Cape Peninsula University of Technology

DEVELOPMENT OF NUCLEAR - RADIOLOGICAL FACILITY MONITORING SYSTEM

by

NASIRU IMAM ZAKARIYA

Thesis submitted in fulfilment of the requirements for the degree

Doctor of Technology: Electrical Engineering

in the Faculty of Engineering

at the Cape Peninsula University of Technology

Supervisor: Prof. MTE Kahn

Bellville

April 2016

DECLARATION

I, Nasiru Imam Zakariya, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

The widespread application of nuclear science and technology has been the subject of much concern as well as nuclear safety issues. And to ensure the safety of public life, property and environment, it is indispensable to improve the emergency system for nuclear accidents and the environmental monitoring system for nuclear radiation, so that the occurrence of nuclear accidents, terrorist incidents and the resulting hazards can be prevented or minimized. Due to the benefits of radiation which were earlier and now recognized in the use of X-rays for medical diagnosis and then later with the discoveries of radiation and radioactivity, there was rush in exploiting the medical benefits which eventually led fairly to the recognition of the risks and induced harm associated with it. Thus, only the most obvious harms resulting from high doses of radiation, such as radiation burns, were initially observed and protection efforts were focused on their prevention, mainly for practitioners rather than patients. Subsequently, it was gradually recognized that there were other, less obvious, harmful radiation effects such as radiation-induced cancer, for which there is certain risk even at low doses of radiation.

Similarly, with the extremely serious repercussions that a nuclear accident could provoke, safety measures are especially important in this kind of facility. As a result, the legislation on nuclear power plants is very strict in safety measures globally. Therefore, the balancing of benefits from nuclear and radiation practices against radiation risk and efforts to reduce the residual risk has become a major feature of radiation protection. Nuclear power plant environmental radiation monitoring is an important component of nuclear accident emergency system with the collection of nuclear radiation data automatically and sending to the data processing centre real-time for decision making. It is therefore important for new systems to be researched and developed in order to improve the prevention systems.

However, in most of the nuclear radiations monitoring systems, data collections were usually transferred by wired network. But these types of systems have a lot of defects, such as high cost of cable deployment, maintenance problems and poor mobility. Therefore in this research, the data packets from radiation detectors installed at various nodes or locations were transmitted to the data processing unit – server room – wirelessly using mesh topology design concept, which transmitted the data from different nodes simultaneously, on high traffic, no failure in data transmission and hence maintenance can be carried out without disrupting other nodes as compared to other topologies. This design concept protects the disruption and breaking of data signals from the source of detection to the destination where control computer processes the data and display the data on real-time monitoring. The results were realized through simulation.

ACKNOWLEDGEMENTS

I wish to thank:

- Dr. Onwunta E. K. Onwunta who stood by me in all supports from admission to submission of this research work.

- Prof. MTE., Kahn, my supervisor, who provided all the academic guidance, moral and financial support I appreciate you.

- Dr. Atanda Raji for his guidance.

- Dr. Yusuf Isa, my brother, my friend for all the support and kindness.

- Sheikh Alhaji Yakub Zakariya, my father, who provided all the encouragement and support from start to completion of this work.

- Hajiya Amina Zakariya, my darling wife, for her patience, endurance and support.

- Mr. Olusanya Olubosola, my professional colleague, for all the technical support.

- Hajiya Fatima Sulaiman, my noble sister for her encouragement.

- Finally, to All-mighty God for seeing me through the programme.

DEDICATION

This work is dedicated to my humble late mother, Hajiya Maryam Zakariya without whom the past would have lost its meaning and my dear late sisters, Munirat Zakariya, Fatima Zakariya and Ketime Zakariya who stood by me during their lifetimes.

TABLE OF CONTENTS

DECLARATION 2
ABSTRACT 3
ACKNOWLEDGEMENTS 4
TABLE OF CONTENTS 6
LIST OF FIGURES 13
LIST OF TABLES 16
GLOSSARY 17
CHAPTER ONE 21
INTRODUCTION 21
1.1 Background 21
1.2 Types of Radiation Monitoring 24
1.3 Problem Statement 24
1.4 Research Objectives 25
1.5 Thesis Statement 25
1.6 Research Scope and Limitations 25
1.7 Significance of the Research 26
1.8 Organization of the Thesis 26
CHAPTER TWO 27
OVERVIEW OF NUCLEAR POWER GENERATIONS 27
2.1 Introduction 27
2.2 Nuclear Power Generation 29
2.3 The Fission Chain Reaction 30
2.4 Nuclear Reactor and Nuclear Power 30
2.4.1 Nuclear Reactor Components 31
2.5 Nuclear Reactors by Generations 32
2.5.1 Generation I 33
2.5.2 Generation II 33
2.5.3 Generation III 33
2.5.4 Generation III+ 33
2.5.5 Generation IV 34
2.6 World Nuclear Reactors by Types 34
2.6.1 BWR 35
2.6.2 FBR 36
2.6.3 GCR 37
2.6.4 LWGR 38
2.6.5 PHWR 39
2.6.6 PWR 40
2.7 Reactor Technology Development and Deployment 41
2.7.1 GIF 44
2.7.1.1 SFR 45
2.7.1.2 VHTR 46
2.7.1.3 LFR 47
2.7.1.4 GFR 48

2.7.1.5 SCWR 49
2.7.1.6 MSR 50
2.7.2 INPRO 52
2.7.3 ENSII 53
2.8 Fast Neutron Reactors (FNR) 54
2.8.1 FBR and Sustainability 55
2.9 Nuclear Reactor Fuel – Uranium 56
2.9.1 Uranium Supply and Demand 57
2.10 Denuclearization 57
2.11 Decommissioning 58
2.12 Radioactive Waste Management 58
2.12.1 Nuclear Fuel Cycle 59
2.12.1.1 Mining and Milling 60
2.12.1.2 Conversion 60
2.12.1.3 Enrichment 60
2.12.1.4 Fuel fabrication 60
2.12.1.5 Spent fuel storage 60
2.12.1.6 Reprocessing 61
2.12.1.7 Vitrification 61
2.12.1.8 Final disposal 61
2.13 Classification of Radioactive Waste 62
2.13.1 Low-level: 62
2.13.2 Intermediate level waste: 62
2.13.3 High level waste: 63
2.14 Conclusion 63
CHAPTER THREE 65
DESIGN FACTORS INFLUENCING BIOLOGICAL EFFECTS OF IONIZING RADIATION 65
3.1 Introduction 65
3.2 Electromagnetic Radiation 65
3.3 An Atom 66
3.3.1 Unstable Atoms and Atomic Decay 67
3.4 Sources of Radiation 69
3.4.1 Natural Radiation 70
3.4.1.1 Cosmic Radiation: 70
3.4.1.2 Terrestrial Radiation: 70
3.4.1.3 Internal Radiation: 72
3.4.2 Artificial (Man-made) Radiation 72
3.5 Ionizing Radiation 72
3.5.1 Types of Ionizing Radiation 73
3.5.1.1 Alpha 73
3.5.1.2 Beta 74
3.5.1.3 Gamma (Y) and X-Ray 74
3.6 Non-Ionizing Radiation 74
3.7 Natural and Artificial Ionizing Radiation Contributions 75

3.8 Health Effects of Ionizing Radiation 76
3.8.1 Acute Respiratory Syndrome 77
3.8.1.1 Prodrome 77
3.8.1.2 Latent Stage 77
3.8.1.3 Manifest Illness Stage 77
3.8.1.4 Recovery or Death 78
3.8.2 Deterministic Effects 78
3.8.3 Stochastic Effects 78
3.9 Radiation Exposure 78
3.9.1 High-level: 78
3.9.2 Medium-Level radiation exposure: 79
3.9.3 Low-level radiation exposure: 80
3.10 The Associated Health Effects of Radiation 80
3.11 Dose Limits 81
3.11.1 Occupational Exposure 81
3.11.2 Public Exposure 82
3.12 Radiation Protection 83
3.12.1 ALARA (As Low as Reasonably Achievable) Concept 85
3.12.2 Radiation Protection Framework 85
3.12.2.1 UNSCEAR 86
3.12.2.2 ICRP 86
3.12.2.3 IAEA 86
3.12.3 Radiation Exposure 86
3.12.3.1 Internal exposure 86
3.12.3.2 External exposure 87
3.12.4 Precautionary Measures of Radiation Protection 87
3.12.4.1Time 87
3.12.4.2 Distance 87
3.12.4.3 Shielding 89
3.13 Conclusion 95
CHAPTER FOUR 96
DESIGN FOR SUSTAINABLE DEVELOPMENT WITH NUCLEAR SOURCES 96
4.1 Introduction 96
4.2 Sources of Electricity Generation in South Africa 97
4.3 Co_2 Emission in South Africa 99
4.3.1 CCS in South Africa 100
4.4 Issues on environmental degradation 102
4.4.1 Ozone layer 103
4.4.2 Acid Rain 103
4.4.3 Global Warming 104
4.4.4 Consequences of radioactive waste management 104
4.4.4.1 International challenges on radioactive waste management 105
4.4.4.2 South Africa’s Radioactive Waste Disposal Facility (Vaalputs) 105
4.4.4.3 United States Radioactive Waste Disposal Facility (Yucca Mountain) 107

4.5 Environmental Protection and Sustainable Development 109
4.5.1 Trust doctrine principle: 110
4.5.2 Precautionary principle (Halt adverse projects): 110
4.5.3 Principle of intergenerational equity (Sustainable development): 111
4.5.4 Principle of intra-generational equity (Access to all): 111
4.5.5 Subsidiarity principle (Consult): 111
4.5.6 Polluter pays principle: 111
4.5.7 User pays principle: 111
4.6 International Environmental Institutions 111
4.6.1 United Nations Environmental Programme (UNEP): 111
4.6.2 United Nations, Educational, Scientific and Cultural Organization (UNESCO): 112
4.6.3 Organization for the prohibition of Chemical Weapons (OPCW): 112
4.6.4 Comprehensive Nuclear Test Ban Treaty Organization (CTBTO): 112
4.6.5 International Atomic Energy Agency (IAEA): 112
4.6.6 International Institute for Environment and Development (IIED): 112
4.6.7 Centre for our common future (Brundtland Commission): 113
4.6.8 International Union for the Conservation of Nature (IUCN): 113
4.6.9 United Nations Commission on Sustainable Development (CSD): 113
4.7 Conventions and Agreements 113
4.7.1 Rio Conventions: 113
4.7.1.1 Convention on Biological Diversity (CBD) (1992–1993): 113
4.7.1.2 United Nations Framework Convention on Climate Change (UNFCC) (1992–1994): . 113
4.7.1.3 United Nations Convention to Combat Desertification (UNCCD) (1994–1996): 114
4.7.1.4 Transboundary Watercourses and International Lakes (Water Convention) (1992–1996): 114
4.7.1.5 Rotterdam Convention on the Prior Informed Consent Procedures for Certain Hazardous Chemicals and Pesticides in International Trade (1998-2004): 114
4.7.1.6 Stockholm Convention on Persistent Organic Pollutants (COP) (2001–2004): 115
4.8 Sustainability in FBR and HTR 115
4.9 Sustainability in Coal and Gas-Fired Power Plants 116
4.9.1 Underground Coal Gasification in South Africa 117
4.10 Conclusion 119
CHAPTER FIVE 120
NUCLEAR SAFETY, SECURITY AND SAFEGUARD DESIGN 120
5.1 Introduction 120
5.2 Physical Security and Protection 120
5.2.1 Physical Protection System (PPS) 121
5.2.2 Concept and requirements of PPS design 124
5.2.2.1 Defence in depth 124
5.2.2.2 Security Culture 125
5.2.2.3 Quality Assurance 125
5.2.2.4 Confidentiality 125
5.2.2.5 Contingency 126
5.3 Safety, Security and Safeguard 126
5.3.1 Nuclear safety 126

5.3.2 Nuclear Security ... 127
5.3.3 Safeguard ... 131
5.4 Nuclear safety and nuclear security synergy ... 132
5.4.1 Legal and regulatory framework ... 135
5.4.2 Responsibility ... 135
5.4.3 Design Concepts and Criteria ... 135
5.4.3.1 Design Basis Threat (DBT) ... 135
5.4.3.2 Design Basis Accident (DBA) ... 135
5.4.3.3 Passive System ... 136
5.4.4 Graded Approach ... 136
5.4.5 Operating principles ... 137
5.4.6 Emergency Response ... 137
5.4.7 Training and education. ... 138
5.5 Nuclear Safety, Security and Safeguard Synergy ... 138
5.6 Conclusion ... 141
CHAPTER SIX ... 142
DEVELOPMENT OF THE RADIATION MONITORING SYSTEM ... 142
6.1 Introduction ... 142
6.1.1 Pre-operational: ... 142
6.1.2 Operational: ... 142
6.1.3 Emergency: ... 142
6.2 The Design of Radiation Dose Monitoring System ... 143
6.2.1 Nuclear radiation dose collection terminal ... 144
6.2.1.1 Radiation Detector ... 144
6.2.2 Wireless Network Platforms ... 149
6.2.2.1 PAN ... 150
6.2.2.2 LAN ... 150
6.2.2.3 MAN ... 151
6.2.2.4 WAN ... 151
6.2.2.5 Wireless Mesh Network (WMN) ... 152
6.2.2.6 The IEEE 802.11 Network Standards ... 157
6.2.2.7 Routing Mechanism of the Mesh Network ... 158
6.2.2.8 Implications of WLAN deployment ... 159
6.2.3 Data Processing Centre ... 162
6.3 Solution Description ... 162
6.3.1 Modular Design ... 162
Table 6.6: GQ GM Data Logger Pro reading in CPM and uSv/h ... 166
6.3.2 Network Design ... 166
6.4 Design Requirements ... 167
6.4.1 Geiger Mueller Counter (GMC) Radiation detector ... 168
6.4.2 NI my RIO Micro Controller ... 168
6.4.3 Cortex-A9 Processor ... 168
6.4.4 Switches ... 169
6.4.5 Wireless Controller ... 171

6.4.6 Core Switching 171
6.4.7 Mesh Access Point 171
6.4.8 Server 173
6.4.9 Wireless Control System (WCS) 174
6.5 Radiation Monitoring System Design 176
6.5.1 Data Packets Transmission 177
6.6 WLAN Configuration 178
6.6.1 Enabling the 802.11n mode: 178
6.6.2 Selecting Frequency band: 178
6.6.3 Defining the SSID: 178
6.6.4 Setting of Beacon: 178
6.6.5 Transmit Power: 178
6.6.6 Transmission Channel: 179
6.6.7 Data Rate: 179
6.6.8 Antenna Diversity: 179
6.6.9 Channel Width: 179
6.6.10 Fragmentation Threshold: 179
6.6.11 RTS/CTS Threshold: 179
6.7 Conclusion 179
CHAPTER SEVEN 181
MODELLING AND SIMULATION 181
7.1 Introduction 181
7.2 Effect of Time on Radiation exposure: 182
7.2.1 CASE 1: 182
7.2.2 CASE 2: 183
7.2.3 CASE 3: 185
7.2.4 CASE 4: 186
7.2.5 CASE 5: 187
7.2.6 CASE 6: 188
7.3 Effect of Distance on Radiation exposure: 189
7.3.1 CASE 1 189
7.3.2 CASE 2: 190
7.3.3 CASE 3: 191
7.3.4 CASE 4: 192
7.3.5 CASE 5: 193
7.3.6 CASE 6: 194
7.4 Effect of Shielding on Radiation exposure: 195
7.4.1 Irridium-192 with Radiation Intensity of 0.05 mSv 195
7.4.2 Cobalt-60 with Radiation Intensity of 0.05 mSv: 198
7.4.3 Summary at 0.05 mSv: 200
7.4.4 Irridium-192 with Radiation Intensity of 2.5 mSv 201
7.4.5 Cobalt-60 with Radiation Intensity of 2.5 mSv 203
7.4.6 Summary at 2.5 mSv 206
7.4.7 Irridium-192 with Radiation Intensity of 20 mSv 206

7.4.8 Cobalt-60 with Radiation Intensity of 20 mSv 209
7.4.9 Summary at 20 mSv..... 211
7.4.10 Irridium-192 with Radiation Intensity of 250 mSv 212
7.4.11 Cobalt-60 with Radiation Intensity of 250 mSv 214
7.4.12 Summary at 250 mSv..... 217
7.4.13 Irridium-192 with Radiation Intensity of 1000 mSv 217
7.4.14 Cobalt-60 with Radiation Intensity of 1000 mSv 220
7.4.15 Summary at 1000 mSv..... 222
7.4.16 Irridium-192 with Radiation Intensity of 10000 mSv 223
7.4.17 Cobalt-60 with Radiation Intensity of 10000 mSv 225
7.4.18 Summary at 10000 mSv 228
7.5 RADIATION MONITORING SYSTEM ANALYSIS 228
7.5.1 CASE 1: Mesh Topology with faulty Node 1 of Radiation Strength of 0.05 mSv 228
7.5.1.1. Star Topology with faulty Node 1 of Radiation Strength of 0.05 mSv 229
7.5.2 CASE 2: Mesh Topology with faulty Node 2 and an increased radiation Strength of 2.5 mSv 229
7.5.2.1 Star Topology with faulty Node 2 of Radiation Strength of 2.5 mSv 230
7.5.2 CASE 3: Mesh Topology with faulty Node 3 and an increased radiation Strength of 20 mSv 231
7.5.2.1 Star Topology with faulty Node 3 of Radiation Strength of 20 mSv 231
7.5.4 CASE 4: Mesh Topology with faulty Node 4 and an increased radiation Strength of 250 mSv 232
7.5.4.1 Star Topology with faulty Node 4 of Radiation Strength of 250 mSv 232
7.5.5 CASE 5: Mesh Topology with faulty Node 5 and an increased radiation Strength of 1000 mSv 233
7.5.5.1Star Topology with faulty Node 5 of Radiation Strength of 1000 mSv 233
7.5.6 CASE 6: Mesh Topology with faulty Node 6 and an increased radiation Strength of 10000 mSv 234
7.5.6.1 Star Topology with faulty Node 6 of Radiation Strength of 10000 mSv 234
7.6 Conclusion: 235
CHAPTER EIGHT 236
CONCLUSION AND RECOMMENDATIONS 236
8.1 Introduction 236
8.2 Conclusion 236
8.3 Recommendations: 238
8.4 Publications: 238
REFERENCES 239
APPENDIX A 261
DISTANCE MODEL 261
APPENDIX B 262
TIME MODEL..... 262
APPENDIX C 263
SHIELDING MODELS 263
APPENDIX D 267
RADIATION MONITORING SYSTEM MODEL 267

LIST OF FIGURES

Figure 1.1: Types of monitoring for radiation protection of the public (IAEA, 2005) 24
Figure 2.1: Typical fission chain reaction (NEA, 2012a; Lamarsh & Baratha, 2001) 30
Figure 2.2: Typical Pressurized Water Reactor (PWR) Power Plant (NEA, 2012a; Cohen, 1983; IEE, 2005; Adee and Guizzo, 2010; USNRC, 2013; IET, 2008; WNA, 2014; Knief, 2013) 31
Figure 2.3: Generations of Nuclear Reactor (EC, 2013; OECD, 2014; Goldberg and Rosner, 2011; NEA, 2012a; NEA, 2007; Kim, 2013) 32
Figure 2.4: Operational Reactors by type (IAEA, 2014) 35
Figure 2.5: Schematic: BWR (IET, 2008; IEE, 2005; Knief, 2013) 36
Figure 2.6: Schematic FBR – Sodium-Cooled (IEE, 2005; Knief, 2013) 37
Figure 2.7: Schematic GCR – MAGNOX (IET, 2008; IEE, 2005; Knief, 2013) 38
Figure 2.8: Schematic LWGR – RBMK (IET, 2008; IEE, 2005; Knief, 2013) 39
Figure 2.9: Schematic: PHWR – CANDU (IET, 2008; IEE, 2005; Knief, 2013) 40
Figure 2.10: Schematic: PWR (IET, 2008; IEE, 2005; Cohen, 1983; NEA, 2012a; Knief, 2013) 41
Figure 2.11: The Russian Sodium-cooled fast reactor BN-600 in operation since 1980 (IAEA, 2013) 42
Figure 2.12: The Japanese Monju loop type sodium- cooled fast reactor (IAEA, 2013) 42
Figure 2.13: China Experimental Fast Reactor (CEFR), first grid connection on 21 July 2011(IAEA, 2013) 43
Figure 2.14: The Russian sodium-cooled fast reactor BN-800: construction initiated in July............... 44
Figure 2.15: Pool-type Sodium-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014) 45
Figure 2.16: Looped-type Sodium-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014) 46
Figure 2.17: Very-high-temperature Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014) 47
Figure 2.18: Lead-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014) 48
Figure 2.19: Gas-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014) 49
Figure 3.1: Electromagnetic Spectrum (Hall, 2012; ARPANSA, 2012; Southworth, 2011) 66
Figure 3.2: Schematic diagram of an atom (DME, 2005; Hall, 2012) 67
Figure 3.3: Radioactive Decay (NU, 2010; Maher, 2006; L'annunziata, 2003; IAEA, 2004) 68
Figure 3.4: Sources of Radiation (Southworth, 2011) 70
Figure 3.5: Penetrating Power of Radiation (DOE, n.d; DME, 2005; Southworth, 2011; IAEA, 2004) . 73
Figure 3.6: Various contributors to the total radiation dose (DME, 2005; Southworth, 2011) 75
Figure 3.7: Radiation health effects at different exposure levels (ARPANSA, 2014) 81
Figure 3.8: Variations in indoor Radon Concentration in a house with moderate levels (IAEA, 2004). 82
Figure 3.9: Scope of Radiation Protection (NEA, 1994) 85
Figure 3.10: A point Source from x-ray tube (Joseph and Phalen, 2006) 88
Figure 3.11:The linear attenuation Coefficient (Joseph and Phalen, 2006) 90
Figure 4.1: South Africa Electricity Generation by Source (Eskom, 2012) 98
Figure 4.2: South Africa CO2 Emissions compared to top global emitters (Urban Earth, 2012) 100
Figure 4.3: Location of Vaalputs (NECSA, 1985) 106
Figure 4.4: Aerial view showing disposal trenches (NNR, 2011) 107
Figure 4.5: Location of Yucca Mountain (U.S.NRC, 2012a). 108
Figure 4.6: Conceptual Design of Yucca Mountain Disposal Plan (U.S.NRC, 2012b) 109
Figure 5.1: Design and evaluation process for physical protection systems (Garcia, 2008; NSSPI, 2014) 122
Figure 5.2: Functions of Physical protection System (Brayon, n.d.) 123
Figure 5.3: The Global Nuclear Security Regime (Everton et al., 2010; CNND, 2013) 128
Figure 5.4: Synergy of safety and security (IAEA, 2014; Batra and Nelson, 2012) 133
Figure 5.5: The Venn diagram of sets of 3S (Suzuki el at., 2010; Batra and Nelson, 2012; Kroening, et al., 2012) 139
Figure 5.6: PPS Layout for Nuclear Facility 140
Figure 6.1: The Basic Schema of Radiation Monitoring System (Huang and Sun, 2011) 143
Figure 6.2: Geiger Mueller tube (Shapiro, 2002; Westinghouse, n.d) 145
Figure 6.3: The GQ GMC-320-Plus Geiger counter (GQE, 2012) 146
Figure 6.4: Type of Wireless Access (Sidhu et al. 2007; Korsah et al. 2009) 149
Figure 6.5: Controller Topology and Network Connections (Cisco, 2011) 156
Figure 6.6: IEEE 802.11 Standards (Geier, 2010) 157
Figure 6.7:Real-Time Data Viewer graphics 163

