

Contents

1	Introduction to Nuclear Batteries and Radioisotopes	1
1.1	Fundamental Concepts	3
1.2	Nuclear Battery Design Considerations	9
1.2.1	Surface Interface	14
1.2.2	Volume Interface	16
1.3	Products from Ionizing Radiation: Heat and Ion Pairs	17
1.4	Geometrical Considerations in the Interface of an Isotropic Radiation Source to a Transducer	28
1.5	Methodology for Analysis	33
1.6	Summary	34
	References	35
2	Radioisotopes	39
2.1	Existing Radioisotope Supplies	39
2.1.1	Primordial Radioisotopes	40
2.1.2	Cosmogenic Radioisotopes	41
2.1.3	Manmade Radioisotopes	45
2.2	Radioisotope Production	49
2.2.1	Separation from Spent Fuel	50
2.2.2	Separation from Natural Decay Chains	57
2.2.3	Production by Neutron Capture in a Reactor	63
2.2.4	Production by Accelerator	64
2.3	Cost of Radioisotopes	67
2.3.1	Cost of Separation	67
2.3.2	Cost of Neutron Capture	69
2.3.3	Cost of Accelerator	73
2.4	Other Factors Influencing Cost	74
2.4.1	Safety	74
2.4.2	Software	74
2.4.3	Liquidity of Capital (Cash)	75
2.5	Isotopes Produced from the Manhattan Project	75

2.6	Mixed Oxide Fuel Fabrication Facility (MOX FFF)	75
2.7	Summary	76
	References	77
3	Interactions of Ionizing Radiation with Matter and Direct Energy Conversion	81
3.1	Ionizing Radiation Types and Ranges.	81
3.1.1	Fission Fragments	81
3.1.2	Alpha Particles	87
3.1.3	Beta Particles and Positrons	90
3.1.4	Shielding Considerations.	92
3.1.5	Rules of Thumb and Their Limitations	95
3.1.6	The Limitations of Average Beta Energy	97
3.1.7	What Types of Radiation Work Best with Nuclear Batteries and Why	102
3.2	Types of Transducers Used in Nuclear Batteries	102
3.2.1	Ion Pair Based.	103
3.2.2	Schottky Barriers	113
3.2.3	Direct Charge Collection.	116
3.2.4	Indirect.	125
3.2.5	Solid-State Emitter and PV	149
3.2.6	Hybrid Solid-State Emitter	155
3.2.7	Heat Based	156
3.3	Summary	171
	References	172
4	Power Density Dilution Due to the Interface of the Isotope with the Transducer	177
4.1	Introduction	178
4.2	Phase of the Radioisotope.	180
4.2.1	Radioisotope in Solid Phase	180
4.2.2	Radioisotope in Liquid Phase	182
4.2.3	Radioisotope in Gaseous Phase	183
4.2.4	Gaseous-like Radioisotopes	187
4.3	Phase of the Transducer	189
4.3.1	Solid Phase Transducer.	189
4.3.2	Liquid Phase Transducer.	189
4.3.3	Gas Phase Transducer	192
4.3.4	Plasma Phase Transducer	192
4.4	Surface Interface	192
4.4.1	Methods of Forming Surface Sources	193
4.4.2	Electroplating, Painting and Baking	195

4.4.3	Evaporation and Sputtering	195
4.4.4	Implanting	196
4.5	Charged Particle Escape Probability from Surface Sources	196
4.6	Scale Length Matching	197
4.6.1	Scale Length of Ionizing Radiation	198
4.6.2	Scale Length of Transducer	205
4.7	Geometrical Considerations	209
4.8	Power Density Dilution Factors for Surface Interfaces	215
4.9	Power Density Dilution Factors for Volume Interfaces	216
4.10	Summary	217
	References	218
5	Efficiency Limitations for Various Nuclear	
	Battery Configurations	221
5.1	Basics of Nuclear Battery Design	221
5.1.1	Transducer Efficiencies	222
5.1.2	Direct Charge Nuclear Battery (DCNB)	230
5.2	Radiation Damage	235
5.3	Health and Safety	240
5.3.1	Nuclear Regulatory Commission Rules and Regulations	240
5.3.2	Po-210 Poisoning	243
5.3.3	NASA RTG Safety	245
5.4	System Efficiencies and Power Density	252
5.4.1	Alphavoltaics Analysis	253
5.4.2	Betavoltaics Analysis	258
5.4.3	PIDEC Analysis	260
5.5	Analysis of Problems in Nuclear Battery Literature	269
5.6	Summary	280
	References	282
6	Potential Applications for Nuclear Batteries	285
6.1	Successful Applications	285
6.1.1	Pacemakers	286
6.1.2	Deep Space Probes	286
6.1.3	Curiosity Rover	289
6.1.4	Remote Power Applications	289
6.1.5	Other	290
6.2	Military Missions	291
6.2.1	Light Weight Portable Nuclear Batteries	292
6.2.2	MEMS	298

6.3	MEMS	298
6.3.1	Drones	298
6.3.2	Nano-Power Systems	299
6.3.3	Fission Reactors	302
6.4	Summary	303
	References	304
Appendix A: Range Calculations		307
Appendix B: Beta Spectra		313
Appendix C: Theoretical Nuclear Battery Design Concepts		337
Appendix D: Ranges for Alpha Emitters		343
Index		351

Nuclear Batteries and Radioisotopes

Prelas, M.; Boraas, M.; De La Torre Aguilar, F.; Seelig,

J.-D.; Tchakoua Tchouaso, M.; Wisniewski, D.

2016, XIV, 355 p. 155 illus., 99 illus. in color., Hardcover

ISBN: 978-3-319-41723-3