

Table of Contents

PREFACE.....	13
.ACKNOWLEDGEMENTS.....	15
1 INTRODUCTION.....	17
1.1 The smallest particles	17
1.2 Theories of nuclear energy	20
1.3 Development during the Second World War	23
1.4 The Manhattan project.....	26
1.5 Other nuclear programs	33
1.6 Energy of the sun.....	35
1.6.1 The American hydrogen bomb	35
1.6.2 The Soviet hydrogen bomb.....	36
1.7 Opposition voices	36
2. NUCLEAR REACTORS.....	38
2.1 The first power reactors	38
2.2 Fast breeder reactors.....	38
2.2.1 USA	38
2.2.2 The United Kingdom	40
2.2.3 France	40
2.2.4 The Soviet Union.....	40
2.3 Graphite reactors.....	42
2.3.1 The Soviet Union.....	42
2.3.2 Magnox in the UK	42
2.3.3 The AGR in the UK.....	43
2.3.4 UNGG in France	43
2.3.5 The HTGR in the US.....	43
2.3.6 The Pebble Bed Reactor in Germany	44
2.4 Pressurized water reactors	44
2.4.1 Westinghouse	45
2.4.2 Combustion Engineering.....	46
2.4.3 Babcock Wilcox.....	46

2.4.4 VVER (Rosatom, Atomstroieexport)	47
2.4.5 European PWR reactors.....	48
2.4.6 The Korean PWR reactors.....	49
2.4.7 The Chinese PWR.....	49
2.5 Boiling water reactors.....	50
2.5.1 General Electric BWR.....	50
2.5.2 ABWR (GE Toshiba).....	50
2.5.3 ESBWR (GE Hitachi).....	51
2.5.4 BWR (Asea Atom)	51
2.5.5 BWR (Areva).....	52
2.6 Heavy water reactor	52
2.6.1 Candu.....	52
2.6.2 ACR-1000	53
2.7 Thorium breeder reactors	53
2.7.1 Molten salt reactor	53
2.7.2 VHTR	53
2.7.3 Candu.....	54
2.7.4 AHWR-300	54
2.7.5 Thorium fired light water reactors	54
3. NUCLEAR PROGRAMS.....	55
3.1 Big plans in the United States.....	55
3.2 Finnish nuclear program.....	57
3.3 The slow-down after Chernobyl	60
3.4 The Chinese program.....	63
3.5 The Russian program	65
3.6 The Korean nuclear program	66
3.7 The Indian nuclear program	67
3.8 The Finnish nuclear program after Chernobyl.....	69
4 CLIMATE CHANGE	73
4.1 Temperature history.....	73
4.2 Aerosols	79
4.3 The influence of CO ₂	81
4.4 CO ₂ -emissions.....	83
4.5 The emission targets for fossil fuels	87

4.5.1 Cumulative emission targets	87
4.5.2 Targets for energy industries.....	88
4.6 The emission targets for electricity generation in 2050	90
4.6.1 North America	91
4.6.2 The European Union	92
4.6.3 Finland	92
4.6.4 China.....	92
4.6.5 India and Africa.....	92
4.7 Emission reduction targets for individuals	92
4.7.5 Household energy consumption targets	93
4.7.6 Transportation energy use.....	93
5 PREFERABLE ELECTRICITY SOURCES	96
5.1 Forecasting future electricity consumption.....	96
5.2 Priorities in electricity generation	98
5.2.1 Renewable energy programs in some countries	98
5.2.2 Capacity planning.....	99
5.3 Hydro	99
5.4 Wind power	101
5.5 Biomass.....	104
5.6 Solar power.....	107
5.7 Municipal CHP.....	110
5.8 Industrial CHP generation.....	112
5.9 Summary.....	114
5.9.1 Renewable energy sources	114
5.9.2 CHP electricity generation	115
5.9.3 Preferable electricity generation	117
6 NUCLEAR ELECTRICITY PLAN UNTIL 2100	118
6.1 Uranium resources	118
6.1.1 History.....	118
6.1.2 Uranium consumption in LWR.....	118
6.1.3 Resources of uranium.....	120
6.2 Breeder reactors	121
6.2.1 Plutonium breeder reactors	121
6.2.2 Thorium breeder reactors	122

