Contents

Abstract iii

Resumen v

Resum ix

Zusammenfassung xiii

Acknowledgements xvii

List of symbols xxxi

Abbreviations and Acronyms xxxv

1 Introduction and Scope 1
- 1.1 Background . . . 1
- 1.2 Motivation . . . 5
- 1.3 Scope of the Thesis . . . 6
- 1.4 Organization of the Thesis . . . 7

2 Preliminaries and State of the Art 11
- 2.1 Introduction . . . 13
- 2.2 Nuclear Fuel Cycle . . . 14
  - 2.2.1 Exploration of Uranium Deposits . . . 15
  - 2.2.2 Mining and Milling . . . 16
  - 2.2.3 Refining and Conversion . . . 17
  - 2.2.4 Enrichment . . . 17
  - 2.2.5 Fuel Fabrication . . . 18
  - 2.2.6 Electricity Generation . . . 18
  - 2.2.7 Reprocessing . . . 20
  - 2.2.8 Geological Disposal and Radiotoxicity . . . 22
- 2.3 Solid Nuclear Fuel . . . 23
  - 2.3.1 Pellets . . . 24
  - 2.3.2 Particle Fuel . . . 26

2.4 Sphere-Pac Fuel Production 27
2.4.1 Water Extraction Process 28
2.4.2 External Gelation 28
2.4.3 Internal Gelation 29
2.5 State of the Art of the Internal Gelation SP Fuel Production 30
2.5.1 Silicon Oil Internal Gelation 30
2.5.2 Microwaves Internal Gelation 32
2.6 Conclusions 35

3 Thermal Model 37
3.1 Introduction 39
3.2 The Heat Equation 42
3.2.1 Definition 43
3.2.2 Common Forms of the Heat Equation 44
3.3 Heat Equation Solution by Numerical Methods 46
3.3.1 Finite Difference Time Domain Method 46
3.4 Boundary Conditions 50
3.4.1 The Dirichlet Boundary Condition 50
3.4.2 The von Neumann Boundary Condition 50
3.5 Implementation and Results 53
3.5.1 Thermal Parameters Influence 55
3.5.2 Influence of the Coordinates System Election 58
3.6 Validation 60
3.6.1 Physically Validation 60
3.6.2 Matlab Pdetools 63
3.6.3 Validation from a Literature Example 65
3.6.4 Validation Results 66
3.7 Conclusions 67

4 Microwave Cavities 69
4.1 Introduction 71
4.2 Rectangular Cavities 72
4.2.1 Empty Rectangular Cavities 77
4.2.2 Rectangular Cavities filled with homogeneous dielectrics 79
4.3 Cylindrical Cavities 83
4.3.1 Empty Cylindrical Cavities 84
4.3.2 Cylindrical Cavities completely filled with homogeneous dielectrics 86
4.4 Cavity coupling 88

4.4.1 The Coupling Factor 89
4.5 Modelling of Microwave Cavities 91
4.5.1 Matlab Modelling 91
4.5.2 Electromagnetic Simulation Software 101
4.6 Perturbation Analysis of Cavities 103
4.6.1 Experimental setup 103
4.6.2 Perturbation Method 103
4.6.3 Power dissipation 107
4.6.4 Model Implementation and Results 110
4.7 Conclusions 118

5 Characterization of Materials 121
5.1 Introduction 124
5.2 Dielectric Loss 124
5.2.1 Polarization 124
5.2.2 Complex Dielectric Constant 126
5.2.3 Volumetric Heating 128
5.3 Dielectric Measuring Techniques 128
5.4 New Characterization Method of Dielectrics 130
5.4.1 Experimental Setup 131
5.4.2 Drop Measurement 134
5.4.3 Drop Simulation 138
5.4.4 Experimental Measurements and Results 139
5.5 Perturbation and Thermal Models of Characterized Materials 144
5.6 Conclusions 148

6 MIG System 151
6.1 Introduction 153
6.2 MIG System description 154
6.3 Equipment 156
6.3.1 Design of the microwave cavity 156
6.3.2 Microwave generator 159
6.3.3 Amplifier 160
6.3.4 Isolator 161
6.3.5 Waveguides 162
6.3.6 Adapter 164
6.3.7 Crystal Detector 164
6.3.8 Vector Network Analyser 165
6.3.9 Oscilloscope 166

6.3.10 Power requirements 167
6.3.11 Calibration 168
6.4 Experimental Techniques 169
6.4.1 Rectangular cavity characterization 169
6.4.2 MIG System Assembly 171
6.4.3 Heating Experiments 175
6.5 Results Analysis 176
6.6 Conclusions 180

7 Conclusions **181**
7.1 Summary 184
7.2 Further Work 185
7.3 List of Publications 186

Appendices **191**

A Convective Heat Transfer Coefficient **193**
A.1 Dimensionless groups in heat transfer 195
A.2 Properties of Air 196
A.2.1 Standard Properties 196
A.2.2 Temperature Dependent Properties 197

B Crank Nicholson Development **203**
B.1 Rectangular Coordinates 207
B.2 Cylindrical Coordinates 208
B.3 Spherical Coordinates 209
B.4 General equation 211

C Energy and Power Solutions **213**
C.1 Calculation of Energies in a Rectangular Empty Cavity . . 215
C.2 Calculation of Power in a Rectangular Empty Cavity 219

D Bessel Function **223**

Bibliography **229**