere.....	37
3.2.3.2	Emissions to aquatic environment	38
3.2.3.3	Emissions to soil	40
3.2.4	Emissions during combustion of coal and oil, and refuse incineration	41
3.2.5	Zinc releases from diffuse sources	41
3.2.5.1	Releases from atmospheric zinc corrosion.....	41
3.2.5.2	Releases from sacrificial zinc anodes.....	42
3.2.5.3	Household zinc emissions.....	42
4.	ENVIRONMENTAL TRANSPORT, DISTRIBUTION AND TRANSFORMATION	44
4.1	Transport and distribution between media	44
4.1.1	Air.....	44
4.1.2	Water and sediment	46
4.1.2.1	Fresh water.....	47
4.1.2.2	Seawater.....	48
4.1.2.3	Wastewater.....	49
4.1.2.4	Groundwater	49
4.1.2.5	Sediment	50
4.1.3	Soil.....	51
4.2	Bioavailability	55
4.2.1	Factors affecting bioavailability	55

4.2.2	Techniques for estimation	56
4.3	Biotransformation	56
4.3.1	Biodegradation	56
4.3.2	Bioaccumulation	57
4.3.2.1	Aquatic organisms	58
4.3.2.2	Terrestrial organisms	59
5.	ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE..	66
5.1	Environmental levels	66
5.1.1	Air.....	66
5.1.2	Precipitation.....	69
5.1.3	Water	70
5.1.3.1	Fresh water.....	70
5.1.3.2	Seawater.....	74
5.1.4	Soil.....	77
5.1.5	Sediments and sewage sludge.....	82
5.1.6	Aquatic and terrestrial organisms	84
5.1.6.1	Aquatic plants and animals	84
5.1.6.2	Terrestrial plants and animals	85
5.2	General population exposure	86
5.2.1	Air.....	86
5.2.2	Food.....	87
5.2.3	Drinking-water	90
5.2.4	Miscellaneous exposures	91
5.3	Occupational levels.....	91
5.4	Total human intake from all sources	93
5.4.1	General population	93
5.4.2	Bioavailability in mammalian systems	93
5.4.3	Occupational exposure	98
6.	KINETICS AND METABOLISM IN MAMMALS	100
6.1	Absorption	100
6.1.1	Inhalation.....	100
6.1.1.1	Human studies.....	100
6.1.1.2	Animal studies	100
6.1.2	Oral.....	100

	6.1.2.1	Human studies.....	100
	6.1.2.2	Animal studies	102
	6.1.3	Dermal... ..	102
	6.1.3.1	Human studies.....	102
	6.1.3.2	Animal studies	102
6.2		Distribution.....	104
6.3		Excretion.....	105
6.4		Biological half-life.....	106
6.5		Zinc status and metabolic role in humans.....	107
	6.5.1	Methods for assessment of zinc status in humans	107
	6.5.1.1	Dietary methods to predict the proportion of the population at risk of inadequate intakes of dietary zinc.....	107
	6.5.1.2	Static tests of zinc status	109
	6.5.1.3	Functional tests of zinc status	114
	6.5.1.4	New approaches.....	116
	6.5.2	Metabolic role.....	117
	6.5.2.1	Zinc metalloenzymes	117
	6.5.2.2	Metallothionein.....	120
	6.5.2.3	Other metabolic functions of zinc.	121
	6.5.3	Human studies	122
	6.5.3.1	Copper	122
7.		EFFECTS ON LABORATORY MAMMALS AND <i>IN VITRO</i> TEST SYSTEMS.....	123
	7.1	Single exposure	123
	7.1.1	Lethality.	123
	7.1.2	Acute studies: summary of key findings	123
	7.2	Short-term exposure	124
	7.2.1	Oral exposure.....	124
	7.2.2	Inhalation exposure	127
	7.3	Long-term exposure.....	130
	7.3.1	Oral exposure.....	130
	7.4	Skin irritation.....	135
	7.5	Reproductive toxicity, embryotoxicity and teratogenicity	135