6.3 A plan until 2100.....	123
6.4 Consumption of uranium.....	127
6.5 The electricity plan after nuclear generation	130
7 FOSSIL ELECTRICITY PLAN FOR 2100.....	133
7.1 Planning process.....	133
7.2 Oil and gas fired plants.....	135
7.3 Coal fired power generation.....	139
7.4 The CO ₂ -emissions of electricity generation.....	140
7.5 Global warming caused by power generation.....	143
7.6 Fossil fuel resources.....	145
8 FROM COAL TO NUCLEAR AGE.....	147
8.1 Electricity generation in the world.....	147
8.2 North America.....	150
8.3 The European Union.....	152
8.4 The rest of Europe (Transitional Economics).....	154
8.5 Japan.....	157
8.6 Latin America.....	159
8.7 The Middle East.....	161
8.8 Africa.....	163
8.9 China.....	165
8.10 India.....	168
8.11 The rest of Asia and Oceania.....	170
9 THE FEASIBILITY OF NUCLEAR POWER.....	173
9.1 Planning of a nuclear project.....	173
9.2 Prefeasibility studies.....	175
9.2.1 Investment costs.....	175
9.2.2 Generation costs.....	176
9.2.3 System costs.....	178
9.3 Site studies.....	180
9.4 State approval.....	181
10 SELECTION OF THE REACTOR SUPPLIER.....	182
10.1 Splitting the project into contracts.....	182
10.2 Prequalified suppliers.....	183
10.3 Boiling water reactor plants.....	183

10.3.1 ABWR	183
10.3.2 ESBWR	183
10.3.3 Kerena.....	186
10.3.4 ABB BWR.....	186
10.4 Pressurized water plants	186
10.4.1 EPR by Areva	186
10.4.4 The APR-1400 by KHNC.....	187
10.4.5 AES-2006.....	188
10.4.6 The EU-APR.....	189
10.5 Technical evaluation	189
10.6 Economical evaluation.....	190
10.6.1 Revenues	190
10.6.2 The costs	191
10.6.3 Cash flow models.....	191
11PROJECT EXECUTION	196
11.1 The preliminary design	196
11.1.1 The preliminary safety analysis report	197
11.1.2 The probabilistic safety assessment	197
11.1.3 Construction license	199
11.2 The detailed design.....	199
11.3 Site preparation	200
11.4 Construction	201
11.5 The installation and startup.....	203
12 PLANT OPERATION AND WASTE DISPOSAL	204
12.1 Operation and maintenance.....	204
12.2 Medium and low level waste disposal.....	205
12.3 High level waste disposal.....	206
12.4 Intermediate storage	207
12.5 Final disposal	207
12.5.1 Fuel canisters	208
12.5.2 Final storage	209
12.6 Spent fuel reprocessing	210
12.7 Financing nuclear waste disposal	211

13 ADVANCED NUCLEAR PLANTS	213
13.1 Construction experiences	213
13.1.1 AP1000.....	214
13.1.2 ATMEA 1	215
13.1.3 ACR-1000	216
13.2 Marine derived reactors	216
13.2.1 The Russian icebreaker derived KLT-40 reactor	217
13.2.2 Merchant ship derived reactors by Babcock Wilcocks	219
13.2.3 NP-300 by Technicatome.....	220
13.3 Modular Fast Breeders	220
13.3.1 SVBR-100	220
13.3.2 Hyperion	221
13.4 Other modular reactors	221
13.4.1 IRIS	221
13.4.2 VK-300	221
13.4.3 VBER-300	222
13.4.4 SSBWR by Hitachi and INET	222
13.4.5 LSBWR by Toshiba	222
14 CONCEPTUAL DESIGN OF A MODULAR NUCLEAR PLANT	223
14.1 Serial production	223
14.1.1 Car manufacturing	223
14.1.2 Power plant manufacturing.....	224
14.2 Selection of a reactor for the modular plant	224
14.3 Conceptual design of the modular plant	225
14.4 Cost reduction trough serial production	227
14.5 Estimating investment costs.....	228
14.6 Cash flow analysis	231
15 LIVING IN A POLLUTED WORLD	235
15.1 Life expectancy	235
15.2 Causes of death	236
15.3 Radiation.....	237
15.3.1 X-rays	237
15.3.2 Radioactivity	238
15.3.3 Radon-222	238