Figure 6.8:Real-Time Data Logger Pro graphics 164
Figure 6.9: NI my RIO Micro Controller 168
Figure 6.10: Cisco Catalyst 2960 24 10/100 PoE + 2 T/SFP LAN (Provantage, 2014a) 170
Figure 6.11: Cisco 2504 Wireless Controller with 15 AP Licenses (Provantage, 2014b) 171
Figure 6.12: Cisco WS-C3560X-24P-E Catalyst 3560-x 24 Port Gbe PoE Ip Services (Provantage, 2014c) 171
Figure 6.13: Cisco Aironet 1552E IEEE 802.11n 300 Mbps Wireless Access Point (FrontierPC, 2013; Das, n.d.) 173
Figure 6.14: HP ProLiant ML350p Gen8 E5-2609 (470065-762) Tower Server (dtcae, 2014) 174
Figure 6.15: Radiation Monitoring System 176
Figure 6.16: Block Diagram of Radiation Monitoring System 176
Figure 6.17: The Mesh Network Topology 177
Figure 7.1: Effect of Time = 30 minutes on radiation exposure of 0.05mSv/min 182
Figure 7.2: Effect of Time = 60 minutes on radiation exposure of 0.05mSv/min 183
Figure 7.3: Effect of Time = 30 minutes on radiation exposure of 2.5mSv/min 184
Figure 7.4: Effect of Time = 60 minutes on radiation exposure of 2.5mSv/min 184
Figure 7.5: Effect of Time = 30 minutes on radiation exposure of 20mSv/min 185
Figure 7.6: Effect of Time = 60 minutes on radiation exposure of 20mSv/min 185
Figure 7.7: Effect of Time = 30 minutes on radiation exposure of 250mSv/min 186
Figure 7.8: Effect of Time = 60 minutes on radiation exposure of 250mSv/min 186
Figure 7.9: Effect of Time = 30 minutes on radiation exposure of 1000mSv/min 187
Figure 7.10: Effect of Time = 60 minutes on radiation exposure of 1000mSv/min 187
Figure 7.11: Effect of Time = 30 minutes on radiation exposure of 10000mSv/min 188
Figure 7.12: Effect of Time = 60 minutes on radiation exposure of 10000mSv/min 188
Figure 7.13: Effect of Distance = 10 meters on radiation exposure of 0.05 mSv 189
Figure 7.14: Effect of Distance = 20 meters on radiation exposure of 0.05 mSv 189
Figure 7.15: Effect of Distance = 10 meters on radiation exposure of 2.5 mSv 190
Figure 7.16: Effect of Distance = 20 meters on radiation exposure of 2.5 mSv 190
Figure 7.17: Effect of Distance = 10 meters on radiation exposure of 20 mSv 191
Figure 7.18: Effect of Distance = 20 meters on radiation exposure of 20 mSv 191
Figure 7.19: Effect of Distance = 10 meters on radiation exposure of 250 mSv 192
Figure 7.20: Effect of Distance = 20 meters on radiation exposure of 250 mSv 192
Figure 7.21: Effect of Distance = 10 meters on radiation exposure of 1000 mSv 193
Figure 7.22: Effect of Distance = 20 meters on radiation exposure of 1000 mSv 193
Figure 7.23: Effect of Distance = 10 meters on radiation exposure of 10000 mSv 194
Figure 7.24: Effect of Distance = 20 meters on radiation exposure of 10000 mSv 194
Figure 7.25: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv 195
Figure 7.26: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv 196
Figure 7.27: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv 196
Figure 7.28: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv 197
Figure 7.29: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv 197
Figure 7.30: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv 198
Figure 7.31: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv 198
Figure 7.32: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv 199
Figure 7.33: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv 199
Figure 7.34: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv 200
Figure 7.35: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv 201
Figure 7.36: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv 201
Figure 7.37: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv 202
Figure 7.38: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv 202
Figure 7.39: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv 203
Figure 7.40: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv 203
Figure 7.41: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv 204
Figure 7.42: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv 204
Figure 7.43: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv 205
Figure 7.44: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv 205
Figure 7.45: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 20 mSv 206
Figure 7.46: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 20 mSv 207
Figure 7.47: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 20 mSv 207
Figure 7.48: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 20 mSv 208
Figure 7.49: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 20 mSv 208
Figure 7.50: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 20 mSv 209
Figure 7.51: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 20 mSv 209

Figure 7.52: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 20 mSv 210
Figure 7.53: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 20 mSv 210
Figure 7.54: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 20 mSv 211
Figure 7.55: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 250 mSv 212
Figure 7.56: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 250 mSv 212
Figure 7.57: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 250 mSv 213
Figure 7.58: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 250 mSv 213
Figure 7.59: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 250 mSv 214
Figure 7.60: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 250 mSv 214
Figure 7.61: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 250 mSv 215
Figure 7.62: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 250 mSv 215
Figure 7.63: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 250 mSv 216
Figure 7.64: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 250 mSv 216
Figure 7.65: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 1000 mSv 217
Figure 7.66: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 1000 mSv 218
Figure 7.67: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 1000 mSv 218
Figure 7.68: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 1000 mSv 219
Figure 7.69: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 1000 mSv 219
Figure 7.70: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv 220
Figure 7.71: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv 220
Figure 7.72: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv 221
Figure 7.73: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv 221
Figure 7.74: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv 222
Figure 7.75: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 10000 mSv 223
Figure 7.76: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 10000 mSv 223
Figure 7.77: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 10000 mSv 224
Figure 7.78: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 10000 mSv 224
Figure 7.79: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 10000 mSv 225
Figure 7.80: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv 225
Figure 7.81: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv 226
Figure 7.82: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv 226
Figure 7.83: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv 227
Figure 7.84: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv 227
Figure 7.85: Effect of Mesh Topology on Wireless Mesh Network (WMN) with Radiation Strength of 0.05 mSv 228
Figure 7.86: of Star Topology on WMN with Radiation Strength of 0.05 mSv 229
Figure 7.87: Effect of Mesh Topology on WMN with Radiation Strength of 2.5 mSv 230
Figure 7.88: Effect of Star Topology on WMN with Radiation Strength of 2.5 mSv 230
Figure 7.89: Effect of Mesh Topology on WMN with Radiation Strength of 20 mSv 231
Figure 7.90: Effect of Star Topology on WMN with Radiation Strength of 20 mSv 231
Figure 7.91: Effect of Mesh Topology on WMN with Radiation Strength of 250 mSv 232
Figure 7.92: Effect of Star Topology on WMN with Radiation Strength of 250 mSv 232
Figure 7.93: Effect of Mesh Topology on WMN with Radiation Strength of 1000 mSv 233
Figure 7.94: Effect of Star Topology on WMN with Radiation Strength of 1000 mSv 233
Figure 7.95: Effect of Mesh Topology on WMN with Radiation Strength of 10000 mSv 234
Figure 7.96: Effect of Star Topology on WMN with Radiation Strength of 10000 mSv 234

LIST OF TABLES

Table 2.1: World Operational Reactors (IAEA, 2014; NEA, 2012b) 28
Table 2.2: World Operational Reactors by Types (IAEA, 2014) 34
Table 3.1: Radioisotopes Half Lives (Maher, 2006) 68
Table 2.2: Average radiation dose from natural sources (UNSCEAR, 2000; WNA, 2014; IAEA, 2004; Crick, 2010) 71
Table 2.3:Average Annual Effective Dose of Ionizing Radiation to Individuals (IAEA, 2010) 72
Table 3.4: Physical Characteristics of the major types of Radiation (Maher, 2006) 74
Table 3.5: Radiation Level Vs Health Effects (Hall, 2012) 83
Table 3.6: HVL when Radiation is from Gamma Source (NDT, 2014) 91
Table 3.7: HVL when Radiation is from X-ray Source (NDT, 2014) 92
Table 4.1: South Africa Electricity Generation by Source (Eskom, 2012) 98
Table 6.1: GQ Geiger counters models and selection criteria (GQE, 2012) 147
Table 6.2: IEEE Standards for Wireless Communications (Hashemian, 2011) 150
Table 6.3: Comparison of Wireless Technology (Sidhu et al. 2007) 153
Table 6.4: The 802.11 Standard Comparisons (Geier, 2010) 158
Table 6.5: GQ GM Data Viewer reading in CPM 165
Table 6.6: GQ GM Data Logger Pro reading in CPM and uSv/h 166
Table 6.7: Design requirements and Specifications 167

GLOSSARY

ABWR	Advanced Boiling Water Reactor
ACR	Advanced CANDU Reactor
AGBOM	Australian Government Bureau of Meteorology
AECL	Atomic Energy of Canada Ltd
AFPR	Atoms for Peace Reactor
AGDOH	Australian Government Department of Health
AGR	Advanced Gas-Cooled Reactors
ALARA	As Low as Reasonably Achievable
ANTARES AREVA	New Technology based on advanced gas-cooled Reactors
AP	Access Point
APR	Advanced Power Reactor
ARE	Aircraft Reactor Experiment
ARP	Address Resolution Protocol
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
APWR	Advanced Pressurized Water Reactor
ASTRID	Advanced Sodium Technological Reactor for Industrial Demonstration
AWCR	Advanced Water Cooled Reactor
AWPP	Adaptive Wireless Path Protocol
BBC	British Broadcasting Corporation
BRC	Blue Ribbon Commission
BSS	Basic service set
BWR	Boiling water reactor
CANDU	Canada Deuterium Uranium Reactor
$CaSO_4$: Dy	Calcium sulphate doped with dysprosium
CBD	Convention on Biological Diversity
CCEI	Canadian Centre for Energy Information
CCS	Carbon Capture and Sequestering
CCSA	Carbon Capture and Storage Association
CCTV	Close Circuit Television
CDCP	Centre for Disease Control and Prevention
CEFR	China Experimental Fast Reactor
CFC	Chlorofluorocarbon
CNND	Centre for Nuclear Non-Proliferation and Disarmament
Co_2	Carbon Dioxide
COP	Stockholm Convention on Persistent Organic Pollutants
CPR	Chinese Pressurized Water Reactor
CPPNM	Convention on the Physical Protection of Nuclear Material
Cs-137	Caesium
CSA	Comprehensive safeguards agreement
CSD	United Nations Commission on Sustainable Development
CTBTO	Comprehensive Nuclear Test Ban Treaty Organization
CWC	Chemical Weapon Convention
DHR	Decay Heat Removal System for Liquid Metal Cooled Reactors
DME	Department of Minerals and Energy of South Africa
DOE	Department of Energy of South Africa
DOS	Department of Safeguards
DoS	Denial-of-service
EBR-I	Experimental Breeder Reactor-1
EC	European Commission
EDF	Électricité de France
ENSI	Federal Nuclear Safety Inspectorate
EPA	United States Environmental Protection Agency
EPR	European Pressurized Reactors

ETX	Expected transmission count
ESBWR	Economic Simplified Boiling Water Reactor
ESNII	European Sustainable Nuclear Industrial Initiative
FBR	Fast Breeder Reactor
FBTR	Fast Breeder Test Reactor
FFTF	Fast Flux Test Facility
FHR	Fluoride salt cooled high-temperature reactor
FNR	Fast Neutron Reactor
FPGA	Field Programmable Gate Array
GCR	Gas-Cooled, Graphite-Moderated Reactor
GDP	Gross Domestic Product
GE	General Electric
Gen I	Generation I
Gen II	Generation II
Gen III	Generation III
Gen IV	Generation IV
GFR	Gas Fast Reactor
GHG	Greenhouse Gas
GHKSAR	The Government of the Hong Kong Special Administrative Region
GHz	Giga Hertz
GIF	Generation IV International Forum
GM	Geiger-Mueller
GMC	Geiger Mueller Counter
GNSSN	Global Nuclear Safety and Security Network
GQE	GQ Electronics LLC
GtCO2-eq	Gigatonnes of CO_2-equivalent
GW (e)	Giga Watts Electrical
HEU	Highly enriched uranium
HP	Hewlett Packard
HPIC	High pressure ionization chamber
HPS	Health Physics Society
HTR	High Temperature Reactor
HTTR	High Temperature Test Reactor
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICSANT	International Convention for the Suppression of Acts of Nuclear Terrorism
IEA	International Energy Agency
IEE	The institution of Electrical Engineers
IEEE	Institute of Electrical Electronics Engineers
IET	The Institution of Engineering and Technology
IIED	International Institute for environment and development
ILO	International Labour Organization
INFCIRC	Information Circular
INPRO	The international Project on Innovative Nuclear Reactors and Fuel Cycles
INSAG	International Nuclear Safety Group
IRIS	International Reactor Innovative and Secure
IRSN	Institute of Radiological Support and Nuclear Safety
ISO	International Organization for Standardization
IUCN	International Union for the Conservation of Nature
KP	Kyoto Protocol
kWe	One thousand watts of electric
kWh	Kilowatt hour
LAN	Local Area Network
LED	Light Emitting Diode
LFR	Lead Fast Reactor

LOCA	Loss-of coolant accident
LOS	Line of Site
LWR	Light water reactor
LWGR	Light-Water-Cooled, Graphite-Moderated Reactor
MAC	Medium access control
MAN	Metropolitan Area Network
MAP	Mesh Access Point
MC	Mesh Client
MDI	Medium dependent interface
MIMO	Multi-input, multi-output
MIT	Massachusetts Institute of Technology
MHI	Mitsubishi Heavy Industries
MHR	Modular Helium Reactor
MPa	Megapascal (Unit of Pressure)
MR	Mesh Relay
MRL	Marathon Resources Limited
MSR	Molten Salt Reactor
MSRE	Molten Salt Reactor Experiment
mSv	Milli Sievert
MW	Megawatt
MWe	Megawatts electric
MW_{th}	Megawatts thermal
Na-22	Sodium
NEA	Nuclear Energy Agency
NECSA	Nuclear Energy Corporation of South Africa
NEI	Nuclear Energy Institute
NESA	National nuclear energy assessments
NGNP	Next Generation Nuclear Plant
NLoS	Non-Line-of-Sight
NNR	National Nuclear Regulator of South Africa
NORM	Natural Occurring Radioactive Material
NPP	Nuclear Power Plant
NPT	Non-Proliferation Treaty
NRC	National Research Council
NSC	Nuclear Safety Commission
NSS	Nuclear Security Summit
NSSPI	Nuclear Security Science and policy Institute
NU	North-western University
OEAP	Office extended access point
OFDM	Orthogonal frequency division multiplexing
OPCW	Organization for the prohibition of Chemical Weapons
OPR	Optimized Power Reactor
OSI	Open Systems Interconnection Model
OECD	Organization for Economic Cooperation and Development
P-32	Phosphorus
PAN	Personal Area Network
Pb-Bi	Lead-Bismuth
PBMR	Pebble Bed Modular Reactor
PDA	Personal digital assistants
PFBR	Prototype Fast Breeder Reactor
PHWR	Pressurized Heavy-Water-Moderated and Cooled Reactor
PoE	Power over Ethernet
PPS	Physical protection System
PRADA	Proliferation Resistance: Acquisition/Diversion Pathway Analysis
PRISM	Power Reactor Innovative Small Module
PRIS	Power Reactor Information System
PROSA	Proliferation Resistance and Safeguard ability Assessment

PUREX	Plutonium and uranium extraction
PWR	Pressurized water reactor
QA	Quality Assurance
QoS	Quality of Service
R & D	Research and Development
RAP	Root Access Point
RF	Radio Frequency
RISC	Review of Innovative Reactor Concepts
RO	Royal Observatory
RTS/CTS	Request-to-send / clear-to-send
SACCCS	South African Centre for Carbon Capture & Storage
SCWR	Super-critical Water Reactor
SFR	Sodium Fast Reactor
SMR	Small modular reactor
SNETP	Sustainable Nuclear Energy Technology Platform
SSID	Service Set Identification
TCP/IP	Transmission Communication Protocol and Internet Protocol
ThFC	Thorium Fuel Cycle
TLD	Thermo luminescent dosimeter
TR	Thomson Reuters
tU	Tonnes of Uranium metal
TWR	Travelling Wave Reactor
UCG	Underground Coal Gasification
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environmental Programme
UNESCO	United Nations, Educational, Scientific and Cultural Organization
UNFCC	United Nations Framework Convention on Climate Change
UOM	University of Maryland
USDOE	United States Department of Energy
USNRC	United States Nuclear Regulatory Commission
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UO_2	uranium dioxide
U_{239}	Plutonium
U_{238}	Uranium
U_3O_8	Solid uranium oxides concentrate
UV-B	Ultraviolet type B
UWEHS	University of Washington Environmental Health and Safety
VHTR	Very High Temperature Reactor
VVER	Vodo-Vodyanoi Energetichesky Reactor
WAN	Wide Area Network
WC	Wireless controller
WCA	World Coal Association
WCED	World Commission on Environment and Development
WCS	Wireless Control System
WEP	Wired Equivalent Privacy
WHO	World Health Organization
Wi-Fi	Wireless fidelity
Wi-Max	Worldwide interoperability for microwave access
WIPS	Wireless Intrusion Prevention System
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WNA	World Nuclear Association
WPA	Wi-Fi Protected Access
WSDOH	Washington State Department of Health
WTO	World Trade Organization

CHAPTER ONE

INTRODUCTION

1.1 Background

The effects of nuclear and radiological radiations are of a major concern globally. Especially, countries trying to develop the technology (nuclear) and those who already using the technology with obsolete reactors that have the potential of leaking dangerous fumes on the health of public and the environment. The need for ionized radiation monitoring system to act as an early warning system is essential for the protection of life, properties and the environment. According to IAEA (2011), radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers, the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled. Activities such as the medical uses of radiation, nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subjected to standards of safety. An appropriate surveillance programme should be established, maintained and kept under review for the systematic evaluation of the radiological conditions at the facility, with the following objectives (IAEA, 2008):

- Monitor exposures of individual workers
- Control any environmental impacts
- Assess trends in radiological parameters
- Detect degradation in systems, such as corrosion and leaks

Accordingly, an environmental monitoring programme should be conducted in accordance with the regulations of countries regulatory bodies. Therefore, based on this compliance, South African National Nuclear Regulator in its National Nuclear Regulator Act, 1999 (Act No. 47 of 1999) that was gazetted (No. 8454) on 28 April 2006 states that "an appropriate environmental monitoring and surveillance programme must be established, implemented and maintained to verify that the storage, disposal or effluent discharge of radioactive waste complies with condition of the nuclear authorization" (NNR, 2006). It is also recommended that a pre-operational programme for environmental monitoring should be conducted two to three years to the planned commissioning of a facility. This should however provide for the measurement of background radiation levels in the vicinity of the facility and their variation over time. This should provide the basis for the operational programme of environmental monitoring and which include the routine collection and radio analysis of various samples, such as vegetation, air, milk, water, sediment, fish and environmental media collected from several fixed and identified locations off the site. The use of sources of radiation in different fields of practice other than in reactors is growing daily (IAEA, 2000). Despite safety precautions in design and operations, accidents involving radiation sources do occur more frequently than reactor accidents. Unlike reactor accidents, the impact of any such accidents generally affects only a small number of people which may be serious. As different countries try to develop nuclear power plants with limited experience and the increase of others with too old nuclear reactors, the risk of accident sets in which lead to the reported case of safety. The Chernobyl accident had caused radioactive contamination of large areas far away from the reactor. This emphasizes the necessity for ionized radiation monitoring system to act as an early warning system. Radiation levels may not be deadly or damaging on short-term bases, but may result in risks to human life and health on long-term bases (Alshamali, 2008). However, IAEA (2005) highlighted that the environmental monitoring programmes include measurement of radiation fields and radionuclide activity concentrations in environmental samples relevant to human exposure, primarily in air, drinking water, agricultural produce and natural foodstuffs. Accordingly, one important purpose of monitoring is to provide data that permit the analysis and evaluation of human radiation exposure. For this purpose, monitoring radionuclide in the environment should focus on pathways of human exposure. An exposure pathway defines routes from a source of radiation to a target individual or a population through media in the environment. IAEA (2010) noted that monitoring should be regarded as an essential element of the control of discharges to ensure protection of the public and the environment. It is also an essential element in determining the actions that should be taken to protect the public in intervention situations. According to Botkin and Keller (2011), the Chernobyl disaster of April 26th 1986 with an explosion and fire released of large radioactive contamination into the atmosphere, which spread over much of Western USSR and Europe is widely considered to have been the worst nuclear power plant accident in history, classified as a level 7 event on the international nuclear event scale. Following the accident, 3 billion people in the Northern Hemisphere received varying amounts of radiation. As many as 24,000 people were estimated to have received an average radiation dose of 0.43 Sv (430 mSv) with the exception of the 30 km zone surrounding the facility made of 115,000 residents that were evacuated. Therefore, studies have found that since the accident, the number of childhood thyroid cancer cases per year has risen steadily in the three countries; Belarus, Ukraine and the Russian Federation that was most affected by Chernobyl. Hence, a total of 1,036 thyroid cancer cases have been diagnosed in children under 15 in the region. However, these cancer cases are believed to be linked to the released radiation from the accident, but other factors, such as environmental pollution may also contribute. While outside the 30 km zone, the increased risk of contracting cancer is very small and not likely to be detected from an ecological evaluation. Similarly, ninety six cases of radiation injury was reported within a year and subsequently many other injuries occurred including the first cancers which were attributed to ionizing radiation after the discovery of x-ray by Roentgen in 1895 as it was introduced into medical practice (Upton, 2010). According to Micro Step-MIS (2007), all sources of ionizing radiation, whether naturals or man-made, should be monitored from the point of view of radiation safety, to minimize and prevent the unnecessary or accidental increase of the dose absorbed by population and individuals. Therefore, Radiation Monitoring System solutions can be used within national networks to monitor potential danger from radioactive plume dispersion from unknown or unpredictable source as well as in the vicinity of Nuclear Power Plants (NPP). With ionizing radiation being found in such wide-ranging applications, radiation protection for workers and the public is an essential aspect. In France, the Institute of Radiological Support and Nuclear Safety (IRSN) saddled with the responsibilities of environmental radiation monitoring has put the following activities in place to checkmate the effect of ionizing radiation within the whole France with the purpose of protecting, the public, radiation workers and the environment (IRSN, 2009):

- Early Alert: continuous measurement and real-time transmission to the IRSN supervision centre with the use of probes.
- Impact Evaluation: on the environment and population, under normal conditions. Sampling the environmental media and detailed characterization of radioactivity taken to sample collection networks. (Manually achieved).
- Teleray network: made of 164 probes (Geiger-Muller tubes) for gamma dose rate measurements.

Similarly, Wang and Gone (1999) have noted that for the Institute of Nuclear Energy Research (INER) in Taiwan, a government-owned and operated research institute located in Taoyuan county 50 km southwest of Taipei, is the largest research institute in the field of radiation application in Taiwan. Two methods of environmental direct radiation measurements in use are as follows:

- Thermo luminescent dosimeter (TLD)
- High pressure ionization chamber (HPIC).

There are 39 TLDs sites and 5 HPIC stations within 5 kilometres radius of the institute. The TLDs used are made of calcium sulphate doped with dysprosium ($CaSO_4$: Dy), collected once every 3 months. The HPICs were operated continuously to detect radiation dose rate in the environment. Each HPIC station is connected to a network system to display, record, and store the radiation dose rate in the central computer. The radiation dose rate of each HPIC station can be shown on the central computer in a real time. Similarly, Benkrid *et al*. (1992), have also noted that, in the research centre in Algiers, 30 environmental stations equipped with TLD were used. These stations were distributed on three concentric circles 1 km apart beyond the site boundary in order to estimate the dose rates in air from outdoor gamma radiation.

1.2 Types of Radiation Monitoring

Radiation monitoring is classified into three categories (IAEA, 2005; IAEA, 2010):

- Source monitoring
- Environmental monitoring
- Individual monitoring – members of the public (very rare cases)

Source monitoring includes measurements of radiation levels and radionuclide from a particular source of radiation or from a practice. Environmental monitoring is conducted outside the facility due to radiation exposure while individual monitoring is concerned with measurements carried out directly on the people. But based on this research, the focus is on the environmental monitoring (person related). According to IAEA (2005), Environmental monitoring is subdivided into two categories: source related environmental monitoring and person related environmental monitoring (See Figure 1.1). Source related environmental monitoring concerns the measurement of absorbed dose rates in air or activity concentrations resulting from a defined source or practice. While the person related environmental monitoring is made of sources that are multiple, widespread or diffuse which is often characterized by a wide geographical coverage. Therefore, the radionuclides released by such sources are mixed in the environment, and there is a need to monitor the total contribution from multiple or widespread sources found in the environment.

