Table of Contents

Acknowledgements 2
Abstract 4
Resumen 6
Resum 8
Table of Contents 10
List of Figures 15
1 Introduction 19
1.1 Historical Working Context 19
1.2 Radiation Detectors 20
1.3 Training 20
1.4 Virtual Reality based computer simulation 21
1.5 Thesis structure 23
1.6 Motivation 24
2 Radiation detection, Virtual Reality and Simulation 27
2.1 Radiation Physics Basics 28
2.1.1 Characterization of Atoms..... 28
2.1.2 Radiation 29
2.1.3 Radioactivity 30
2.1.4 Energy 31
2.2 Gamma Radiation Detectors 32
2.2.1 Gas-filled detectors 32
2.2.2 Scintillation detectors 34
2.2.3 Semiconductor detectors 34
2.3 Virtual Reality 36
2.3.1 VR Systems 36
2.3.2 Haptic Interfaces and devices 37
2.3.3 Application of VR in Science and Industry 39
2.3.4 VR applied to Nuclear Safeguards and Security 40
2.4 Radiation transport simulation methods 42

2.4.1 The Monte Carlo Method 43
2.4.2 The Discrete Ordinates Method 46
2.4.3 The Point-Kernel method 48
2.4.4 Hybrid methods 55
3 Precursory development 57
3.1 Characteristics of VR based radiation detector.simulator . 58
3.2 Structure of a VR basedsimulator of a radiation detector. 60
3.3 3D Modelling 62
3.4 Task Behaviours 65
3.5 Physics Behaviours: 1st version: No Dose rate calculation . 68
3.6 Physics Behaviours: 2nd Prototype - Dose Rate mapping ... 70
4 Developed Methodology 76
4.1 Application Structure 77
4.2 1st version: Mono Point Kernel (PK) 79
4.2.1 Rationale of Mono PK version 79
4.2.2 Software architecture of the solution 80
4.2.3 Algorithm description 83
4.3 2nd version: Mono PK with shielding and Build Up..... 85
4.3.1 Rationale of shielding & Buildup version 85
4.3.2 Software architecture of the solution 86

4.3.3 Algorithm Description 88
4.4 3rd version: Octree Multi PK shielding and Buildup 91
4.4.1 Rationale of multi PK version 91
4.4.2 Mesh resolution in Multi PK 92
4.4.3 The solid angle concept 95
4.4.4 Software architecture 97
4.4.5 Algorithmic description 98
4.5 4th version: Octree non-regular Multi PK (S & Buildup) ... 102
4.5.1 Rationale of non-regular division 102
4.5.2 Algorithmic description 103
4.6 5th version: KD tree non-regular Multi PK (S & Buildup) .. 105

4.6.1 Rationale of KD tree version 105
4.6.2 KD-tree division method 106
4.6.3 Algorithmic description of the KD-tree method 107
4.7 6th version: Multi shape Multi PK (S & Build up) 111
4.7.1 Rationale of Multi shape version 111
4.7.2 Finite element boundary representation concept ... 112
4.7.3 Boundary representation challenges 113
4.7.4 Algorithm of finite element BREP post-processing .. 115
4.8 7th version: Multiple sources 117
4.8.1 Rationale of Multi source version 117
4.8.2 Software architecture of the solution 118
4.8.3 Algorithm description 119
4.9 Complementary development 119
5 Testing and Results..... 124
5.1 Test 1: Simulated Cs-137 source 125
5.1.1 Experiment setup 125
5.1.2 Benchmark software codes 126
5.1.3 V1: Mono PK 127
5.1.4 V2: Mono PK with Shielding & Build up 129
5.1.5 V3: Multi PK with Shielding and Build up 132
5.1.6 V4: Multi PK non regular 141
5.1.7 V5: Multi PK non regular KD 147
5.2 Test 2: Real K-40 source 157
5.2.1 Experiment setup 157
5.2.2 Real hand held radiation detector (survey meter) ... 158
5.2.3 V1: Mono PK 160
5.2.4 V2: Mono PK with Shielding & Build up 161
5.2.5 V3: Multi PK with Shielding and Build up 162
5.2.6 V4: Multi PK non regular 168
5.2.7 V5: Multi PK non regular KD 177
5.3 V6 Prototype: Multi PK + Trimming post process 185

5.3.1 Limitations of the parallelepiped representation 185
5.3.2 Post-processing of the source representation 187
5.3.3 Recalibration of the algorithm 189
5.3.4 Testing simulated Cs-137 spherical source 191
5.3.5 Testing simulated Cs-137 cylindrical source 194
5.4 V7 Prototype: Multiple sources 198
5.5 Testing and Results summary table 202
6 Conclusions 204

6.1 Summary of conclusions 204
6.1.1 V1 Mono PK prototype 205
6.1.2 V2 Mono PK with shielding and buildup 205
6.1.3 V3 Multi PK with shielding and buildup 206
6.1.4 V4 Non regular Multi PK with shielding & buildup... 206
6.1.5 V5 KD tree based division method for Multi PK 207
6.1.6 V6 Post processed multi PK 207
6.1.7 V7 Multiple sources 208
6.1.8 Summary of methods 208
6.2 Limitations of the work 209
6.2.1 Inherent PK limitations 209
6.2.2 Geometrical limitations 209
6.2.3 Shielding limitations 209
6.2.4 Flux limitations 210
6.3 Future developments 210
6.4 Concluding statement 211
Bibliography 213
Appendix A 225