15.3.4 Polonium-210	239
15.3.5 Cesium-137	239
15.3.6 Cesium-134	240
15.3.7 Iodine-131	240
15.3.8 Strontium-90	241
15.4 Other pollutants	241
15.4.1 Particle emissions	241
15.4.2 Nitrogen oxides	244
15.4.3 Sulfur oxides	245
15.4.4 Heavy metals and other difficult substances	246
16 NUCLEAR POWER ACCIDENTS AND THEIR CONSEQUENCES	248
16.1 Nuclear accidents	248
16.2 Three Mile Island	249
16.3 The Chernobyl Accident	250
16.4 The Fukushima accident	253
16.5 Fatalities caused by nuclear accidents	257
16.6 Fatalities in coal production	259
16.7 Accidental fatalities in normal life	259
16.8 The economic costs of accidents and insurance	262
16.9 Learning from the nuclear accidents	263
16.9.1 Core catcher	263
16.9.2 Aircraft protection	264
16.9.3 Blackout protection	264
16.9.4 Safety culture	265
16.9.5 Safety rules	266
17 LIVING UNDER THREAT OF NUCLEARS WEAPONS	267
17.1 The iron curtain	267
17.2 Nuclear tests and crises	268
17.3 Shelters for nuclear war	271
17.4 Nuclear weapons	272
17.4.1 The plutonium bomb	272
17.4.2 The uranium bomb	273
17.5 Nuclear Non-Proliferation Treaty (NPT)	274
17.6 The peace making process	275

18 NUCLEAR ENERGY POLICY.....	277
18.1 Energy without CO ₂ -emissions	277
18.2 New nuclear safety standards	279
18.2.1 Meltdown probability	279
18.2.2 Large release probability	280
18.2.3 Siting rules	281
18.3 New nuclear plants	281
18.4 Nuclear power and democracy.....	282
19 SUMMARY AND CONCLUSIONS	287
APPENDIX A. ELECTRICITY GENERATION SOURCES IN DIFFERENT AREAS	288
Appendix A1 Electricity generations sources in the world	288
Appendix A2 Market shares of electricity sources	288
Appendix A3 Electricity generation sources in North America.....	289
Appendix A4 Electricity generation sources in European Union	289
Appendix A5 Electricity generation sources in Rest of Europe.....	290
Appendix A6 Electricity generation sources in Japan	290
Appendix A7 Market shares of electricity generation in Latin America	291
Appendix A8 Electricity generation sources in the Middle East	291
Appendix A9 Electricity generation sources in Africa	292
Appendix A10 Electricity generation sources in China	292
Appendix A11 Electricity generation sources in India	293
Appendix A12 Electricity generation sources in Rest of Asia Pacific	293
APPENDIX B. SHARE OF ELECTRICITY SOURCES	294
Appendix B1 Share of hydro in electricity generation.....	294
Appendix B2 Share of wind and wave in electricity generation	294
Appendix B3 Share of biomass in electricity generation	295
Appendix B4 Share of solar in electricity generation.....	295
Appendix B5 Share of municipal CHP in electricity generation	296
Appendix B6 Share of industrial CHP in electricity generation.....	296
Appendix B7 Share of nuclear in electricity generation	296
Appendix B8 Share of oil and gas in electricity generation	297
Appendix B9 Share of coal in electricity generation	297

APPENDIX C PROBABILITY TABLES OF REDUNDANT SYSTEMS	298
Appendix C1 Probability that at least $n - m$ units are in operation ($R = 90\%$).....	298
Appendix C2 Probability that at least $n - m$ units are in operation ($R = 95\%$)	299
Appendix C3 Probability that at least $n - m$ units are in operation ($R = 97\%$).....	300
Appendix C4 Probability that at least $n - m$ units are in operation ($R = 99\%$).....	301
CONVERSION FACTORS.....	302
Some examples of radiation doses	303
Some examples of external dose rates.....	303