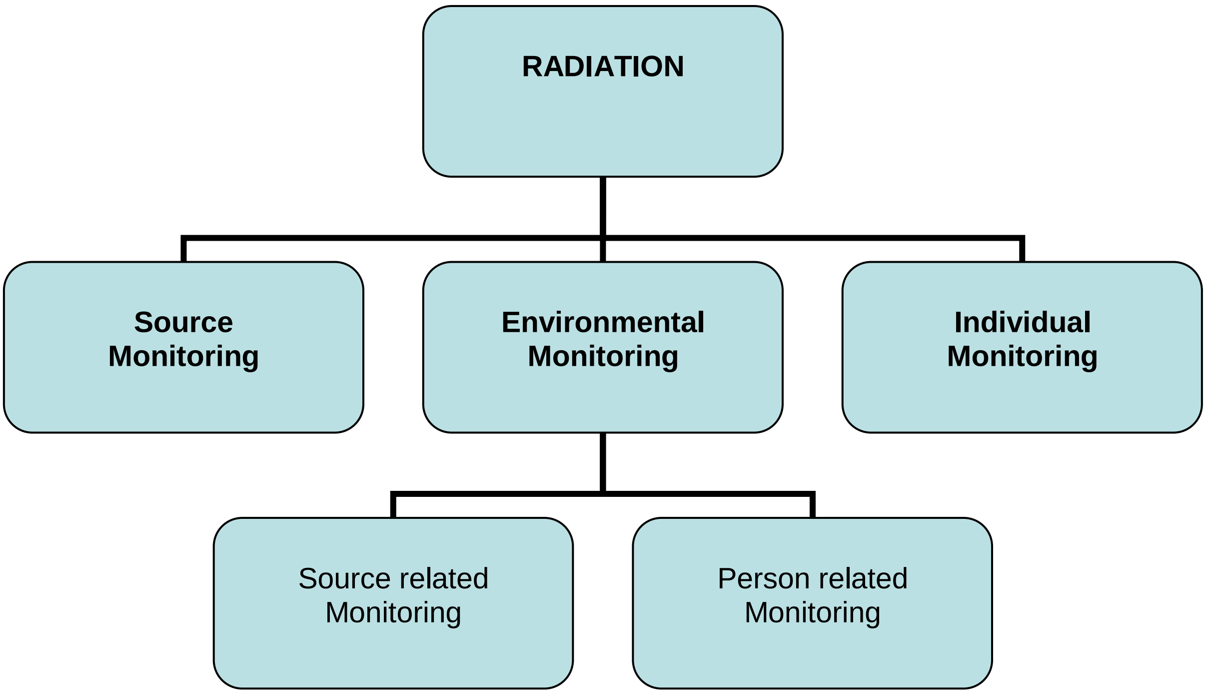


Figure 1.1: Types of monitoring for radiation protection of the public (IAEA, 2005)

1.3 Problem Statement

Facilities or activities that use radioactive material generate variety of radioactive gaseous and a liquid residue which needs to be managed safely (IAEA, 2010). However, the discharge of radionuclide to the atmosphere and aquatic environments is a legitimate practice in the nuclear and other industries such as hospitals and research institutes. But uncontrolled releases of it or dangerous fumes due to leakages coming from obsolete reactors of nuclear power plants to the atmosphere and aquatic environments may occur as a result of nuclear or radiological accidents. Therefore, monitoring of the discharges and of relevant environmental media is an essential regulatory requirement and demonstration of compliance with authorized limits. Thereby ensuring appropriate radiation protection of the public in providing actual information on the amounts of radioactive material discharged and the radionuclide concentrations in the environment.

1.4 Research Objectives

Radiation monitoring systems are critical systems that operate 24 hours a day, which involves monitoring the radiation conditions in work environments inside the facility and the radiation concentrations in air and fluids discharged outside the facility (Ooi *et al, n.d.*; IAEA, 2005). Therefore, with the measurements of radiation fields and radionuclide activity concentrations in the environment, hazards due to overexposure which may cause injuries, ill health and loss of lives to the public, properties and the environment can quickly be identified for timely intervention and necessary mitigation. However, environmental radiation monitoring is conducted as part of emergency measures (NSC, 2008; Huang and Sun, 2011) and to realize this, the following concepts were examined:

- To design a system that will serve as an early warning indicator to the facility management for immediate necessary intervention thereby mitigate the severity of over exposure to general public and the environment due to the effect of ionizing radiation.
- To provide appropriate turn-key solutions for measurement, data acquisition, processing, reporting and analysis of radiation and radioactivity concentration data as well as radionuclide's dispersion and contamination simulations for hydro-meteorological institutes, nuclear regulatory authorities, civil defence, radiation protection authorities or researchers.

1.5 Thesis Statement

Design of nuclear and radiological monitoring system, that is reliable, cost effective, easy to maintain and environmentally friendly that can withstand test of time.

1.6 Research Scope and Limitations

The research will cover the following areas and will be limited to the nuclear facility only.

- The design of radiation detection station: responsible for the environmental detection of ionizing radiations and forwarding the data captured through a wireless telecommunication channel to the central server for processing.

- The telecommunication media design: responsible for the transmission and transporting of the data to the central server. The proposed transmission design is based on wireless mesh network (WMN).

1.7 Significance of the Research

- Complying with legislation and International Atomic Energy Agency (IAEA) safety standards (IAEA, 2008; NNR, 2006).
- Providing a monitoring system that will serve as an early warning indicator to the facility management for immediate necessary intervention of over exposure to general public and the environment from harmful effect of ionizing radiation.
- To provide appropriate turn-key solutions for measurement, data acquisition, processing, reporting and analysis of radiation and radioactivity concentration as well as radionuclide's dispersion and contamination simulations for hydro meteorological institutes, nuclear regulatory authorities, civil defence, radiation protection authorities or researchers.
- Facilitating data exchange with neighbouring countries.
- Maintaining competence for nuclear emergency situations.

1.8 Organization of the Thesis

The thesis is organized as follows:

- Chapter 1: Introduction
- Chapter 2: Overview of Nuclear Power generations
- Chapter 3: Design Factors Influencing Biological Effects of Ionizing Radiation
- Chapter 4: Design for Sustainable Development with Nuclear Sources
- Chapter 5: Nuclear Safety, Security and Safeguard Design
- Chapter 6: Development of The Radiation Monitoring System
- Chapter 7: Modelling and Simulation
- Chapter 8: Conclusion and Recommendation.

CHAPTER TWO

OVERVIEW OF NUCLEAR POWER GENERATIONS

2.1 Introduction

In this chapter, we shall be looking at the overview of nuclear power generations. Nuclear power as we all know is a proven technology for large scale base load electricity generation which can reduce dependence on imported gas and carbon dioxide (CO_2) emission, less vulnerable to fuel price changes than coal and gas-fired power plants. The growth, prosperity and security of any country depend, to a large extent, on the adequacy, efficiency and functionality of its electricity industry. Therefore, unreliable power supply constitutes a major challenge to economic growth and development (Chiejina, 2012). According to Oyedepo (2012), energy plays the most vital role in the economic growth, progress, and development, as well as poverty eradication and security of any nation. However, uninterrupted energy supply is a vital issue for all countries today. Future economic growth crucially depends on long-term availability of energy from sources that are affordable, accessible, and environmentally friendly. Hence, security, climate change, and public health are closely interrelated with energy. Energy is an important factor in all the sectors of any country's economy. The standard of living of a given country can be directly related to the per capita energy consumption. The recent world's energy crisis is due to two reasons: the rapid population growth and the increase in the living standard of whole societies. The per capita energy consumption is a measure of the per capita income as well as a measure of the prosperity of a nation. In 2008, there were 436 NPP in operation with a total net installed capacity of 370 GW (e), and producing about 14% of the world's electric power with 56 NPP of 52 GW under construction, and 5 NPP, on long term shutdown (Lior, 2010). According to NEA (2012) and IEA (2012), at the end of 2010, a total of 440 commercial nuclear reactors were connected with a net generating capacity of 375 GW (e). By 2013 according to Brunton (2013), there were 434 operational power reactors. 67 under construction, 159 planned and 318 proposed. But as at July 2014, there were 435 operational reactors in 31 countries with a total of net installed capacity of 373GW (e) (IAEA, 2014) as shown on Table 2.1 with 72 reactors under construction and 2 others on permanently shutdown. Accordingly, the highlighted portion on Table 2.1, indicates countries that added and reduced operational reactors in 2014 power reactor information system (PRIS) bringing the total to 435 operational reactors as at July 2014 as against 440 in 2010.

Table 2.1: World Operational Reactors (IAEA, 2014; NEA, 2012b)

S/N	Country	Number of Reactors 2010	Number of Reactors 2014	Difference Between 2010 and 2014	Total Net Electrical Capacity [MW]
1	Argentina	2	2		935
2	Armenia	1	1		375
3	Belgium	7	7		5927
4	Brazil	2	2		1884
5	Bulgaria	2	2		1906
6	Canada	17	19	+2	13500
7	China	13	21	+8	17056
8	Czech Republic	6	6		3884
9	Finland	4	4		2752
10	France	58	58		63130
11	Germany	17	9	-8	12068
12	Hungary	4	4		1889
13	India	19	21	+2	5308
14	Iran, Islamic Republic Of	0	1	+1	915
15	Japan	54	48	-4	42388
16	Korea, Republic Of	21	23	+2	20721
17	Mexico	2	2		1330
18	Netherlands	1	1		482
19	Pakistan	2	3	+1	690
20	Romania	2	2		1300
21	Russia	32	33	+1	23643
22	Slovakia	4	4		1815
23	Slovenia	1	1		688
24	South Africa	2	2		1860
25	Spain	8	7	-1	7121
26	Sweden	10	10		9474
27	Switzerland	5	5		3308
28	Taiwan /China	6	6		5032
29	Ukraine	15	15		13107
30	United Kingdom	19	16	-3	9243
31	USA	104	100		99081
	Total	**440**	**435**	**-5**	**372812**

The major current driver for the use of nuclear power is the potential to alleviate global warming (Lior, 2010). Accordingly, most of the available archival and authoritative sources agree that nuclear power produces, per unit power generated, only about half the CO_2 of wind power, 1/10 of solar PV and 30 fold less than natural gas. Similarly, another major concern is in the price of oil that was lately growing very rapidly (IEA, 2006; Lior, 2010), from $28/barrel in 2003, to $38 in 2005 and occasionally to above $80 in 2006 and peaking at $147 in 2008, but then precipitously dropping to $40 by the end of 2008, and rising again in February 2010 to between $71 and $81. However, despite the unresolved problems of waste storage, proliferation risk, and to some extent safety, nuclear power plants are likely to be constructed at least for special needs, especially countries that have much better access to uranium than to fossil fuels coupled with the cost of carbon emissions. Accordingly, the amount of uranium-235 (U^{235}) in the world is insufficient for massive long-term deployment of nuclear power generation. Therefore, nuclear will be sufficient if breeder reactors are used. Sailor (2010) noted that of recent, experts and non-experts alike have looked enthusiastically at nuclear power as a possible solution to the intractable problems posed by climate change and continued fossil-fuel dependence. Consequently, several next-generation nuclear reactor designs hold the promise of almost completely solving the worst concerns about nuclear energy. According to MacDonald (2006), nuclear power represents one of the best solutions to the world's energy needs in a compact, cost effective and environmentally responsible format. Hence, by capturing and sequestering waste products during the entire fuel cycle, nuclear power is one of the cleanest base load energy sources available. However, long term storage of used fuel is technically feasible both aboveground storage containers and in underground geologic formations. Therefore, continued research into new nuclear reactors is expected to allow for almost complete consumption of the available unused fuel in high level waste. Similarly, as one time chairman of Atomic Energy Commission in 1954 once predicted, that nuclear power generators would provide power so cheap, nearly unlimited and clean that we may not have need to meter it (Botkin and Keller, 2003). Also, if issues of cost, availability of nuclear fuel, safety and storage of waste can be resolved, nuclear energy which does not contribute to the global warming is one of several technologies that may eventually replace fossil fuels and needs to be looked at as a major source of energy.

2.2 Nuclear Power Generation

Nuclear reactors generate energy through fission, the process by which an atomic nucleus splits into two or more smaller nuclei (Karam, 2006). During fission, a small amount of mass is converted into energy, which can be used to power a generator to create electricity. In order to harness this energy, a controlled chain reaction is required for fission to take place. When a uranium nucleus in a reactor splits, it produces two or more neutrons that can then be absorbed by other nuclei, causing them to undergo fission. As a result, more neutrons are released in turn and continuous fission is achieved. According to Tagare (2011), nuclear power generation is derived from controlled fission of heavy elements principally of uranium. Through thermal generation which consists essentially of removing heat optimally at desired temperature and pressure from a reactor core and the steam generated drives the steam turbines coupled to electricity generators, the electricity is then produced. He however highlighted the merits of nuclear power generation as follows:

1. Steady reliable supply of electricity
2. Environmentally acceptable
3. Moderate and limited space requirements as compared to hydroelectric
4. Fuel costs are low and fuel life is long

5. Frees a society from overdependence on fossil fuels (oil and coal)

2.3 The Fission Chain Reaction

Nuclear energy is released by way of a fission chain reaction. In this process, neutrons emitted by fission nuclei induce fissions in fissionable nuclei; the neutrons from these fissions also induce fissions in other fissile or fissionable nuclei and others (Lamarsh & Baratha, 2001; Knief, 2013). Such a chain reaction can be described quantitatively in terms of the multiplication factor, which is denoted by the symbol k as shown in equation 2.1 below. This is defined as the ratio of the number of fissions (or fission neutrons) in one generation divided by the number of fissions (or fission neutrons) in the preceding generation as shown in the following equation.

$$K = \frac{\text{Number of Fissions in one generation}}{\text{Number of Fissions in preceding generation}} \qquad (2.1)$$

Where;

$K > 1$ = Supercritical
$K = 1$ = Critical
$K < 1$ = Subcritical

2.4 Nuclear Reactor and Nuclear Power

From Fig 2.1 below, if K is greater than 1, then the number of fissions increases from generation to generation.

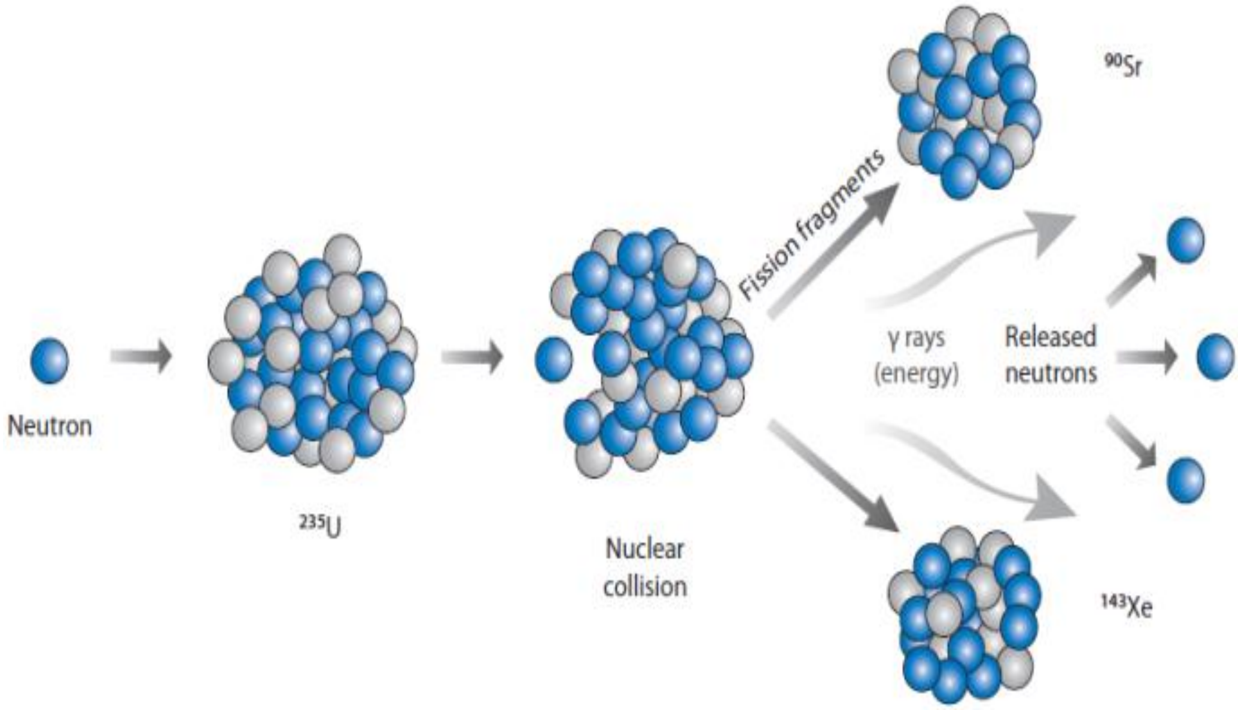


Figure 2.1: Typical fission chain reaction (NEA, 2012a; Lamarsh & Baratha, 2001)

In this case, the energy released by the chain reaction increases with time and the chain reaction is said to be supercritical. However, if K is less than 1, the number of fissions decreases with time and the chain reaction is called subcritical. Similarly whereby K is equal to 1, the chain reaction proceeds at a constant rate with energy being released at a constant level the system is then said to be critical. Therefore, devices that are designed so that the fission chain reaction can proceed in a controlled manner are called nuclear reactors. However, the control of a reactor is accomplished by varying the value of K, which can be done by reactor operator.

2.4.1 Nuclear Reactor Components

A nuclear power plant comprises a number of systems and components, including the reactor itself and turbine hall that are designed together to harness and control the energy of nuclear fission in turning it into electricity (see Figure 2.2). However, there are different types of nuclear reactors with several components in common such as fuel, moderator, coolant and control rods (NEA, 2012a).

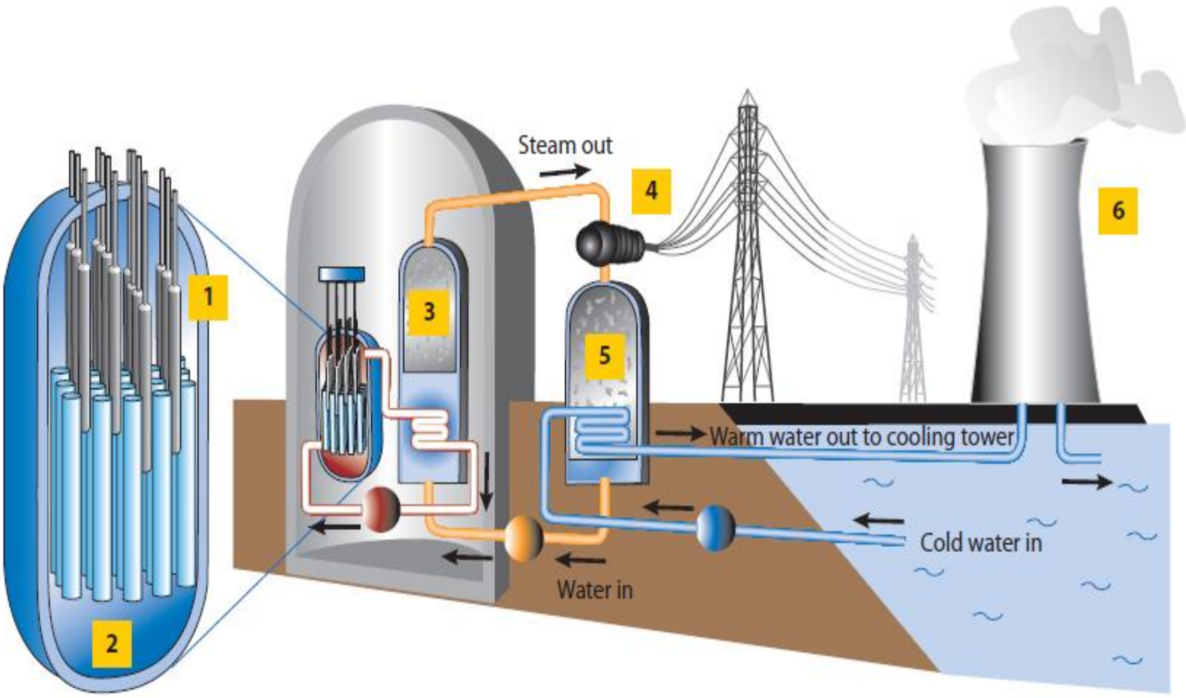


Figure 2.2: Typical Pressurized Water Reactor (PWR) Power Plant (NEA, 2012a; Cohen, 1983; IEE, 2005; Adee and Guizzo, 2010; USNRC, 2013; IET, 2008; WNA, 2014; Knief, 2013)

Figure 2.2, shows the details of various neutron reactor components:

1. Reactor: fuel (light blue) heats up pressurised water. Control rods (grey) absorb neutrons to control or halt the fission process.
2. Coolant and moderator: fuel and control rods are surrounded by water (primary circuit) that serves as coolant and moderator.
3. Steam generator: water heated by the nuclear reactor transfers heat through thousands of tubes to a secondary circuit of water to create high-pressure steam.
4. Turbo-generator set: steam drives the turbine, which spins the generator to produce electricity.
5. Condenser: removes heat to convert steam back to water, which is pumped back to the steam generator.
6. Cooling tower: removes heat from the cooling water that circulated through the condenser, before returning it to the source at near-ambient temperature.

2.5 Nuclear Reactors by Generations

Nuclear reactor technology has been under continuous development since 1950s. These technological developments are presented in different generations. Each generation as shown in Figure 2.3 represents a significant technical advancement either in terms of performance, costs or safety compared to the previous ones. They range from Generation-I nuclear systems, such as the first commercialised power plants of various designs (gas-cooled / graphite moderated, or prototype water cooled & moderated), through Generation-II designs, which are the standard light-water pressurised and boiling water reactors in operation today, to the Generation-III designs that are now in construction in several countries and to Generation-IV reactor designs that could be commercially deployed from 2030 (EC, 2013; OECD, 2014; Goldberg and Rosner, 2011; Kim, 2013).

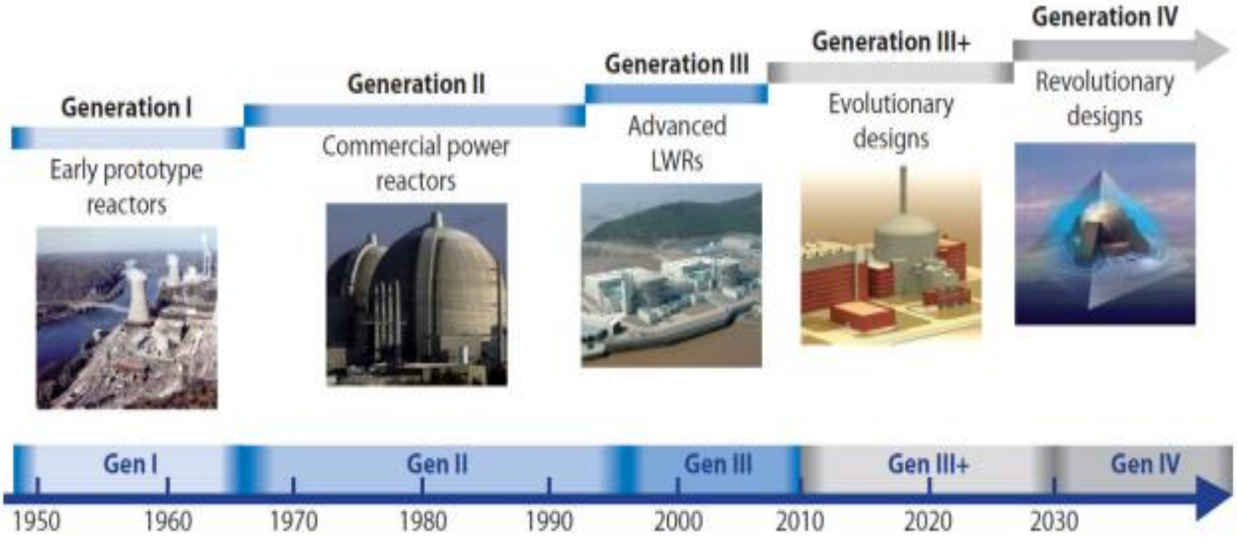


Figure 2.3: Generations of Nuclear Reactor (EC, 2013; OECD, 2014; Goldberg and Rosner, 2011; NEA, 2012a; NEA, 2007; Kim, 2013)

2.5.1 Generation I

Gen I nuclear reactors were the early prototype reactors from the 1950s and 1960s such as Shippingport (1957–1982) in Pennsylvania, Dresden-1 (1960–1978) in Illinois, and Calder Hall-1 (1956–2003) in the United Kingdom. This kind of reactor typically ran at power levels that were "proof-of-concept." The only remaining commercial Gen I plant, the Wylfa Nuclear Power Station in Wales, was scheduled for closure in 2010. However, the UK Nuclear Decommissioning Authority announced in October 2010 that the Wylfa Nuclear Power Station will operate up to December 2012. But according to BBC (2014), the 43 year old facility was later planned for decommissioning in 2014.

2.5.2 Generation II

Gen II nuclear reactors refers to a class of commercial reactors designed for a typical operational lifetime of 40 years to be economical and reliable. The Gen II reactors include pressurized water reactors (PWR), Canada Deuterium Uranium reactors (CANDU), boiling water reactors (BWR), advanced gas-cooled reactors (AGR), and Vodo-Vodyanoi Energetichesky Reactors (VVER). Gen II systems began operation in the late 1960s and comprise the bulk of the world's over 400 commercial PWRs and BWRs. Most of the Gen II plants are still in operation in the West and were manufactured by one of these three companies: Westinghouse, Framatome (AREVA), and General Electric (GE).

