

CONTENTS

1. INTRODUCTION	1
1.1. Background	1
1.2. Objectives	3
1.3. Scope	4
1.4. Related IAEA publications	6
1.5. Organization	6
2. NATURALLY OCCURRING RADIONUCLIDES	7
3. PROCESSES ENHANCING CONCENTRATIONS AND THE POTENTIAL FOR PUBLIC EXPOSURE TO NORM	7
3.1. Enhanced concentrations versus enhanced exposure potential	7
3.2. Technologically enhanced concentrations	10
3.3. Enhanced potential for human exposure to NORM	11
4. FUELS	12
4.1. Oil and gas	12
4.1.1. Introduction	12
4.1.2. Processes	13
4.1.3. Residues	15
4.1.4. Management of residues	18
4.1.5. Residue management technologies	21
4.2. Coal mining and combustion	22
4.2.1. Introduction	22
4.2.2. Processes	25
4.2.3. Residues	26
4.2.4. Management of residues	31
5. WATER	33
5.1. Geothermal energy production	33
5.1.1. Introduction	33
5.1.2. Processes	34
5.1.3. Residues	36
5.1.4. Management of residues	39

5.1.5. Environmental impacts	40
5.2. Drinking water treatment	41
5.2.1. Introduction	41
5.2.2. Processes	43
5.2.3. Residues	44
5.2.4. Management of residues	45
5.2.5. Environmental impacts	47
5.3. Wastewater treatment	48
5.4. Industrial process waters	48
5.5. Irrigation	49
 6. METALS	49
6.1. Mining and processing methods	49
6.1.1. Open pit mining	49
6.1.2. Underground mining	50
6.1.3. Solution mining	51
6.1.4. Beneficiation	52
6.1.5. Mining and milling residues	52
6.2. Mine waters	54
6.3. Aluminium	55
6.3.1. Introduction	55
6.3.2. Processes	57
6.3.3. Residues	58
6.3.4. Management of residues	58
6.4. Iron	59
6.4.1. Introduction	59
6.4.2. Processes	59
6.4.3. Residues	60
6.5. Copper	62
6.5.1. Introduction	62
6.5.2. Processes	63
6.5.3. Residues	64
6.6. Gold	65
6.6.1. Introduction	65
6.6.2. Processes	66
6.6.3. Residues and their management	67
6.6.4. Radionuclide contents	70
6.6.5. Environmental impacts	71
6.7. Mineral sands and related industries	71
6.7.1. Introduction	71

6.7.2.	Occurrence	73
6.7.3.	Processes	74
6.7.4.	Residues	78
6.7.5.	Radionuclide contents	83
6.7.6.	Remediation	83
7.	INDUSTRIAL MINERALS	87
7.1.	Phosphate mining and fertilizer production	87
7.1.1.	Introduction	87
7.1.2.	Basic processes in the phosphate industry	87
7.1.3.	Processing of phosphate ore: Acid leaching	88
7.1.4.	Elemental phosphorus production with the thermal process	96
7.1.5.	Environmental impact of residues	98
7.1.6.	Concentrations of radionuclides in fertilizers	99
7.1.7.	Utilization of by-products and residues	101
7.1.8.	Measures for improvement and remediation	102
7.2.	Clay, ceramics and building materials	103
7.2.1.	Introduction	103
7.2.2.	Processing	106
7.2.3.	Residues	106
8.	USE OF VARIOUS RADIO-ELEMENTS	108
8.1.	Uranium	108
8.1.1.	Introduction	108
8.1.2.	Mining processes	109
8.1.3.	Residues	109
8.2.	Radium	111
8.3.	Thorium..	111
9.	VARIOUS INDUSTRIAL PROCESSES	113
9.1.	Sulphuric acid production by burning pyrites	113
9.1.1.	Introduction	113
9.1.2.	Processes	113
9.1.3.	Residues	114
9.2.	Burning of shales to extract oil	116
9.3.	River and harbour dredging	116
9.4.	Wastes from the decommissioning of industrial facilities	117

10. REGULATORY ASPECTS	117
11. IMPACTS OF NORM CONTAINING RESIDUES	119
12. SELECTED MANAGEMENT AND REMEDIATION STRATEGIES AND TECHNOLOGIES	123
12.1. Principles	123
12.2. Cleanup technologies	127
12.2.1. Containment	128
12.2.2. Immobilization	130
12.2.3. Dilution/dispersion	132
12.2.4. Natural attenuation	133
12.2.5. Separation	135
12.2.6. Treatment of waters and effluents	135
12.3. Cleaner technologies	136
12.3.1. Tools	136
12.3.2. Reuse/recycle	138
12.3.3. Avoidance at source	139
13. SOCIOECONOMIC IMPACT OF MANAGEMENT AND REMEDIATION MEASURES	140
14. SUMMARY AND CONCLUSIONS	142
APPENDIX I: TIN MINING AND RELATED PROCESSES IN MALAYSIA	145
APPENDIX II: TITANIUM PROCESSING	151
APPENDIX III: RARE EARTH ELEMENT PROCESSING IN MALAYSIA	158
APPENDIX IV NIOBIUM PROCESSING IN BRAZIL	164
REFERENCES	173
GLOSSARY	195
CONTRIBUTORS TO DRAFTING AND REVIEW	197