7.6	Mutagenicity and related end-points	141
7.6.1	<i>In vitro</i> studies	142
7.6.2	<i>In vivo</i> studies	142
7.7	Carcinogenicity... ..	143
7.8	Interactions with other metals.....	148
7.8.1	Zinc and copper	148
7.8.2	Zinc and other metals	151
7.9	Zinc deficiency in animals.....	152
8.	EFFECTS ON HUMANS.....	157
8.1	Human dietary zinc requirements.....	157
8.1.1	Estimation of zinc requirements	157
8.2	Zinc deficiency	169
8.2.1	Clinical manifestations	169
8.2.2	Brain function.....	169
8.2.3	Immune function	170
8.2.4	Growth... ..	170
8.2.5	Dermal effects	171
8.2.6	Reproduction	171
8.2.7	Carcinogenicity.....	172
8.3	Zinc toxicity: general population.....	175
8.3.1	Poisoning incidents.....	175
8.3.2	Dermal effects	176
8.3.3	Immune function	176
8.3.4	Reproduction	177
8.3.5	Zinc-induced copper deficiency	178
	8.3.5.1 Controlled human studies	178
	8.3.5.2 Case reports	181
8.3.6	Serum lipids and cardiovascular disorders ...	181
8.4	Occupational exposure	184
8.4.1	Acute toxicity	184
8.4.2	Short-term exposure	184
8.4.3	Long-term exposure.....	187
8.4.4	Epidemiological studies.....	187
8.5	Subpopulations at special risk	188
8.5.1	Dialysis patients.....	188
8.5.2	People with diabetes	188
8.5.3	Hospital patients	189

8.5.4	Other populations	189
8.6	Interactions	190
8.6.1	Copper	190
8.6.2	Iron	190
8.6.3	Calcium	192
9.	EFFECTS ON OTHER ORGANISMS IN THE LABORATORY AND FIELD	193
9.1	Laboratory experiments.....	194
9.1.1	Microorganisms.....	195
9.1.1.1	Water.....	195
9.1.1.2	Soil.....	195
9.1.2	Aquatic organisms	196
9.1.2.1	Plants.....	196
9.1.2.2	Invertebrates and vertebrates	200
9.1.2.3	Effects on communities	229
9.1.3	Terrestrial organisms	231
9.1.3.1	Plants.....	231
9.1.3.2	Invertebrates	238
9.1.3.3	Vertebrates.....	239
9.2	Tolerance to zinc	242
9.3	Interactions with other metals.....	244
10.	EVALUATION OF HUMAN HEALTH RISKS AND EFFECTS ON THE ENVIRONMENT	246
10.1	Homeostatic model.....	246
10.2	Evaluation of risks to human health	246
10.2.1	Exposure of general population.....	247
10.2.2	Occupational exposure	248
10.2.3	Risks of zinc deficiency.....	249
10.2.4	Risks of zinc excess.....	249
10.3	Evaluation of effects on the environment.....	250
10.3.1	Environmental risk assessment.....	250
10.3.2	Components of risk assessment for essential elements	251
10.3.3	Environmental risk assessment for zinc	252
10.3.3.1	Environmental concentrations	252

10.3.3.2	Overview of toxicity data	253
11.	CONCLUSIONS AND RECOMMENDATIONS FOR PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	256
11.1	Human health.....	256
11.2	Environment	257
12.	RECOMMENDATIONS FOR FURTHER RESEARCH ...	258
12.1	Zinc status.....	258
12.2	Functional indices of zinc status.....	258
12.3	Interactions with other trace elements	258
12.4	Supplementation	259
12.5	Occupational medicine	259
12.6	The molecular mechanism	259
12.7	Environment	259
	REFERENCES	260
	RÉSUMÉ ET CONCLUSIONS	337
	RESUMEN Y CONCLUSIONES	349