2.5.3 Generation III

Gen III nuclear reactors are essentially state-of-the-art standardized design improvements in the areas of fuel technology, thermal efficiency, modularized construction, safety systems especially the use of passive rather than active systems. The improvements have aimed at a longer operational life, typically 60 years of operation with the potential to exceed 60 years before complete overhaul and replacement of reactor pressure vessel. However, confirmatory research to investigate nuclear plant aging beyond 60 years is needed to allow these reactors to operate over such extended lifetimes. The Westinghouse 600 MW advanced PWR (AP-600) was one of the first Gen III reactor designs and Advanced Boiling Water Reactor (ABWR) from GE Nuclear Energy. Others include the Enhanced CANDU 6, which was developed by Atomic Energy of Canada Limited (AECL) and System 80+, a Combustion Engineering design.

2.5.4 Generation III+

Gen III+ nuclear reactor designs are an evolutionary development of Gen III reactors with significant improvements in safety. The development of Gen III+ systems started in 1990s, building on the operating experience of the American, Japanese and Western European LWR fleets. The most significant improvement of Gen III+ systems is the incorporation of passive safety features designs that do not require active controls or operator intervention but instead rely on gravity or natural convection to mitigate the impact of emergency. These reactors, once on line, are expected to achieve higher fuel burn-up by reducing fuel consumption and waste production than their evolutionary predecessors. Examples of Gen III+ designs include:

- VVER-1200/392M Reactor of the AES-2006 type
- Advanced CANDU Reactor (ACR-1000)
- AP1000: based on the AP600, with increased power output
- European Pressurized Reactor (EPR)
- Economic Simplified Boiling Water Reactor (ESBWR): based on the ABWR
- APR-1400: an advanced PWR design.
- EU-ABWR: based on the ABWR, with increased power output.
- Advanced PWR (APWR): designed by Mitsubishi Heavy Industries (MHI)
- ATMEA I: a 1,000–1,160 MW PWR, (collaboration between MHI and AREVA).

2.5.5 Generation IV

Gen IV nuclear reactors have all of the features of Gen III+ reactors and the ability when operating at high temperature, to support economical hydrogen production, thermal energy off-taking, and perhaps even water desalination. Additionally in the design includes advanced actinide management.

2.6 World Nuclear Reactors by Types

Development of nuclear power generating plants for propulsion and electricity generation depends primarily on the type of fuel used (Tagare, 2011; Knief, 2013; Disosway, 2006). However, Table 2.2 and Figure 2.4, shows the world reactors by type and compositions (IAEA, 2014).

Table 2.2: World Operational Reactors by Types (IAEA, 2014)

Reactor Type	Reactor Type Descriptive Name	Number of Reactors	Total Net Electrical Capacity [MW]
BWR	Boiling Light-Water-Cooled and Moderated Reactor	81	75958
FBR	Fast Breeder Reactor	2	580
GCR	Gas-Cooled, Graphite-Moderated Reactor	15	8045
LWGR	Light-Water-Cooled, Graphite-Moderated Reactor	15	10219
PHWR	Pressurized Heavy-Water-Moderated and Cooled Reactor	48	23900
PWR	Pressurized Light-Water-Moderated and Cooled Reactor	274	254110
Total		435	372812

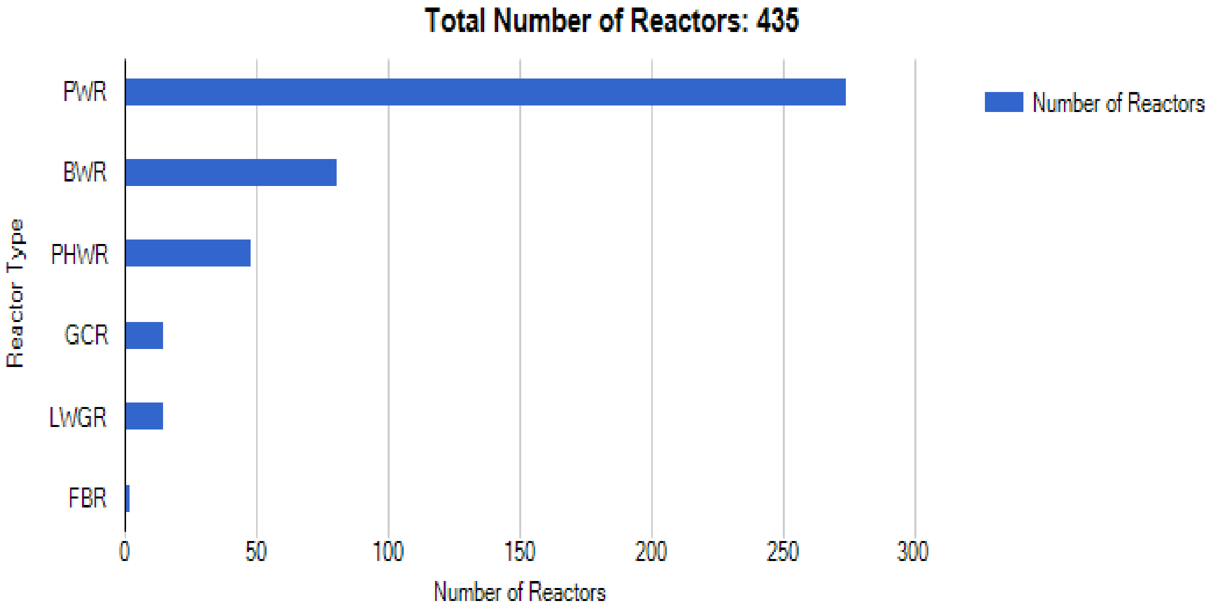


Figure 2.4: Operational Reactors by type (IAEA, 2014)

From the literature, there are six types of reactors (IET, 2008; IEE, 2005; IAEA, 2014; DME, 2005; IAEA, 2004; NEA, 2012a; Knief, 2013) namely:

1. Boiling Light-Water-Cooled and Moderated Reactor (BWR)
2. Fast Breeder Reactor (FBR)
3. Gas-Cooled, Graphite-Moderated Reactor (GCR)
4. Light-Water-Cooled, Graphite-Moderated Reactor (LWGR)
5. Pressurized Heavy-Water-Moderated and Cooled Reactor (PHWR)
6. Pressurized Light-Water-Moderated and Cooled Reactor (PWR)

2.6.1 BWR

BWR is the second type of water cooled and moderated reactor as shown in Figure 2.5 below. By allowing the water within the reactor circuit to boil, it raises steam directly for electrical power generation. This, however, leads to some radioactive contamination of the steam circuit and turbine, which then requires shielding of these components and the reactor surrounding.

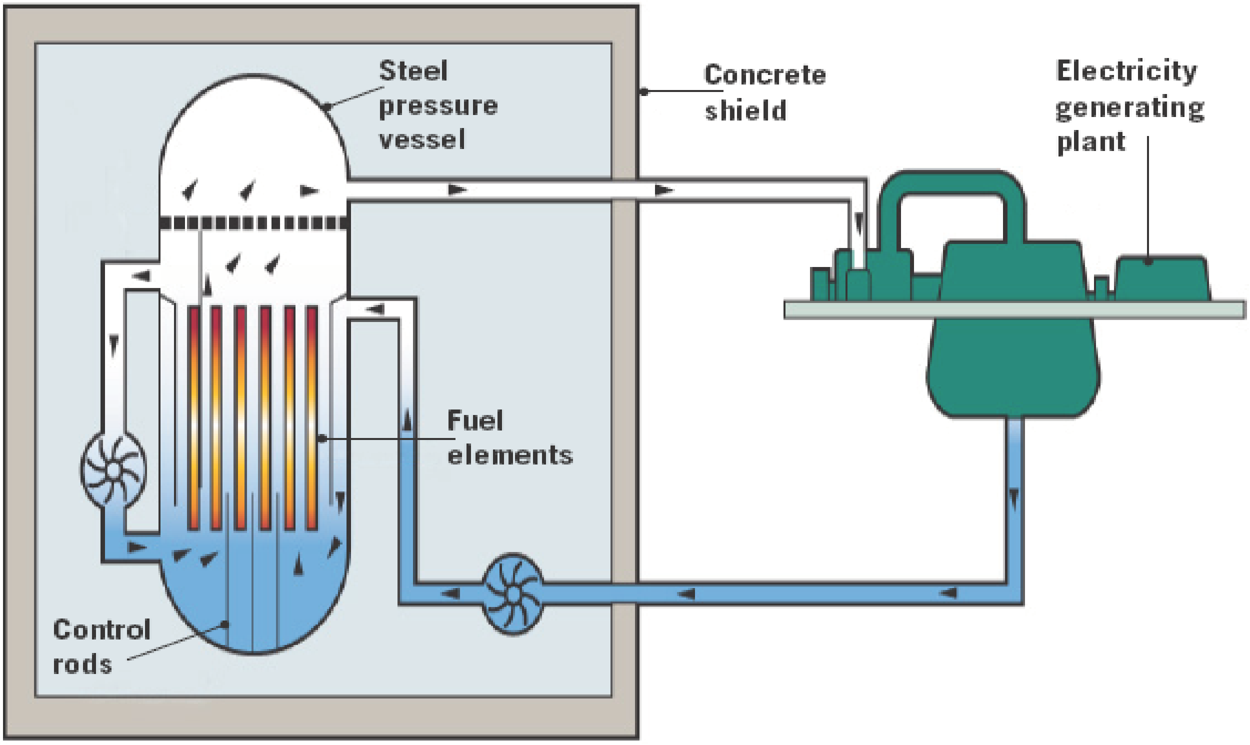


Figure 2.5: Schematic: BWR (IET, 2008; IEE, 2005; Knief, 2013)

2.6.2 FBR

All of today's commercially successful reactor systems are thermal reactors, using slow or thermal neutrons to maintain the fission chain reaction in the U^{235} fuel, while FBR produces more fissile material than it consumes, their neutrons however are un-moderated. It has core with a high fissile concentration around 20% Plutonium. The active core is surrounded by U^{238} material largely left over from the thermal reactor enrichment process. Due to the absence of a moderator, and the high fissile content of the core, heat removal requires the use of a high conductivity coolant such as liquid sodium which is circulated through the core and heats a secondary loop of sodium coolant, which then heats water in a steam generator to raise steam. The core is either immersed in a pool of coolant or coolant is pumped through the core and hence to a heat exchanger. FBR is largely un-pressurised since sodium does not boil at the temperatures experienced and is contained within steel and concrete shields. Therefore, it has the potential to increase the energy available from a given quantity of uranium by a factor of fifty or more, and can utilise the existing stocks of depleted uranium, which would otherwise have no value. Figure 2.6 below is the schematic of Sodium cooled FBR.

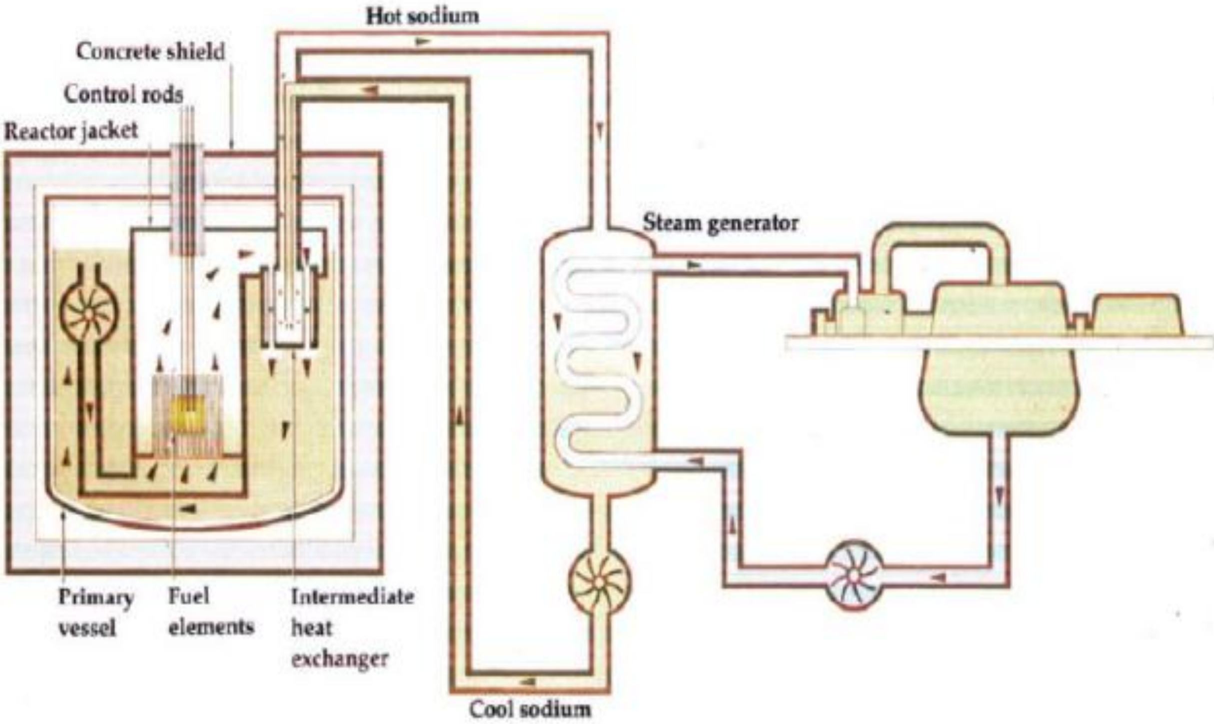


Figure 2.6: Schematic FBR – Sodium-Cooled (IEE, 2005; Knief, 2013)

2.6.3 GCR

GCR are graphite moderated and gas cool reactor design such as Magnox and AGR as shown below on Figure 2.7. They were the oldest reactor designs that were built in the UK from 1956 to 1971. The Magnox reactor is named after the magnesium alloy used to encase the fuel, which is natural uranium metal. The fuel elements consisting of fuel rods encased in Magnox cans are loaded into vertical channels in a core constructed of graphite blocks. The vertical channels contain control rods – strong neutron absorbers which can be inserted or withdrawn from the core to adjust the rate of the fission process and the heat output. The whole assembly is cooled by blowing carbon dioxide gas past the fuel cans which are specially designed to enhance heat transfer while the hot gas converts water to steam in a steam generator. The early designs used a steel pressure vessel, which was surrounded by a thick concrete radiation shield. While in later designs, a dual-purpose concrete pressure vessel and radiation shield was used.

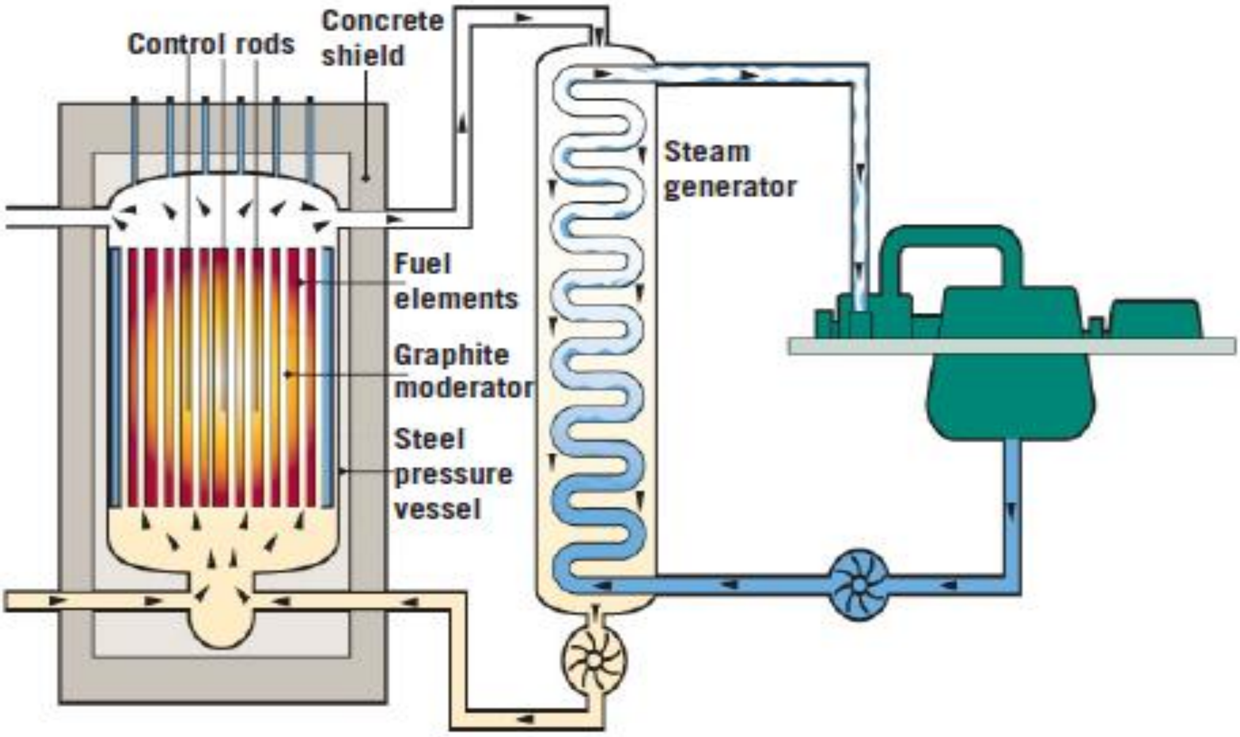


Figure 2.7: Schematic GCR – MAGNOX (IET, 2008; IEE, 2005; Knief, 2013)

2.6.4 LWGR

The LWGR has been developed and enlarged, many reactors of this type have been constructed in the USSR, including the ill-fated Chernobyl. The layout consists of a large graphite core containing some 1700 vertical channels, each containing enriched uranium dioxide fuel (1.8% U^{235}). Heat is removed from the fuel by pumping water under pressure up through the channels where it is allowed to boil to steam drums to drive electrical turbo-generators. Many of the major components, including pumps and steam drums, are located within a concrete shield to protect operators against the radioactivity of the steam. At about the same time Magnox design was being commissioned at Calder Hall in 1956, the Russians were testing a water cooled, graphite moderated plant at Obninsk known as the RBMK reactor as shown on Figure 2.8 below:

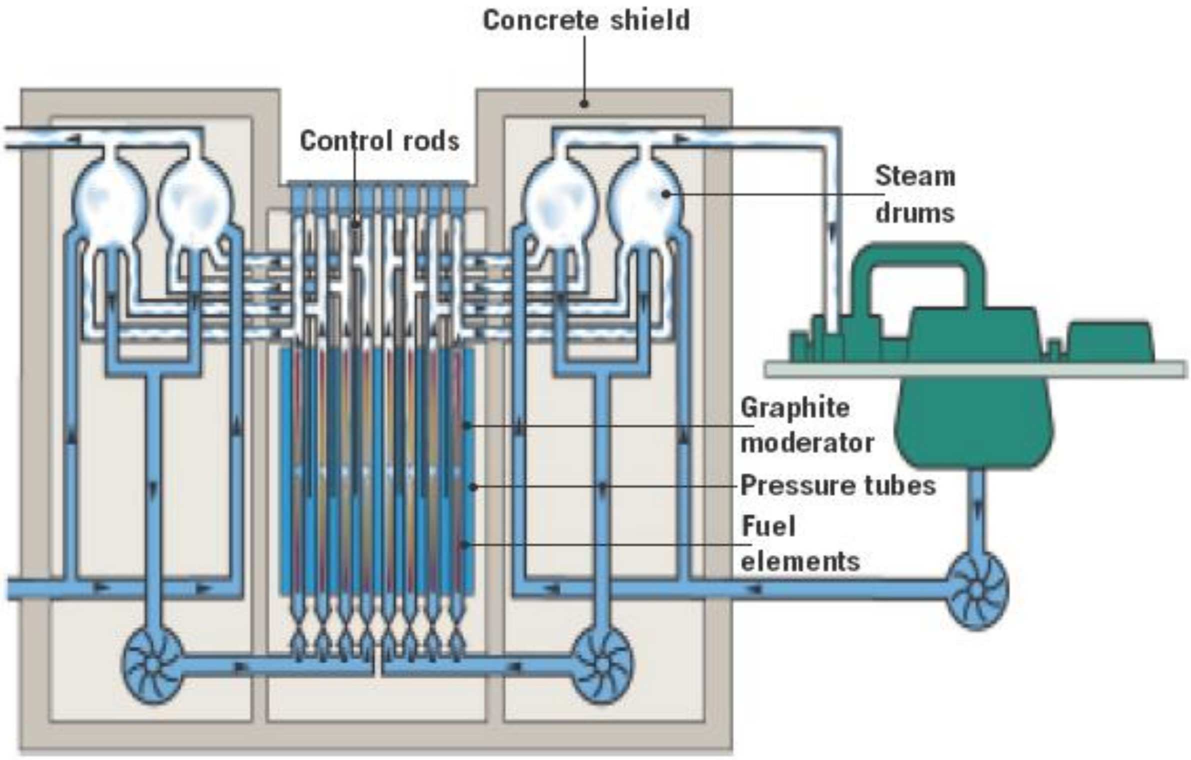


Figure 2.8: Schematic LWGR – RBMK (IET, 2008; IEE, 2005; Knief, 2013)

2.6.5 PHWR

The only PHWR design in commercial use is the CANDU (See Figure 2.9), designed in Canada and subsequently exported to several countries. With CANDU reactor, the un-enriched uranium dioxide is held in zirconium alloy cans loaded into horizontal zirconium alloy tubes. The fuel is cooled by pumping heavy water through the tubes (under high pressure to prevent boiling) and then to a steam generator to raise steam from ordinary water – also known as natural or light water in the normal way. However, the necessary additional moderation is achieved by immersing the zirconium alloy tubes in an un-pressurised container called a callandria containing more heavy water. Therefore, the control is achieved by inserting or withdrawing cadmium rods from the callandria. The whole assembly is contained inside the concrete shield and containment vessel.

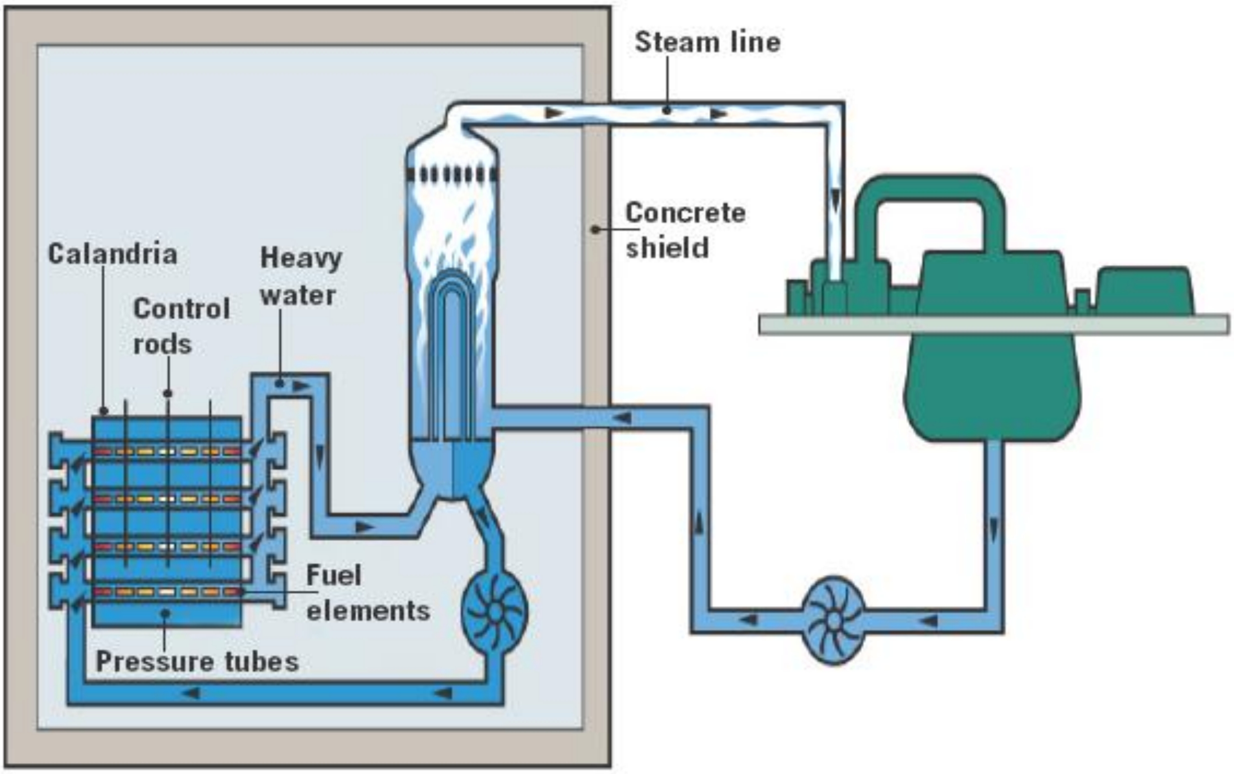


Figure 2.9: Schematic: PHWR – CANDU (IET, 2008; IEE, 2005; Knief, 2013)

2.6.6 PWR

The PWR as shown in Fig 2.10 is the most widely used reactor type in the world which uses enriched uranium dioxide (about 3.2% U^{235}) as a fuel in zirconium alloy cans. The fuel, which is arranged in arrays of fuel pins and interspersed with the movable control rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator. The high-pressure water is then passed through a steam generator, which raises steam in the usual way. As in the CANDU design, the whole assembly is contained inside the concrete shield and containment vessel.

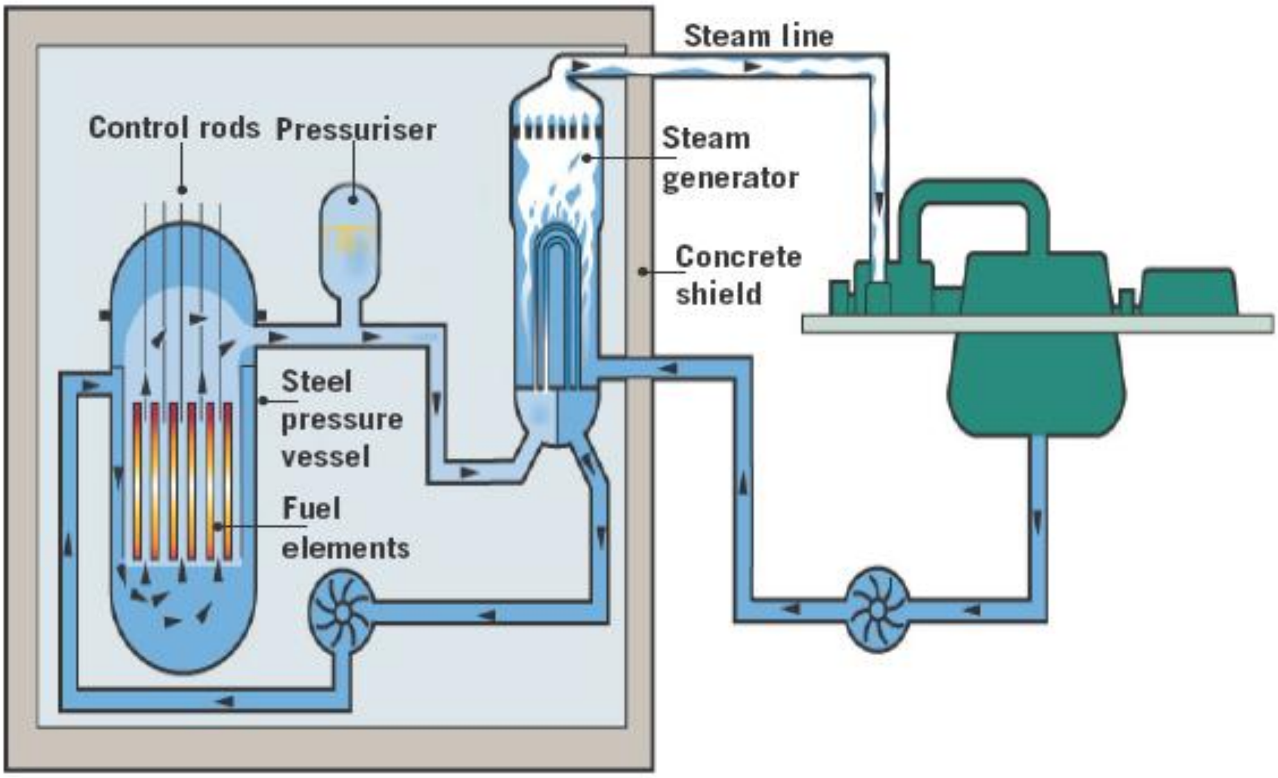


Figure 2.10: Schematic: PWR (IET, 2008; IEE, 2005; Cohen, 1983; NEA, 2012a; Knief, 2013)

According to Cohen (1983) by fission reactions, water is heated to 600°F (315.56°C) in a PWR, which is prevented from boiling by maintaining its high pressure. It is then pumped to the steam generator and the heat is transferred to a secondary water system where the water is boiled to steam, which drives the turbines to drive the generator to produce the electricity. The Republic of South African Koeberg nuclear power station is of PWR design. The station is owned by Eskom, made of 2 units of 900MW of PWR each with a total capacity of 1800MW (Eskom, 2014).

2.7 Reactor Technology Development and Deployment

It is generally recognized that long term development of nuclear power as a part of the worlds future energy mix will require fast reactor technology with closed fuel cycle (IAEA, 2013). The fast neutron spectrum allows fast reactors to increase the energy yield from natural uranium by a factor of sixty to seventy compared to thermal reactors, thereby realizing nuclear power program for thousands of years, as well as a significant improvement of nuclear waste management. However, the necessary condition for successful deployment in the near and mid-term is the understanding and assessment of technological and design options, based on both past knowledge and experience, as well as on scientific and technological research efforts. Therefore, the design and operation of several sodium-cooled fast reactors, such as the Fast Flux Test Facility (FFTF) in USA, the small size Prototype sodium-cooled 250MWe Fast Reactor (PFR) in the United Kingdom, the prototype Phénix in

France (a pool-type reactor, 250MW) went into commercial operation in 1974, the BN-350 in Kazakhstan, the demonstration plant BN-600 in Figure 2.11 of Russia and Monju in Figure 2.12 of Japan designed to generate 280MWe 714MWt) respectively.

Figure 2.11: The Russian Sodium-cooled fast reactor BN-600 in operation since 1980 (IAEA, 2013)

Figure 2.12: The Japanese Monju loop type sodium- cooled fast reactor (IAEA, 2013)

Similarly, with the commercial size Super phénix in France which was shutdown February 2, 1998 and others. Similarly, there is a considerable base of experience with lead-bismuth (eutectic) cooled propulsion (submarine) reactors operated in Russia. Examples of current sodium-cooled fast reactors are the China Experimental Fast Reactor (CEFR) a sodium cooled 65MWt experimental fast reactor as in Figure 2.13, which has been connected to the grid since July 2011. The Russian BN-800 (See Figure 2.14) below was still under construction as at 2009 (Pshakin, 2010). According to Komaki (2013) as highlighted by site officials said that the BN-800 was 70 percent completed and was in the final stage of construction, with about 5,000 people working around the clock to build it. The reactor is scheduled to enter operations in 2014 with an output capacity of 800MW. Also the Prototype Fast Breeder Reactor (PFBR) in India (Rouault *et al*., 2010; IAEA, 2013) both under construction.

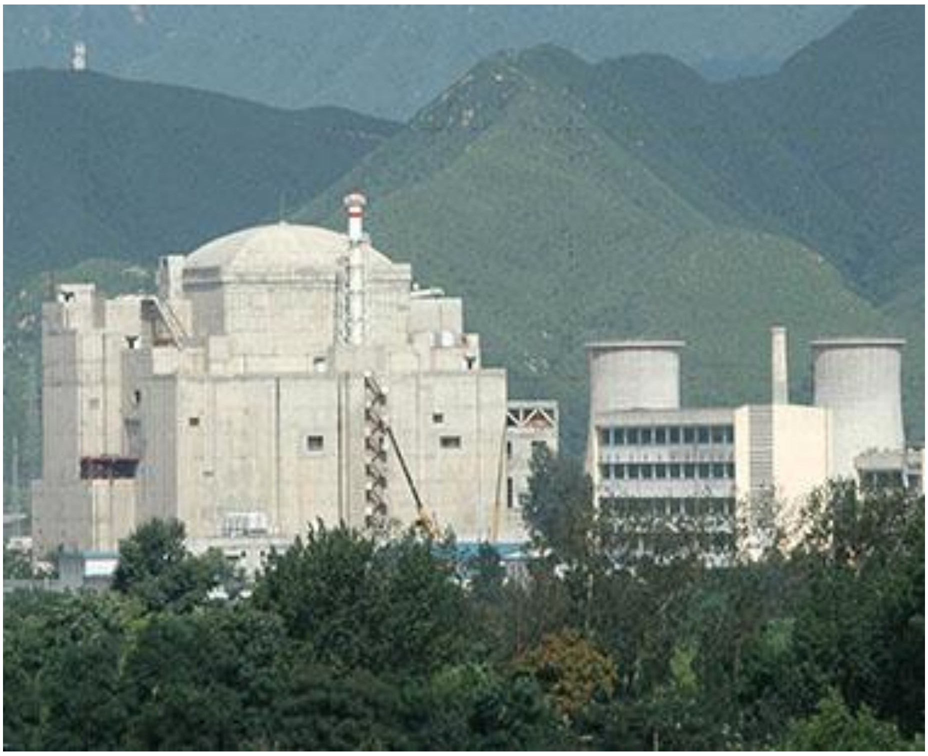


Figure 2.13: China Experimental Fast Reactor (CEFR), first grid connection on 21 July 2011(IAEA, 2013)

Figure 2.14: The Russian sodium-cooled fast reactor BN-800: construction initiated in July

According to IAEA (2013) besides current fast reactors construction projects, several countries are engaged in intense research and development programs for the development of fast reactors innovative (Generation IV - GENIV) concepts. Therefore, to establish multilateral international cooperative frameworks to carry out research and development (R&D) in support of the next generation of nuclear reactors, the following initiatives have been launched:

- The Generation IV International forum (GIF)
- International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)
- European Sustainable Nuclear Industrial Initiative (ESNII)

2.7.1 GIF

The GIF was created in January 2000 by 9 countries and today, it has 13 members; Argentina, Brazil, Canada, France, Japan, the Republic of Korea, South Africa, the United Kingdom and the United States which signed the GIF Charter in July 2001, Switzerland in 2002, Euratom in 2003 and the People's Republic of China and Russian Federation in 2006 (Kim, 2013). The GIF offers a forum for cooperation in the R&D of a number of more promising nuclear reactor concepts. Therefore, the following six types of Gen IV systems are currently being investigated. Four are fast neutron reactor designs, one is a thermal neutron reactor (very high temperature reactor, VHTR) and one is a supercritical water reactor (SCWR), which could be operated as either thermal or fast reactor (EC, 2013; OECD, 2014; OECD-NEA, 2014; MIT, 2003; NEA, 2012a; NEA, 2007; Knief, 2013; Kim, 2013):

- Sodium Fast Reactor (SFR),
- High Temperature Reactor (VHTR),
- Lead Fast Reactor (LFR),
- Gas Fast Reactor (GFR),
- Super-critical Water Reactor (SCWR), and
- Molten Salt Reactor (MSR).

2.7.1.1 SFR

The SFR uses liquid sodium as the reactor coolant, allowing a low-pressure coolant system and high-power-density operation with low coolant volume fraction in the core as shown in Figure 2.15 (pool type) and Figure 2.16 (looped type) respectively. The GIF consideration of plant sizes ranges from small, 50 to 300 MW (e), modular reactors, to larger plants, up to 1500 MW (e). The outlet temperature is 500-550°C. The basic technology for the SFR has been established in former fast reactor programmes, and was further confirmed by the Phénix end-of-life tests in France, the lifetime extension of BN-600 in Russia, the restart and success of core confirmation tests of Monju in Japan and the start-up of an experimental fast reactor in China. France, Japan and Russia are designing new SFR demonstration units for near-term deployment; China, the Republic of Korea and India are also proceeding with their national SFR projects.

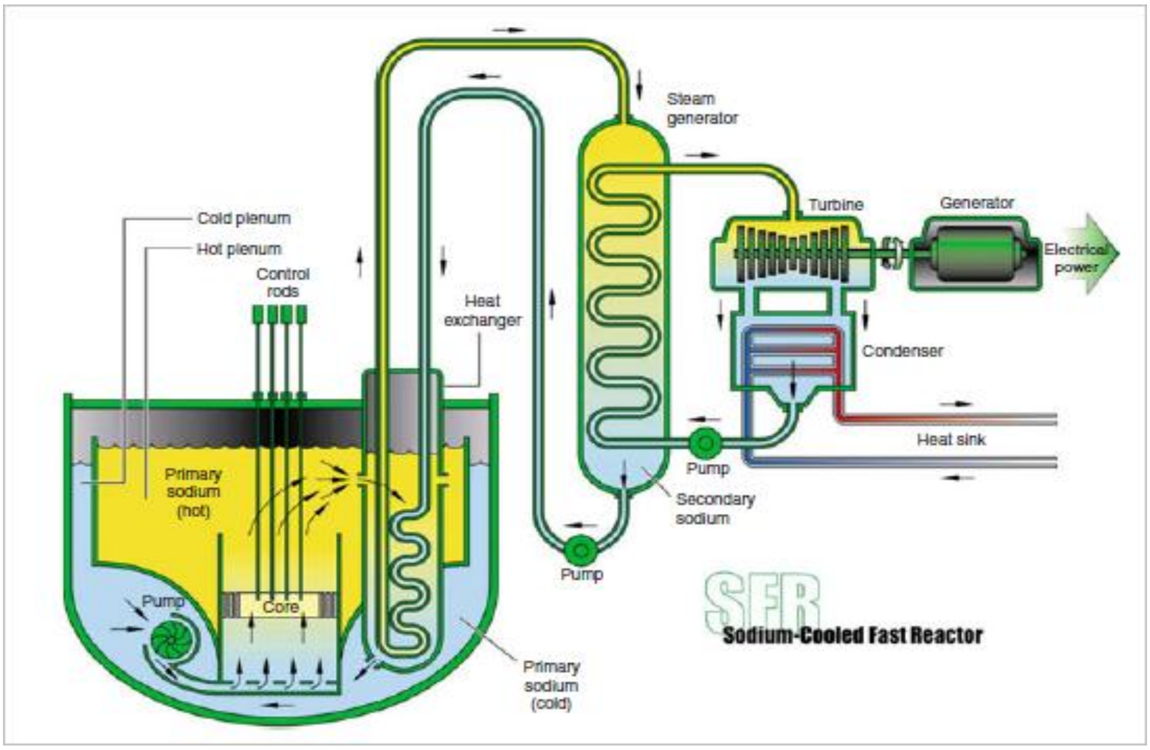


Figure 2.15: Pool-type Sodium-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014)

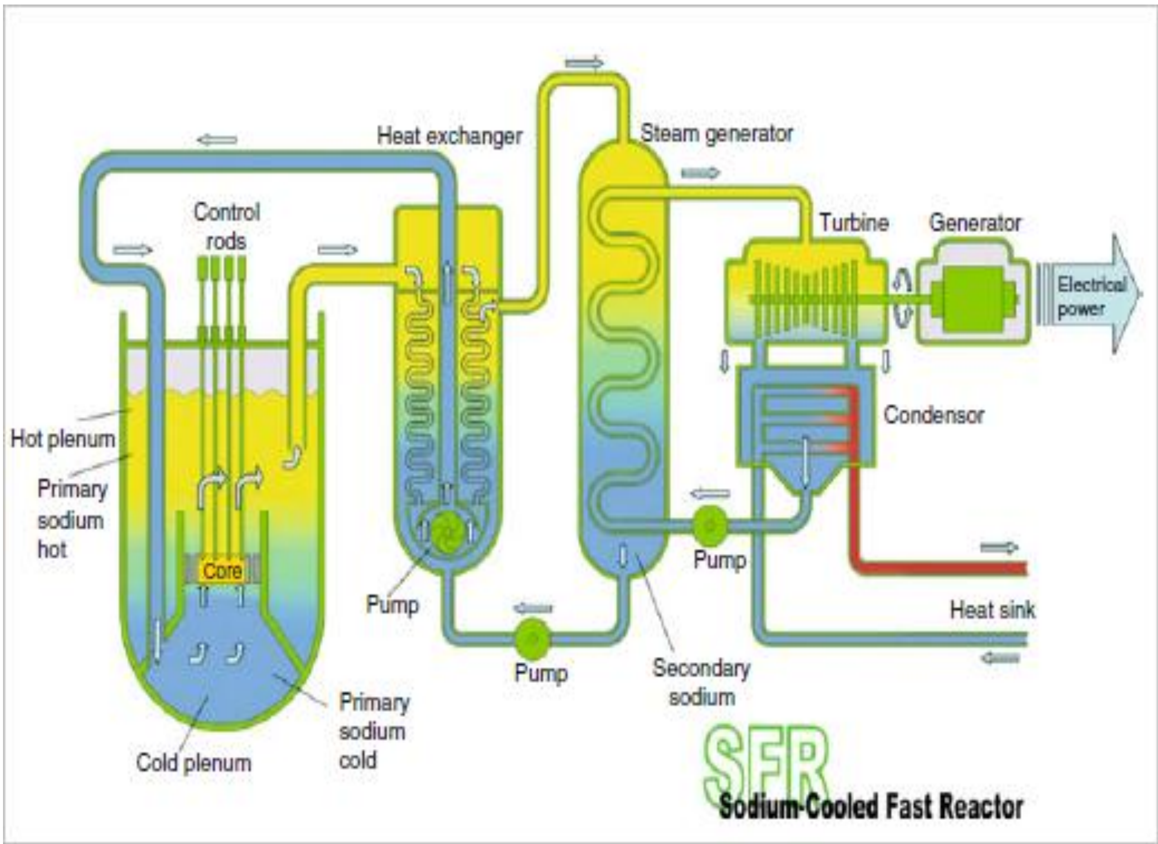


Figure 2.16: Looped-type Sodium-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014)

2.7.1.2 VHTR

It is a graphite-moderated, helium-cooled reactor with thermal neutron spectrum. It can supply nuclear heat and electricity over a range of core outlet temperatures between 700 and 950°C, and potentially more than 1 000°C in the future (See Figure 2.17). The reactor core of the VHTR can be a prismatic-block type such as the Japanese HTTR, or a pebble-bed type such as the Chinese HTR-10. The co-generation of heat and power makes the VHTR an attractive heat source for large industrial complexes. Because of its highly safety characteristics, the VHTR can be deployed in refineries and petrochemical industries to substitute large amounts of process heat at different temperatures, including hydrogen generation for upgrading heavy and sour crude oil.

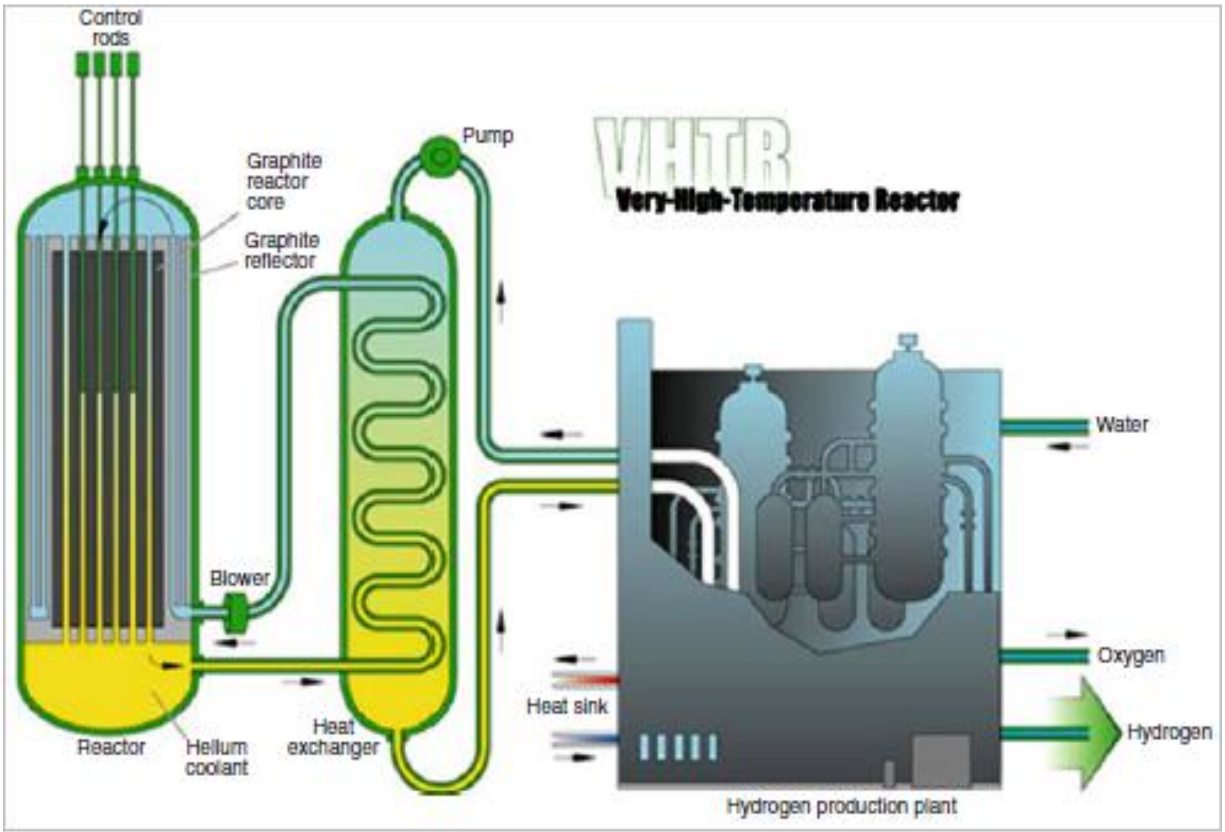


Figure 2.17: Very-high-temperature Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014)

2.7.1.3 LFR

LFRs are Lead (Pb) or Lead-Bismuth (Pb-Bi) alloy-cooled reactors as shown in Figure 2.18 below operating at atmospheric pressure and at high temperature that is due to the very high boiling point of the coolant (up to 1743°C). The core is characterised by a fast-neutron spectrum due to the scattering properties of lead. Although, Pb-Bi reactors have been operated successfully in some of the Russian submarine programmes, this experience cannot be easily extrapolated to the LFR since the propulsion reactors were small, operated at low capacity factors, featured an epithermal (not fast) neutron spectrum and operated significantly at lower temperatures than those anticipated in GENIV lead-cooled fast reactors.

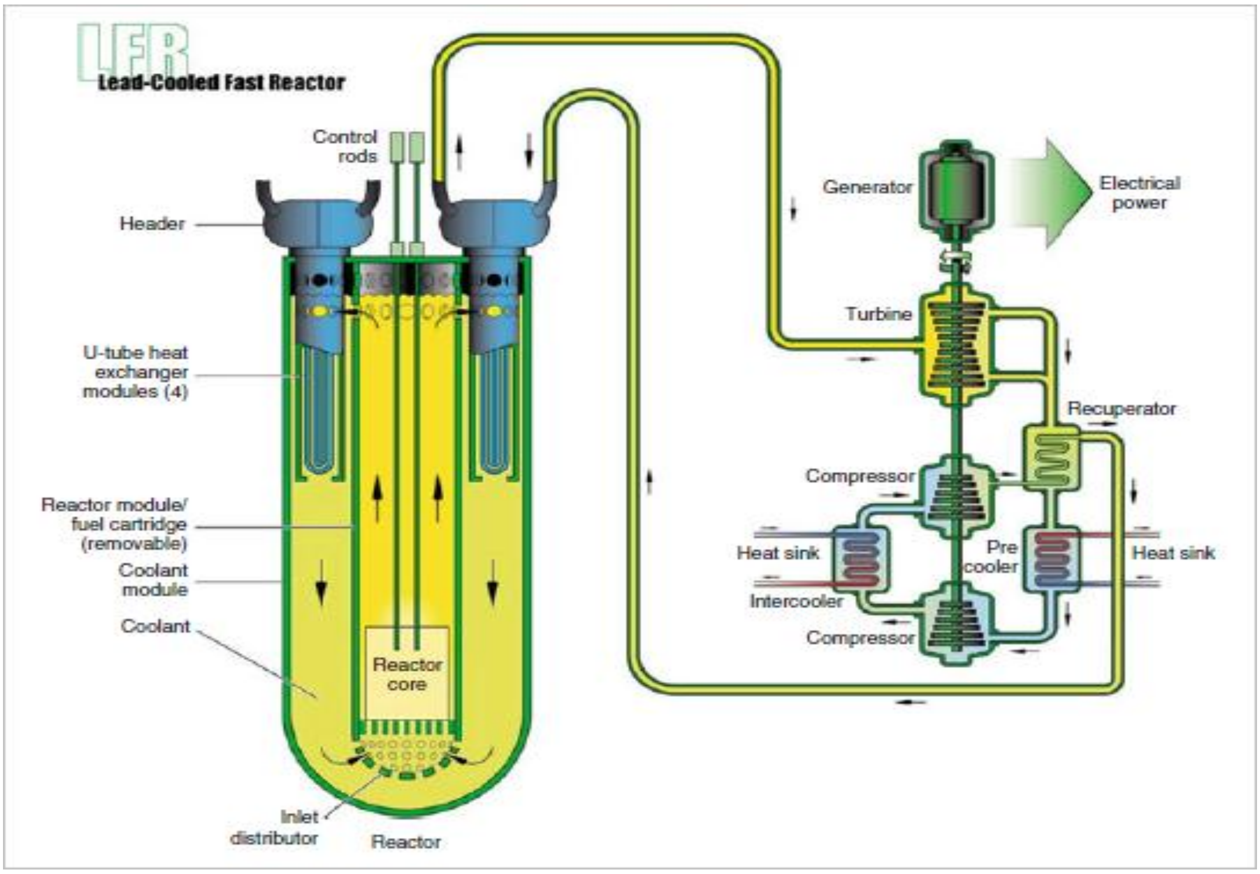


Figure 2.18: Lead-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014)

2.7.1.4 GFR

The GFR system is a high-temperature helium-cooled fast-spectrum reactor (See Figure 2.19) with a closed fuel cycle. It combines the advantages of fast-spectrum systems for long-term sustainability of uranium resources and waste minimisation (through fuel multiple reprocessing and fission of long-lived actinides), with those of high-temperature systems (high thermal cycle efficiency and industrial use of the generated heat, similar to VHTR). The reference design for GFR is currently based around 2400 MW_{th}, since the 600 MW_{th} reactor presented in the original roadmap could not meet the breakeven breeding requirement. The 600 MW_{th} is still considered as an option for a gas-cooled small modular reactor (SMR) that does not need to be a breakeven-breeder.

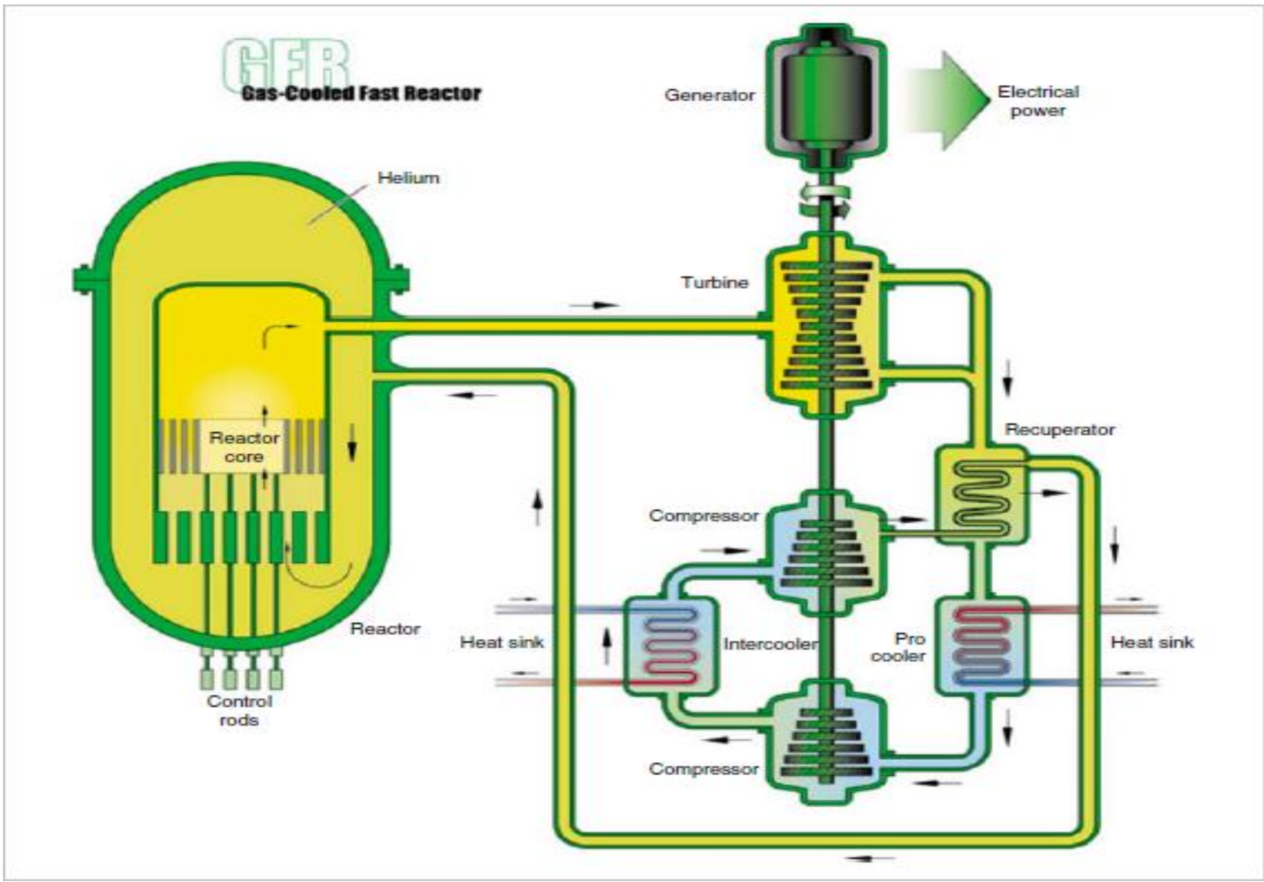


Figure 2.19: Gas-cooled Fast Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014)

2.7.1.5 SCWR

SCWRs are high temperature, high-pressure, light water reactors that operate above the thermodynamic critical point of water (374°C, 22.1 MPa) as shown in (Figure 2.20) below. The reactor core may have a thermal or a fast-neutron spectrum, depending on the core design. The concept may be based on current pressure-vessel or on pressure-tube reactors, and thus may use light water or heavy water as a moderator. The concepts of SCWR combine the design and operation experience gained from hundreds of water-cooled reactors with the experience from hundreds of fossil-fired power plants operated with supercritical water (SCW).

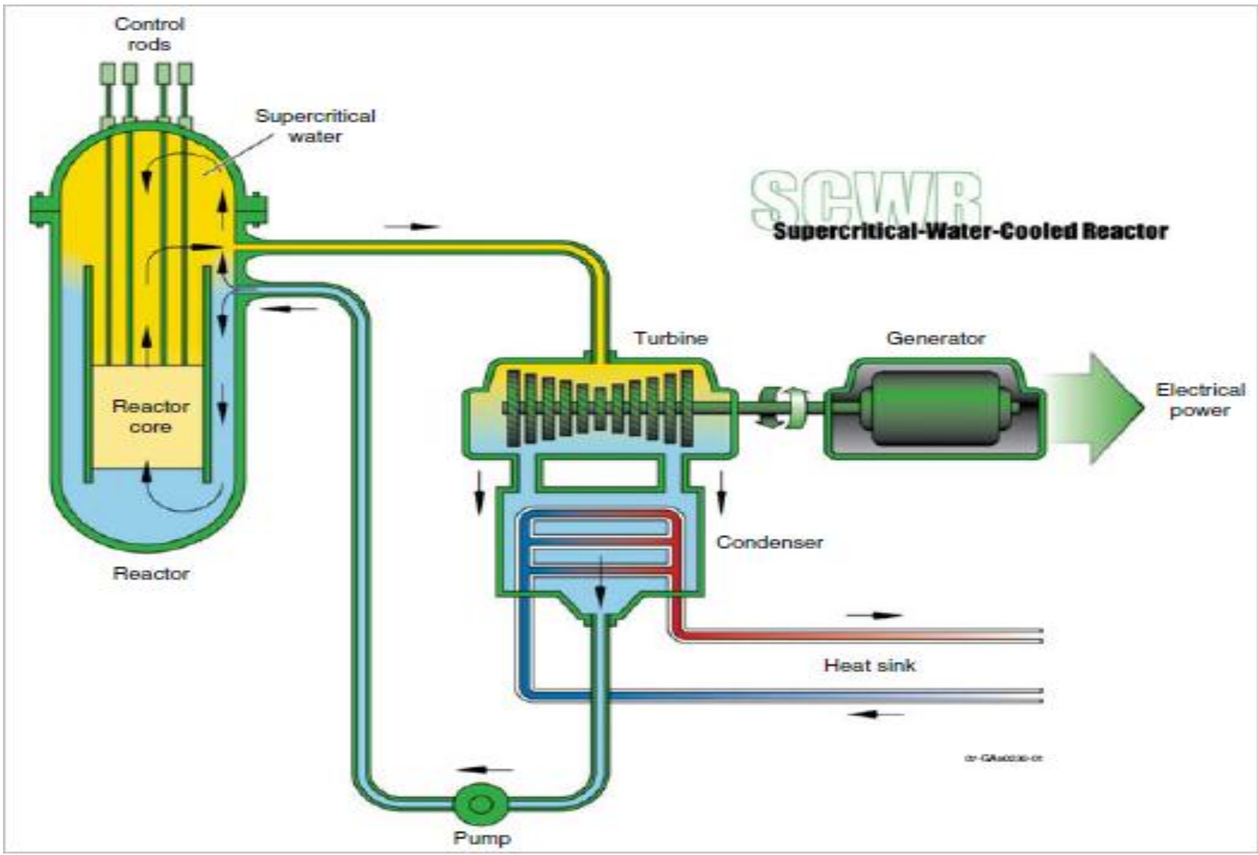


Figure 2.20: Supercritical Water-cooled Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014)

2.7.1.6 MSR

MSRs is as shown in Figure 2.21. MSRs can be divided into two subclasses. In the first subclass, fissile material is dissolved in the molten fluoride salt. In the second subclass, the molten fluoride salt serves as the coolant of a coated particle fuelled core similar to that employed in VHTRs. To distinguish reactor types, the solid fuel variant is typically referred to as a fluoride salt cooled high-temperature reactor (FHR). A large MSR development programme was conducted in the United States between 1950 and 1976. Two test reactors were successfully operated: the Aircraft Reactor Experiment (ARE) and the Molten Salt Reactor Experiment (MSRE). A preliminary design of a 1 000 MW (e) reactor, the Molten Salt Breeder Reactor (MSBR) based on the 232Th/233U cycle was completed, and a design was partially developed for a demonstration reactor. These programmes created the basis of the thermal neutron MSR technology. However, the concept of an FHR has its origin in the 1970s with the advent of TRISO fuel. Therefore, the FHRs may offer large-scale power generation while maintaining full passive safety; they can also support both high-efficiency electricity generation and high-temperature industrial process heat production.

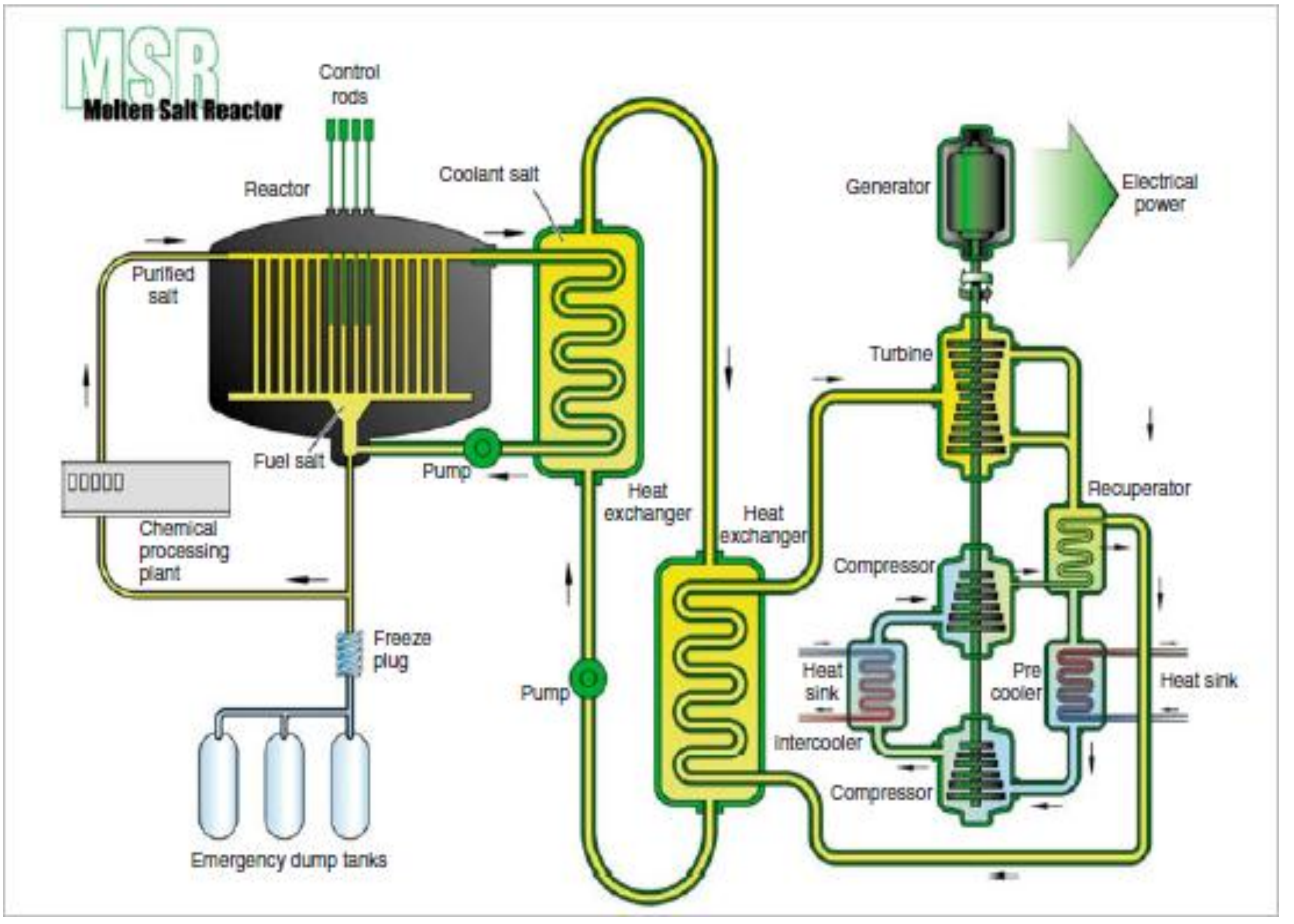


Figure 2.21: Molten Salt Reactor (EC, 2013; Kim, 2013; Knief, 2013; MIT, 2003; NEA, 2007; NEA, 2012a; OECD, 2014; OECD-NEA, 2014)

In summary, GIF subclasses were all chosen through solicitation of expertise and wide selection range of possible designs, and are considered to exhibit the greatest potential to show the desired GENIV characteristics of increased sustainability, competitive economics, high level of safety, increased proliferation resistance and, for some designs, the ability to cogenerate high grade heat for use in industrial processes (chemical industry, production of hydrogen or synthetic fuels and others. According to Tagare (2011), Disosway (2006) and EC (2013), the fully ratified GIF member nations are Canada, China, France, Japan, Korea, Russia, South Africa, Switzerland, and USA, with EURATOM as a member. EC (2013) noted that GENIV research covers and includes work on the fuel cycle as well as the reactor components. Though, its commercial deployment is not expected before 2040. Accordingly, the aim of GIF is to develop fast reactors that can also burn the minor actinides recycled from spent fuel. Actinides are responsible for much of the heat, radiation produced by the waste. By recycling it into the reactor, careful design of the fuel and operation of the reactor, they can be transmuted into less radiotoxic and shorter-lived radionuclide. This is not only an effective way of reducing waste quantities, but the recycling of the minor actinides along with the plutonium also greatly reduces the risk of proliferation. This would make the fuel cycle an extremely unattractive source of nuclear material for illicit atomic weapons program.

2.7.2 INPRO

INPRO was initiated in 2000 as an IAEA flagship project through a General Conference resolution, to help ensure that nuclear energy sustainably is available to contribute in meeting the global energy needs of the 21st century. Based on this objective, a national nuclear energy assessments (NESA) methodology (INPRO-IAEA, 2013; NEA, 2011; NEA, 2007; IAEA, 2009) as in Figure 2.22 was developed for national energy planners in making informed decisions on the choice of the most appropriate nuclear system and assess whether their strategic deployment plan will be sustainable.

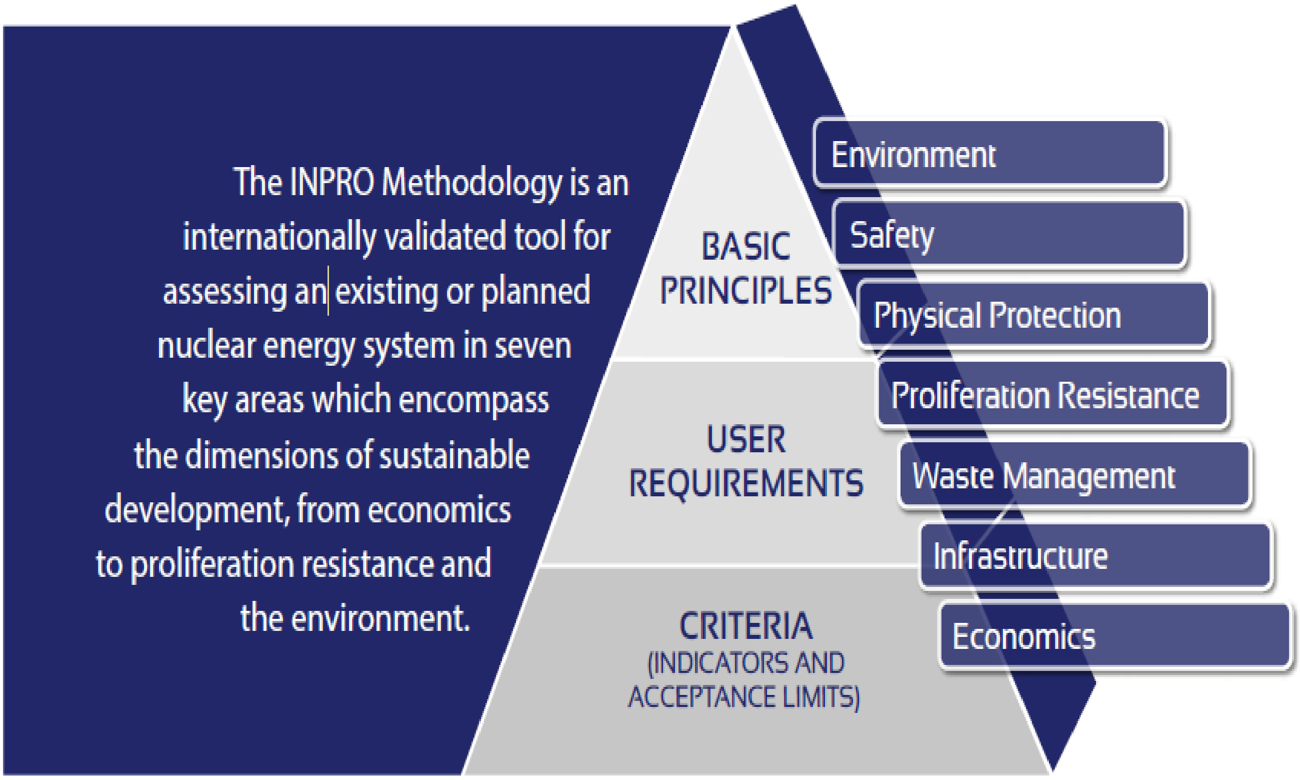


Figure 2.22: INPRO Methodology (INPRO-IAEA, 2013; NEA, 2011)

INPRO activities are centred on the key concepts of global nuclear energy sustainability such as understanding the challenges, developing options and implementing solutions. To facilitate these activities, the following projects were initiated:

- PRADA: Proliferation Resistance: Acquisition/Diversion Pathway Analysis.
- PROSA: Proliferation Resistance and Safeguard ability Assessment Reactors including Closed Fuel Cycles.
- FINITE: Fuel Cycles for Innovative Nuclear Energy Systems through Integration of Technologies.
- ThFC: Further Investigation of the 233U/Thorium Fuel Cycle.
- SYNERGIES: Synergistic Nuclear Energy Regional Group Interactions Evaluated for Sustainability.
- ROADMAPS: Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems.

- AWCR: Advanced Water Cooled Reactor Case Studies in Support of Passive Safety Systems
- COOL: Investigation of Technological Challenges Related to the Removal of Heat by Liquid Metal and Molten Salt Coolants from Reactor Cores Operating at High Temperatures.
- DHR: Decay Heat Removal System for Liquid Metal Cooled Reactors.
- RISC: Review of Innovative Reactor Concepts for Prevention of Severe Accidents and Mitigation of their Consequences.
- LOADCAPS: Load Following Capability in Innovative Designs which addresses the issue of flexible operation of nuclear power plants and identifies the requirements of INPRO Members.

2.7.3 ENSII

The prime objective of ENSII is to develop a nuclear technology which will make the use of nuclear energy more sustainable through more efficient use of uranium resources through recycling of Plutonium – by reduction of the radio toxicity and of the potential impact of the ultimate radioactive wastes (SNETP, 2010; Agostini and Sepielli, 2013). Based on this objective, three GENIV reactor concepts, the SFR, the LFR and the GFR are being considered in Europe. However, out of these three, SFR is considered to be the reference technology called ESNII-1 as shown on Figure 2.23 with both LFR and GFR being considered longer-term alternative technologies.

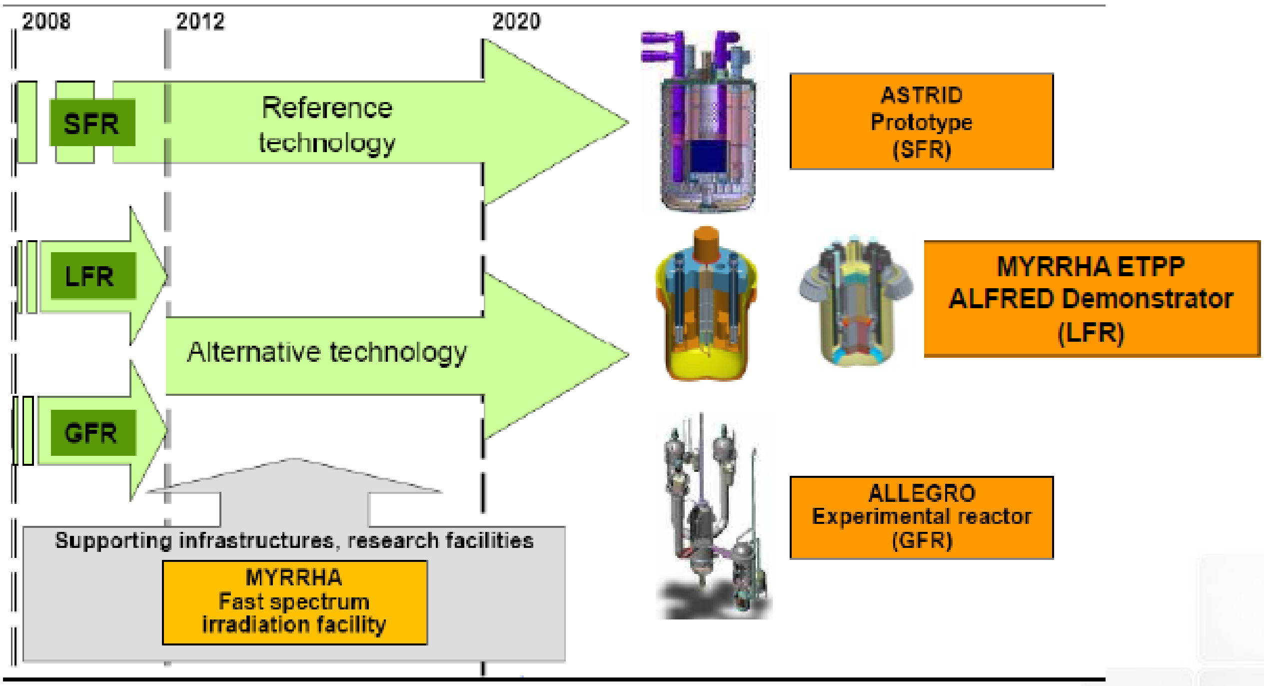


Figure 2.23: European strategy for Fast Neutron systems (SNETP, 2010)

Accordingly, the required priority activities in R&D of all the three fast neutron reactor concepts (Sodium, Lead and Gas fast reactors) are identified with their challenges and milestones below:

- Primary system design simplification.
- Innovative heat exchangers and power conversion systems.
- Advanced instrumentation, in-service inspection systems.
- Enhanced safety.
- Partitioning and transmutation.
- Innovative fuels (including minor actinide-bearing) and core performance.
- Improved materials

However, the objectives of the ESNII-1 Task are to promote, develop and construct a prototype SFR coupled to the grid – ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration), with the start of operation in the 2020. Accordingly, significant progresses are required in the following key programs in order to attain GENIV criteria for the acceptance of a new SFR (reference technology):

- Robustness of the safety demonstration, in particular by prevention and mitigation of severe accidents, including those linked to sodium.
- Economic competitiveness, covering investment and operational costs, reliability and availability.
- Meeting operator's needs: Ease of maintenance, in-service inspection, occupational safety and limited sensitivity to human factors.
- Capability to reduce the long-term burden of ultimate radioactive waste for geological disposal by recycling and transmutation of actinides extracted from spent nuclear fuel.

2.8 Fast Neutron Reactors (FNR)

FNR more deliberately use the U^{238} as well as the fissile U^{235} isotope used in most reactors. If they are designed to produce more plutonium than they consume, they are called FBR (WNA, 2012; Karam, 2006; EC, 2013). But according to WNA (2012), many designs are net consumers of fissile material including plutonium. Fast neutron reactors can also burn long-lived actinides which are recovered from used fuel out of ordinary reactors. About 20 FNR have already been operating, some since the 1950 and some supplying electricity commercially. By ending of 2010, about 400 reactor-years of operating experience have been accumulated. Several countries have R&D programs for improved FBR and the IAEA–INPRO program involving 22 countries has FBR as a major emphasis in connection with closed fuel cycle especially, France with the plan of half of the present nuclear capacity to be replaced with FBR by 2050. Accordingly, there has been progress on the technical front, but the economics of FNR still depends on the value of the plutonium fuel which is bred and used relative to the cost of fresh uranium. Hence, there is international concern over the disposal of ex-military plutonium, and there are proposals to use FBR as burners for this purpose. Therefore, a long-term consideration of the technology is important for the world energy sustainability. According to Karam (2006), FBRs uses a coolant that is not an efficient moderator, such as liquid sodium, so its neutrons remain high-energy. Although these fast neutrons are not as good at causing fission, they are readily captured by an isotope of uranium (U_{238}), which then becomes plutonium (Pu_{239}). This plutonium isotope can be reprocessed and used as more reactor fuel or in the production of nuclear weapons. Also, fast neutrons are ideal for plutonium production because they are easily absorbed by U_{238} to create Pu_{239}, and they cause less fission than thermal neutrons. Some FBR can generate up to 30 percent more fuel than they use. According to Pshakin (2010), the FBR program has several goals:

- To develop a closed uranium-plutonium fuel cycle.
- To produce chain-reacting U_{233} from neutron capture in thorium blankets as a potential fuel for thermal-neutron reactors.
- Fissioning the minor transuranics, neptunium, americium and curium.
- Significantly reduce highly radioactive waste volume for a final geological repository.

2.8.1 FBR and Sustainability

According to Monti (2013), FBR operating in a closed fuel cycle would be able to provide energy for thousands of years as well as easing concerns about waste. Hence, its versatile and flexible technology promises to create or breed more fuel by converting nuclear waste into fissile material. The heat generated by that fission chain reaction, contained within a nuclear power reactor, is used to produce steam, which then spins turbines to produce electricity. Since FBR burn up or consume material that would otherwise be considered spent fuel, the total volume of nuclear material that needs to be handled as waste is reduced. Accordingly, the technology relies upon a closed fuel cycle. Even though the fertile material is not fissionable, but it can be converted into fissionable material by exposure to radiation in a reactor. Once converted into fissile material, it will be consumed in the chain reaction. This conversion from fertile to fissionable material significantly improves nuclear fuel efficiency. Therefore, FBR can thus be used to breed more fissile material than they consume or to burn nuclear waste or for a combination of these two tasks. Therefore, they offer significant benefits in making nuclear energy production more sustainable. Similarly, the technology has the potential to make the production of energy from uranium 100 times more efficient than with the existing thermal reactor, reducing the amount and toxicity of radioactive waste, as well as the heat emanating from the waste and also shortening the waste's hazardous life span. According to NEA (2011), future nuclear power programme decisions will increasingly be based on strategic considerations involving the complete nuclear fuel cycle requirements related to:

- Availability of resources and fuel supply assurances
- Uranium utilisation
- Fuel cycle flexibility
- Waste minimisation
- Proliferation resistance (PR), safety and licensing and, obviously
- Cost competitiveness.

2.9 Nuclear Reactor Fuel – Uranium

Uranium is a very heavy metal which can be used as an abundant source of concentrated energy. Natural uranium has a melting point of 1132°C and is largely a mixture of two isotopes: uranium-238 (U^{238}), accounting for 99.3% and uranium-235 (U^{235}) about 0.7%. U_{235} is fissile and decays slightly faster (Hippel, 2010; WNA, 2014). Accordingly, the nucleus of the U_{235} atom comprises 92 protons and 143 neutrons (92 + 143 = 235) as in Figure 2.24 below:

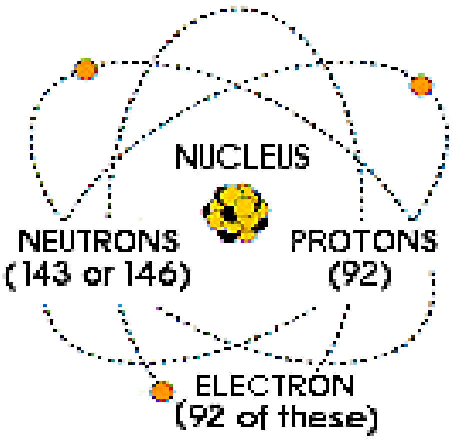


Figure 2.24: Uranium Atom (WNA, 2014)

When the nucleus of a U^{235} atom captures a moving neutron it splits to two (fissions) and releases heat energy. However, when this process continues, large amount of heat is produced which makes steam to spin a turbine and drive generator to produce electricity. But U^{238} decays very slowly, its half-life being about the same as the age of the Earth (4500 million years). The global resource life of uranium based on the current rates of consumption is 100 years (NEA, 2010; Bruneton, 2013). But according to Fetter (2009), if the Nuclear Energy Agency (NEA) has accurately estimated the planet's economically accessible uranium resources, reactors could run more than 200 years at current rates of consumption. Accordingly, two technologies could greatly extend the uranium supply itself. First, the extraction of uranium from seawater which would make available 4.5 billion metric tons of uranium a 60,000 per year supply at present rates and secondly, fuel-recycling FBRs, which generate more fuel than they consume, would use less than 1 percent of the uranium needed for current LWR. This could match today's nuclear output for another 30,000 years more.

2.9.1 Uranium Supply and Demand

Annual reactor requirements for uranium are determined principally by the amount of electricity generated in operating nuclear plants (IEA, 2006). In 2010, world uranium production was 54 670 tU (85%) of world reactor requirements – 63 875 tU, with the difference coming from already mined secondary sources which include excess government and commercial inventories, low-enriched uranium (LEU) produced by down blending highly enriched uranium (HEU) from the dismantling of nuclear warheads, re-enrichment of depleted uranium tails and spent fuel reprocessing (NEA, 2012b). In 2013, the annual requirement was increased to 68 000 tU as against 63 875 tU for 2010 (Bruneton, 2013). According to Dasnois (2012), South Africa is Africa's fourth- and the world's twelfth-largest producer of uranium with 1% of global uranium production of 583 tU in 2010. Therefore, South Africa has 4.6% of the world's most accessible uranium, and possesses the second largest reserves in the world.

2.10 Denuclearization

In the post-Fukushima Daiichi era, many countries have had second thoughts about nuclear power, and some – notably Germany – have firmly turned their back on the industry, ordering shutdowns of plants (Lokhov, 2012; NEA, 2012b ; Mecklin, 2012; ; Mecklin, 2013; Schreurs, 2012 ; Mez, 2012 ; Harris and Venables, 2011; Faro, 2013; Squassoni, 2013; Rossnagel and Hentschel, 2012 ; Amory, 2013 ; Schneider, 2013; Bradford, 2013 ; Hibbs, 2012 ; Lovins, 2013; Ramana, 2013). Switzerland on the other hand, that have shown guarded support on the nuclear energy over the years, has taken a middle path by dropping all plans for new plants but allowing existing plants to keep operating so long as the government regulator validates their safety. Switzerland has five operating nuclear power reactors, ranging in ages from 28 to 43 years old which generated two-fifths of their country's electricity needs in 2010 while the rest was from hydropower. The Swiss initiative on Energy Strategy 2050 is working out the policy implications on the decision not to build any new plants but essentially phasing out nuclear energy gradually. However, other nations around the world require significant increase in clean, safe and reliable electrical power that is commercially and environmentally competitive over several other options, to meet the needs of their citizens and to protect the environment, countries such as the United States, China, and India are exploring the feasibility of expanding their nuclear energy programs to provide this needed power (Al Kaabi, 2011). Accordingly, in 2010 there were 15 new constructions of 15 nuclear plants globally with 12 of them in Asia, more than in any year since 1985. Likewise, more than 60 other countries that do not currently have nuclear programs are considering them, and 25 others have made firm plans to build nuclear power plants. Similarly, the United Arab Emirates (UAE) will start supplying electricity in 2017 from her first nuclear reactor which was commissioned March 14, 2011 with subsequent plans to build three other reactors at the same site. This was as a result of the evaluation of several viable options for meeting future energy demands and they decided that nuclear power is the most reliable, efficient, safe, commercially competitive, and environmentally friendly means of producing electricity. Similarly, despite the fact of their aggressive development in pursuing of solar power and other renewable energy options, which can only meet a small portion of the future energy demand, nuclear energy emerged as their best option based on their analysis. According to NEA (2012b), Sweden remains committed to upholding a recent decision to allow construction of replacement reactors in the existing fleet and the Czech Republic, Finland, France, Hungary, the Slovak Republic and the Republic of South Korea remain committed to maintaining nuclear energy as an important part of the national energy mix. In North America, some new construction plans are slowly advancing but others have been put on hold temporarily.

2.11 Decommissioning

Decommissioning of a nuclear power plant is the termination of operations, the withdrawal of the facility from service and its complete removal from the site as a result of its transformation into an out-of-service state without radiological risks (Cumo, 2010; IAEA, 2004). However, these activities shall be carried out with top priority consideration to health and safety of the decommissioning workers, general public and the environment. Nuclear power plants are normally designed for an operating lifetime of several decades. But by appropriate refurbishment, replacement, or upgrading of some equipment, the life of a plant may be extended to 60 or more years. In many cases, it is even very advantageous to extend the operating life of a NPP beyond the amortization period and the initial design life, into life extension but it is technically or economically advantageous to dismantle the facility and replace it with a new one. Accordingly, based on decommissioning, nuclear installations can be classified as follows:

- Nuclear power plants for electricity production (or, in general, thermal energy production)
- Research, experimental, or isotope production reactors with various thermal powers
- Fuel fabrication plants
- Spent-fuel reprocessing plants
- Experimental laboratories related to the fuel cycle
- Hot cells for activities on activated materials, contaminated materials, or radioisotopes

2.12 Radioactive Waste Management

Radioactive waste is a waste product containing radioactive material and it is usually as a result of a nuclear process such as nuclear fission and other industries that produce it (Rafferty, 2011). According to Bonin (2010), at every stage of the nuclear fuel cycle, there is a production of waste. However, large volumes of short-lived radioactive waste are already handled by the nuclear industry in surface storage facilities, the management mode of high-activity long-lived waste has not been decided in detail and is still under study in all nuclear countries. In South Africa, Vaalputs is the national radiological waste disposal facility for the Republic (NECSA, *n.d.;* Eskom, 2014; Carolissen, *n.d*.). It was designed as a national facility for the disposal of low and intermediate level waste only. Therefore, it is not licensed to accept any other types of radioactive waste at the moment except low and intermediate level waste from Koeberg NPP. According to Eskom (2014), NECSA's low and intermediate level waste at present is being stored at Pelindaba, west of Pretoria, but negotiations could also lead to permission of disposing at Vaalputs in the near future. Vaalputs is situated in Namaqualand, approximately 600km north of Cape Town.

2.12.1 Nuclear Fuel Cycle

The nuclear fuel cycle (See Figure 2.25) is the chain of processes whereby nuclear fuel is produced and managed during and after its use in a reactor for generating electricity. However, to prepare Uranium for use in a nuclear reactor, it undergoes the steps of mining and milling, conversion, enrichment and fuel fabrication as detailed below (DME, 2005;IEA, 2011; MIT, 2003; Stott, 2013)

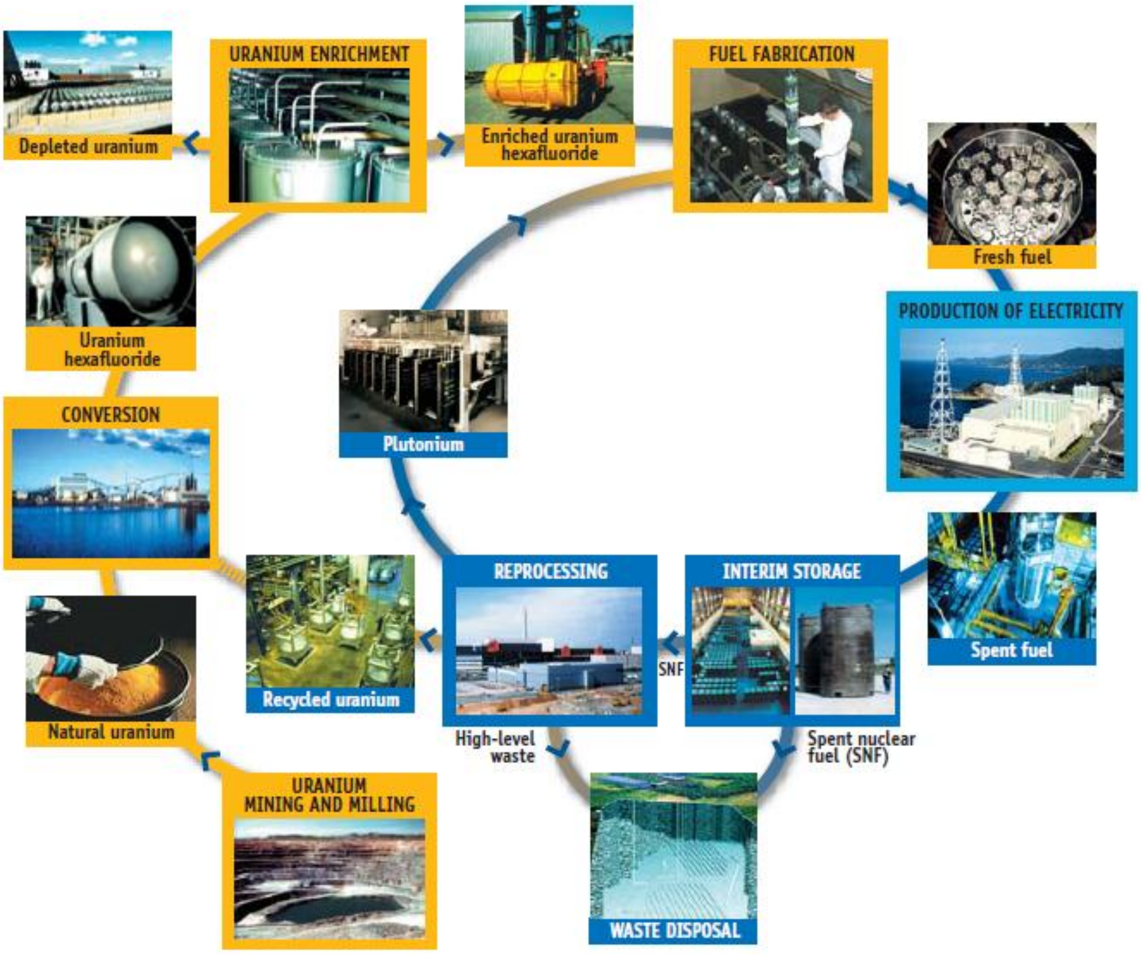


Figure 2.25: Nuclear Fuel Cycle (IEA, 2011; MIT, 2003; NEA, 2012a; Stott, 2013)

2.12.1.1 Mining and Milling

These two processes are the first in the 'front end' of the nuclear fuel cycle. Uranium is mined either by surface often called open cut mining, underground mining techniques, or using in situ leaching – a method whereby a solvent is injected underground to dissolve the uranium and is recovered from wells and pumped to the surface for further processing depending on the depth at which the ore was found. Thereafter, it is sent to a mill where the ore is physically reduced to a suitable size and chemically treated to extract and purify the uranium. The resulting solid uranium oxides concentrate (U_3O_8) is called yellowcake.

2.12.1.2 Conversion

This is the process that transforms yellowcake into uranium hexafluoride (UF_6) because to enrich uranium, it must be in a gaseous state at a conversion plant in Europe, Russia or North America.

2.12.1.3 Enrichment

This is the process of increasing the amount of the U_{235} isotope, compared with the U_{238} isotope. However, enrichment involves the partial separation of uranium into its two main naturally occurring isotopes (U_{235} and U_{238}). Majority of all nuclear power reactors in operation and under construction require enriched uranium fuel in which the proportion of the U_{235} isotope has been raised from the natural level of 0.7% to 3.5% or slightly more. However PHWR uses natural uranium and does not require enrichment. With the enrichment process, 85% of U_{238} is removed by separating gaseous uranium hexafluoride into two streams: One is enriched to the required level and proceeds to the next stage of the fuel cycle and the other stream is depleted in U_{235} and is called tails. The composition of the tail is usually less that 0.25% which is no further use for energy.

2.12.1.4 Fuel fabrication

The enriched uranium is then sent to a fuel fabrication plant where it is changed into uranium dioxide (UO_2) powder. The powder is pressed into small pellets, which are then put into metal tubes, forming fuel rods. The rods are then sealed and assembled in clusters to form fuel assemblies for use in the core of the nuclear reactor. The fuel assemblies are put into the core of the nuclear reactor along with a moderator such as graphite or water. A typical boiling water reactor (BWR) contains over 730 assemblies containing about 46 000 fuel rods.

2.12.1.5 Spent fuel storage

The “back end” of the fuel cycle starts when the irradiated or “spent” fuel is unloaded from the reactor for interim storage. To maintain efficient reactor performance, about one-third of the spent fuel is removed every year or 18 months, to be replaced with fresh fuel. When the spent fuel is removed from the reactor, it is hot and very radioactive. It must be cooled and shielded from people. It is put into storage ponds at the reactor site. The water provides cooling and radiation shielding. The heat and radioactivity decrease over time - after about 40 years they are down to about 1/1000 of what they were when taken from the reactor. Spent fuel can be stored safely in these ponds for long periods. It can also be dry stored in engineered facilities, cooled by air. However, both kinds of storage are intended only as an interim step before the spent fuel is either reprocessed or sent to final disposal. The longer it is stored, the easier it is to handle due to decay of radioactivity. There are two alternatives for spent fuel: reprocessing to recover the usable portion and vitrification. However, reprocessing steps are not undertaken in South Africa.

2.12.1.6 Reprocessing

Reprocessing is the operation by which the unused energy content of spent fuel is recovered for future re-use or where various constituents in the spent fuel are separated for waste management reasons. Spent fuel still contains approximately 96% of its original uranium, of which the fissionable U_{235} content has been reduced to less than 1%. About 3% of spent fuel comprises waste products and the remaining 1% is plutonium (Pu) produced while the fuel was in the reactor and not "burnt”. Therefore approximately 97% of spent fuel can be recycled for further use. Reprocessing separates uranium and plutonium from waste products and this is achieved commercially using a chemical process called plutonium and uranium extraction (PUREX). Recovered uranium can be returned to the conversion plant for conversion to UF_6 and subsequent re-enrichment.

2.12.1.7 Vitrification

After reprocessing, the rejected high-level fission product waste stream which also contains the minor actinides is stored for subsequent solidification in a highly leach resistant glass. The glass is then poured into stainless steel canisters. The canisters are then sealed and sent to a cooled storage facility until they are eventually sent for deep geological disposal. For allowing some relaxation of criticality constraints and safeguards requirements, it is a fact that vitrified glass canisters, no longer contains any fissionable materials after its disposal.

2.12.1.8 Final disposal

After more than 60 years of nuclear technology, there is still no universally accepted mode of disposal yet (Abbott, 2012; MIT, 2003; Pickard, 2009). However, technical solutions are emerging due to progressive scientific knowledge and there is necessity to find a final place for the final waste. According to MIT (2003), preserving the nuclear option for the future means planning for growth, as well as for a future in which nuclear energy is competitive, safer, and more secure source of power. Similarly, Macfarlane (2011) noted that, it is no longer the safe production of electricity but also the safe, secure, and sustainable lifecycle of nuclear power, from the mining of uranium ores to the disposal of spent nuclear fuel. Therefore, the deep geological underground disposal seems to be the only long-term solution which does not require a continuous control by the society. The safety of the underground disposal relies on its capacity to confine radionuclide within an underground facility until radioactive decay has brought their radio-toxicity down to an acceptable level. The technologies exist, but their implementation requires a political decision. Contrary to a widespread view within the public, much progress has been made towards technically and socially acceptable nuclear waste repositories. Most of the experts agree, but the public and the political circles are still reluctant and in the process of building their confidence, they must be convinced faultlessly. According to Lidskog and Andersson (2001) and USNRC (2002), in many countries, public involvement seems to be a key issue for the successful implementation of radiological waste management. It is believed however that more public involvement and improved communication will lead to a greater social acceptance.

2.13 Classification of Radioactive Waste

Radioactive waste is generally classified on the basis of the quantity, type of radiation and the length of time it will continue to emit radiation. The purpose of the classification therefore is to ensure that radioactive waste is handled, stored and disposed through appropriate procedures according to its characteristics. From the literature, radioactive materials are classified as low, intermediate, or high level respectively(Carolissen, *n.d.*; Coertze, 2011; DME, 2005; Eskom, 2014; IAEA, 2004; IEA, 2006; Lidskog and Andersson, 2001; Macfarlane, 2011; NEA, 2012a; NECSA, *n.d.*; Rafferty, 2011; Stott, 2013; USNRC, 2002).

2.13.1 Low-level:

This type of radioactive waste globally comprises 90% by volume with 1% of the radioactivity such as paper, equipment, tools, clothing, filters etc. They contain small amounts of mostly short-lived (radioactive materials with half-life of less than thirty years of radioactivity) generated from hospitals, laboratories, industries and the nuclear fuel cycle. It does not require shielding but usually buried in shallow landfill sites. To reduce its volume, it is often compacted or incinerated (in a closed container) before disposal.

2.13.2 Intermediate level waste:

This type of radioactive waste comprises of long-lived and short-lived. They require shielding, but need no provision for heat dissipation. For long-lived radioactive waste, the radionuclide has half life of more than thirty years. But short-lived radioactive waste contains low concentrations of long-lived radionuclide of less than 4000 Becquerel/gram of alpha-emitters with half-life of less than thirty years. Examples are resins, chemical sludge, metal fuel cladding, and materials from nuclear electricity plants. Intermediate-level waste can be solidified in concrete before putting into a waste repository.

2.13.3 High level waste:

This type of waste contains large concentrations of both short- and long-lived radionuclide and is sufficiently radioactive to require both shielding and cooling. Example is the spent fuel used to fuel nuclear reactors in generating electricity. It is composed of 3% of the volume of all radioactive waste but it holds 95% of radioactivity. It generates a considerable amount of heat, contains highly-radioactive fission products and some heavy elements with long-lived radioactivity. It is temporarily stored in special pond (See Figure 2.26) to decrease its radioactivity.

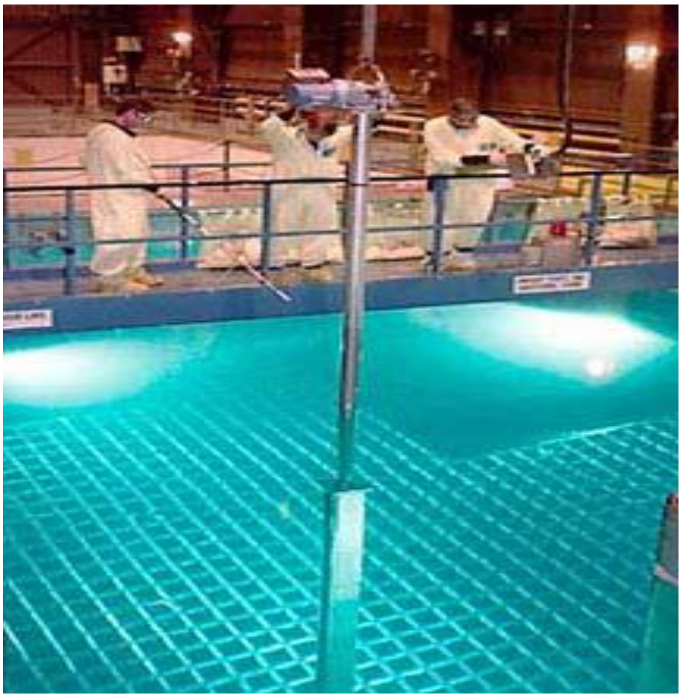


Figure 2.26: Spent Fuel Pool (Carolissen, n.d; Rafferty, 2011; Stott, 2013)

Spent fuel pools are about 40 feet deep and are actively cooled with circulated borated water, which helps absorb neutrons and stops the chain reaction that occurs in a reactor. All countries with well-established nuclear programs have found themselves requiring spent fuel storage in addition to spent fuel pools. Dry storage tends to be cheaper and can be more secure than wet storage because active circulation of water is not required. In order to ensure safety, a country with a new nuclear program should include additional spent fuel storage in its waste management plan from the beginning instead of adding it as an ad hoc (Macfarlane, 2011).

2.14 Conclusion

This chapter highlighted on an in-depth literature on the nuclear energy generations, and how the energy contributes to the global energy needs without environmental damage in a safe and secure manner. However, due to the most difficult challenges in the nuclear industry such as waste management and proliferation risk, with continued research and technological improvements, the Gen III and Gen IV designs are to resolve these difficult problems. So far, the results from some of the first Generation III plants already built support this expectation. Therefore, to appreciate more on this technology, in the next Chapter, we shall examine the design factors influencing the biological effects of ionizing radiation due to nuclear power generation.

CHAPTER THREE

DESIGN FACTORS INFLUENCING BIOLOGICAL EFFECTS OF IONIZING RADIATION

3.1 Introduction

In previous chapter, we discussed on the overview of nuclear power generation, in this chapter, we shall be looking at the design factor that influences biological effects of ionizing radiation. Naturally, radiation is present in our environment and has been there since the birth of the planet. Consequently, life has evolved in an environment which has significant levels of ionizing radiation. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies (Internal). It is present in the air we breathe, the food we eat, the water we drink (USNRC, 2011; Tsoulfanidis, 1995) likewise in the construction materials used to build our homes. However, brick and stone homes have higher natural radiation levels than homes made of wood. Hence, the levels of natural or background radiation can vary greatly from one location to another. The naturally occurring radioactive materials (NORM) are present in the earth's crust, the floors and walls of our homes, schools, and offices. Our bodies – muscles, bones and tissues, contain naturally occurring radioactive elements (DOE, *n.d.*; DME, 2005). Man has always been exposed to natural radiation arising from earth as well as from outside. Most people, upon hearing the word radioactivity, only think about something harmful or deadly; especially events such as the atomic bombs that was dropped at Hiroshima and Nagasaki in 1945, or the Chernobyl Disaster of 1986. However, upon understanding radiation, people will learn to appreciate that radiation has peaceful and beneficial applications to our everyday lives. According to UNSCEAR (2000) new challenges as regards to global levels of radiation exposure continue to arise and new biological information on the effects of radiation exposure is becoming available. For example, large amounts of radioactive waste have built up as a result of both peaceful uses of nuclear energy and military nuclear operations, and radiation sources used in military and peaceful operations have been abandoned, creating a situation that is prone to illicit trafficking and other criminal activities. Moreover, the potential risks from low-level radiation exposure, such as exposure to radiation comparable with natural background radiation, are the cause of lively debate and controversy.

3.2 Electromagnetic Radiation

Electromagnetic radiation is transmitted through empty space at 3.0×10^8 meters per second -300, 000 kilometres per second (ARPANSA, 2012). The electromagnetic spectrum includes radio waves, microwaves, infrared rays, light rays, ultra violet rays, X-rays and gamma rays as shown in Figure 3.1.

Figure 3.1: Electromagnetic Spectrum (Hall, 2012; ARPANSA, 2012; Southworth, 2011)

They are distinguished from each other by their wavelength and the amount of energy they transfer. These properties also determine their ability to travel through objects, their heating effects and their effect on living tissue. According to the quantum theory model, electromagnetic radiation consists of bundles of energy called photons, which travel at the speed of light. Gamma rays and X-rays are identical--they both are photons--but differ in origin. Gamma rays result from transformations that take place in the nucleus of an atom, and X-rays are formed by interactions outside the nucleus (NU, 2010).

3.3 An Atom

The smallest particles, into which an element can be divided without losing its properties, are called atoms (DME, 2005; Glasstone and Dolan, 1977). All material in the universe is composed of combinations of different basic substances called chemical elements. There are 92 different chemical elements in nature and everything in nature is composed of atoms. An atom consists of two main parts namely a nucleus with a circling electron cloud (IAEA, 2004). The nucleus consists of subatomic particles called protons and neutrons as shown in Figure 3.2 below. According to Tsoulfanidis (1995), every atom consists of a central positively charged nucleus around which negative electrons revolve in stable orbits (Glasstone and Dolan, 1977). It has a radius of the order of 10^{-10} m and radius of the nucleus of the order of 10^{-l4} m. The number of electrons is equal to the number of positive charges of the nucleus which is called the atomic number that identifies the chemical element. Therefore, all atoms of an element have the same chemical properties. However, the atomic electrons move around the nucleus as a result of the attractive electrostatic Coulomb force between the positive nucleus and the negative charge of the electron; thus the atom is electrically neutral (in its normal state).

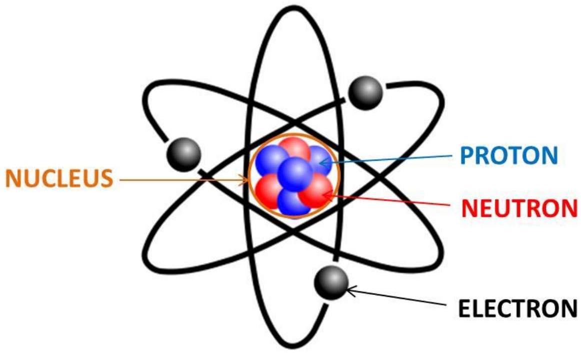


Figure 3.2: Schematic diagram of an atom (DME, 2005; Hall, 2012)

3.3.1 Unstable Atoms and Atomic Decay

Ionizing radiation comes from the nuclei of atoms and each element exists in the form of atoms with several different sized nuclei called isotopes (Hall, 2012). Accordingly, most atoms are stable such as carbon-12 atom and oxygen-16 atom. But others change or disintegrate into totally new atoms. Such atoms are said to be unstable or radioactive. An unstable atom has excess internal energy, which can undergo a spontaneous change towards a more stable form. This is called radioactive decay. Therefore, the unstable isotopes which are radioactive are called radioisotopes. Meanwhile, an atom of a radioisotope is said to decay when it gives off some of its excess energy as radiation such as gamma rays or fast-moving sub-atomic particles. Gamma rays are often emitted with alpha or beta radiation as the nucleus decays to a less excited state. Similarly, DME (2005) noted that radioactive elements are those in which the atoms are unstable and break down (decay) to form atoms of another element. This decay is accompanied by the release of ionising radiation in the form of invisible small particles and high energy. Because radioactive decay is a random process, which means that there is a probability it will occur within a specified interval. Hence, for a population of atoms of the same element and mass number, this probability is called the decay constant, lambda (λ). Lambda therefore is equal to the natural logarithm of 2 divided by the half-life as represented below in Equation 3.1 (NU, 2010; L'annunziata, 2003).

$$\lambda = \frac{0.693}{t1/2} \qquad (3.1)$$

One half-life is the time during which one-half of the radioactive atoms in a sample will decay or disintegrate. The rates of radionuclide decay are usually expressed in terms of half-life. This is the time, t, required for a given amount of radionuclide to lose 50% of its activity or to decay. The decay curve in Figure 3.3, illustrates the concept of half-life (L'annunziata, 2003).

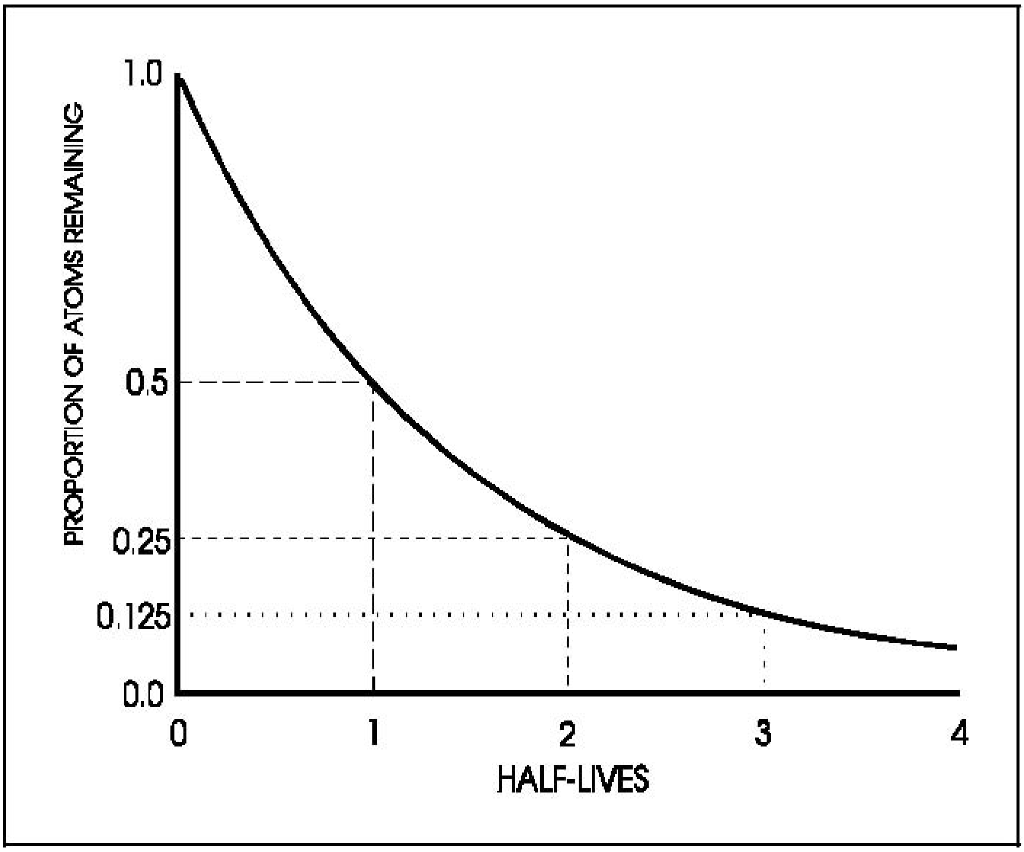


Figure 3.3: Radioactive Decay (NU, 2010; Maher, 2006; L'annunziata, 2003; IAEA, 2004)

The half-life does not express how long a material will remain radioactive but simply the length of time for its radioactivity to be halved as shown on Table 3.1 below (Maher, 2006):

Table 3.1: Radioisotopes Half Lives (Maher, 2006)

Radioisotope	Half life (approx.)
^{81m}Kr	13 seconds
^{99m}Tc	6 hours
^{131}I	8 days
^{51}Cr	1 month
^{137}Cs	30 years
^{241}Am	462 years
^{226}Ra	1620 years
^{238}U	4.51×10^9 years

Where;

^{81m}Kr	=	Krypton
^{99m}Tc	=	Technetium
^{131}I	=	Iodine
^{51}Cr	=	Chromium
^{137}Cs	=	Caesium
^{241}Am	=	Americium
^{226}Ra	=	Radium
^{238}U	=	Uranium

Accordingly, it was observed that some of these have relatively short half-life and are being used for medical diagnostic purposes. Therefore, they do not remain radioactive for very long and hence results in a relatively low radiation dose. NU (2010) noted that an exponential function (See Figure 3.3) enables us to determine, the number of radioactive atoms remaining at any time t, provided we know how many were present to begin with. The decay equation therefore is as shown in Equation 3. 2 below:

$$N = Noe^{-\lambda t} \qquad (3.2)$$

Where;

N = number of atoms at time t,

No = number of atoms at start (time t = 0)

e = base of natural logarithms.

3.4 Sources of Radiation

Radiation is the energy that travels through space, in the form of particles or electromagnetic waves such as radio, microwaves, infra-red, visible light, ultra-violet, alpha particles, X-rays and Gamma-rays and others (NU, 2010; DME, 2005). According to Chen (2014) and IAEA (2010), these sources of ionizing radiation could be from natural background radiation such as radon and Thoron, cosmic and terrestrial radiation, or man-made radiation such as those from x-ray or nuclear medicine (NM) procedures as illustrated in Figure 3.4 below:

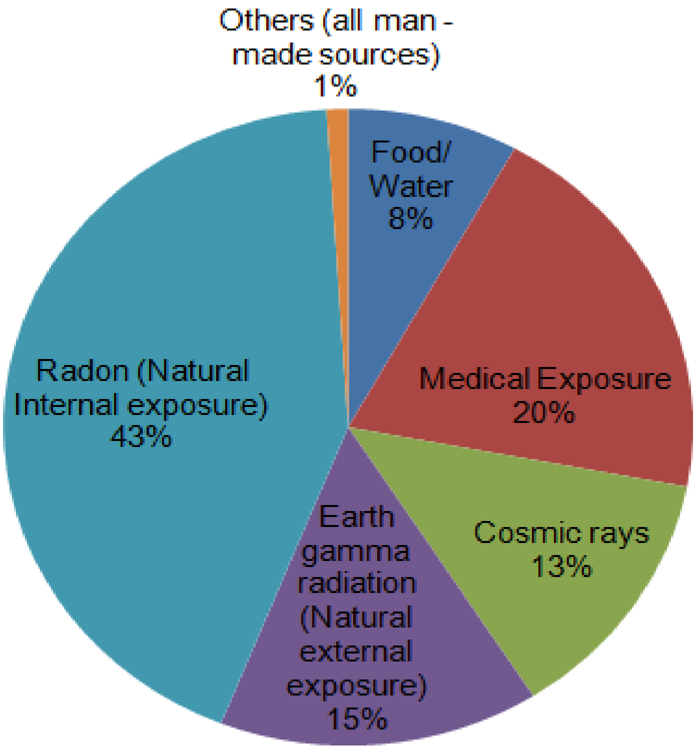


Figure 3.4: Sources of Radiation (Southworth, 2011)

3.4.1 Natural Radiation

From the literature, there are three sources of natural background radiation: Cosmic Radiation, Terrestrial Radiation and Internal Radiation (USNRC, 2013; DOE, *n.d*; EPA, 2013; IAEA, 2004).

3.4.1.1 Cosmic Radiation:

This is simply the radiation from the sun and stars. Especially flying based at high altitudes much frequently and for long duration will attract extra cosmic radiation exposure.

3.4.1.2 Terrestrial Radiation:

This is the radiation due to the presence of radioactive materials such as uranium, thorium, and radium that exist naturally in soil, water and rocks. Essentially air contains radon, which is responsible for the dose from natural background sources, and all organic matter (plant and animal) also contains radioactive carbon and potassium. However, the dose from these sources varies in different parts of the world, but locations with higher soil concentrations of uranium and thorium generally have higher doses.

3.4.1.2.1 Background Radiation

Background radiation is emitted from both natural and human-made radioactive chemicals known as radionuclide's (Wahl and Berkeley, 2010;

HPS, 2012). However, some naturally occurring radionuclide is found in the earth beneath our feet, while others are produced in the atmosphere by radiation from space. Therefore, human-made radionuclide have entered the environment from activities such as medical procedures that use radionuclide's to image the body and electricity generation that uses radioactive uranium as fuel. The global annual effective dose due to natural radiation sources as shown in Table 3.2 below is 2.4 mSv (UNSCEAR, 2000; WNA, 2014). While additional of 0.4022mSv is due to man-made radiation is as in Table 3.3, the range of individual doses varies. In any large population, about 65% would be expected to have annual effective doses between 1 mSv and 3 mSv, while about 25% of the population would have annual effective doses less than 1 mSv and 10% would have annual effective doses greater than 3 mSv (UNSCEAR, 2000). However, the background radiation levels vary in certain areas due to geological differences and sometimes the exposure can be more than 200 times higher than the global average. The highest known level of background radiation affecting a substantial population is in Kerala and Madras States in India where some 140,000 people receive doses which average over 15 mSv per year from gamma radiation in addition to a similar dose from radon for a total of 30 mSv. Comparative levels of 40 mSv/yr also occur in Brazil and Sudan, with average exposures to many people (DME, 2005; WSDOH, 2002; Hall, 2012; MRL, 2014; IAEA, 2004).

Table 2.2: Average radiation dose from natural sources (UNSCEAR, 2000; WNA, 2014; IAEA, 2004; Crick, 2010)

Source	Worldwide average annual effective dose (mSv)	Typical range (mSv)
External exposure Cosmic rays Terrestrial gamma rays	 0.4 0.5	 0.3-1.0 a 0.3-0.6 b
Internal exposure Inhalation (mainly radon) Ingestion	 1.2 0.3	 0.2-10 c 0.2-0.8 d
Total	**2.4**	**1-10**

- a Range from sea level to high ground elevation.
- b Depending on radionuclide composition of soil and building materials.

- c Depending on indoor accumulation of radon gas.
- d Depending on radionuclide composition of foods and drinking water.

Table 2.3: Average Annual Effective Dose of Ionizing Radiation to Individuals (IAEA, 2010)

Source	Dose (mSv)	Range (mSv)
External exposure Cosmic rays Terrestrial gamma rays	 0.4 0.5	 0.3-1.0 a 0.3-0.6 b
Internal exposure Inhalation (mainly radon) Ingestion	 1.2 0.3	 0.2-10 c 0.2-0.8 d
Total	**2.4**	**1-10**
Man-made (artificial) Medical Nuclear Testing Chernobyl accident Nuclear power production	 0.4 0.002 0.0002	 0.04 – 1.0 0.15 – decreasing trend 0.04 – decreasing trend Decreasing trend
Total	**2.8**	**1-10**

3.4.1.3 Internal Radiation:

This type of radiation is due to the internal composition of human bodies such as radioactive potassium-40 and carbon-14 from birth till death.

3.4.2 Artificial (Man-made) Radiation

Man-made radiation involves the following USNRC (2013), DOE (*n.d*), EPA (2013) and IAEA (2004):

- Radiation due to medical procedures, such as diagnostic x-rays, nuclear medicine, and radiation therapy. Also in this group, is radiation from consumer products, such as building materials, combustible fuels (gas and coal), television, cell phones and others.
- Radiation from nuclear sites which account for less than 0.01% per year of the average dose and the exposure from shipment of radioactive materials and residual fallout from nuclear weapons testing and accidents like Chernobyl.

3.5 Ionizing Radiation

Ionizing radiations are generally characterized by their ability to excite and ionize atoms of matter with which they interact. Since the energy needed to cause a valence electron to escape from an atom is of the order of 4-25 eV, radiations must carry kinetic or quantum energies in excess of this magnitude to be called ionizing (Attix, 2003). Therefore the radiation that has enough energy to remove tightly bound electrons from atoms, thus creating ions is referred to as ionizing radiation (EPA, 2013 ; Southworth, 2011; NU, 2010).This is the type of radiation which we leverage on its benefits to generate electric power, to kill cancer cells, and in many manufacturing processes. According to WHO (2012), ionizing radiation is the type of energy released by atoms that travels in the form of electromagnetic waves (gamma or X-rays) or particles (neutrons, beta or alpha). This spontaneous disintegration of atoms is called radioactivity, and the excess energy emitted is a form of ionizing radiation. Consequently, people are exposed to natural sources of ionizing radiation, such as in soil, water, vegetation, and in human-made sources, such as x-rays and medical devices. It has many beneficial applications, including uses in medicine, industry, agriculture and research, so does its potential for health hazards if not properly used or contained. Accordingly, all ionizing radiation is capable of directly or indirectly removing electrons from most molecules, such as X-ray and gamma ray which are at the upper end of magnetic radiation. They have very high frequency in the range of 100 billion Hertz and very short wavelengths a million millionth meter. Radiation of this range has extremely high energy to strip off electrons especially the very high-energy radiation, break up the nucleus of atoms. It can also be referred to as the process in which a charged portion of a molecule (usually an electron) is given enough energy to break away from the atom. However, this process results in two charged particles or ions, the molecule with a net positive charge and the free electron with a negative charge. Similarly, WNA (2014) noted that radiation particularly associated with nuclear medicine, nuclear energy and X-rays, is ionizing radiation, which has sufficient energy to interact with matter, especially the human body, and produce ions that can remove an electron from an atom.

3.5.1 Types of Ionizing Radiation

There are three main types of ionizing radiation (EPA, 2013; DOE, *n.d*; ARPANSA, 2012; Hall, 2012; Southworth, 2011; DME, 2005), as shown in Figure 3.5 below:

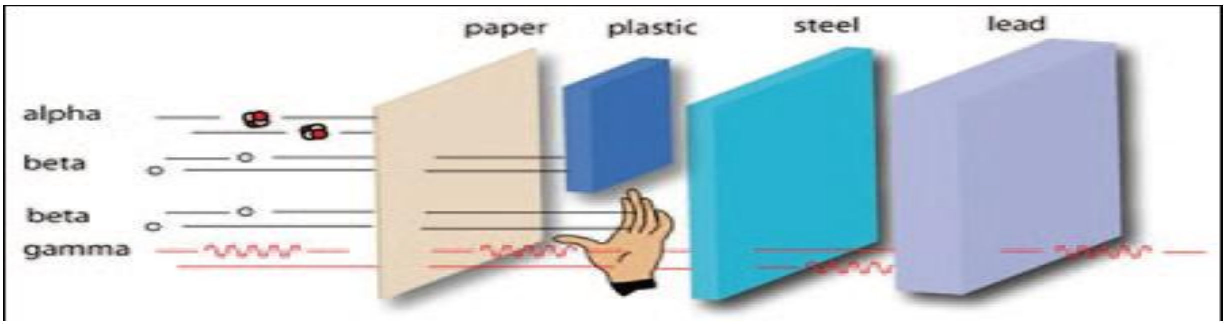


Figure 3.5: Penetrating Power of Radiation (DOE, n.d; DME, 2005; Southworth, 2011; IAEA, 2004)

3.5.1.1 Alpha

Alpha (α) particles, include two protons and two neutrons, are heavy and positively charged particles which do not travel very far in the air and cannot penetrate the skin. But if ingested or inhaled, it can be harmful. However, they are easily stopped by a thin sheet of paper or the human body skin. Hence, if alpha emission enters the body, it poses risk to sensitive body organs such as the lungs and the bones. But this risk can be reduced by ensuring that the inhalation or ingestion of emitted alpha particles is kept at minimum level by either installing dust controls or by the appropriate use of respiratory protection devices such as dust masks.

3.5.1.2 Beta

Beta (β) are essentially fast moving and negatively charged particles that can travel much further through air than alpha particles. Quite penetrating even through the skin but can be easily shielded with a sheet of plastic. They are more harmful if ingested or inhaled.

3.5.1.3 Gamma (Y) and X-Ray

Gamma (Y) and X-Ray are pure energy (photons): Gamma rays are waves of energy similar to light and they have much higher energy and can travel great distance through air. They are very penetrating and require shielding of concrete or lead plating to stop them. Unshielded Gamma rays are harmful inside and outside the body while X-ray has lower energy Gamma rays similar in nature to light. They can easily penetrate the skin than the bones as shown in Figure 3.5 above. Similarly on Table 3.4 below are the physical characteristics of ionizing radiations:

Table 3.4: Physical Characteristics of the major types of Radiation (Maher, 2006)

Radiation	Mass	Electric Charge	Velocity
Alpha Particles	relatively heavy	double positive	relatively slow
Beta Particles	about 8,000 times lighter	negative	less than the velocity of light
Gamma Rays	None	None	$3x10^8$ m/s in free space

3.6 Non-Ionizing Radiation

Non-ionizing radiation is the radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons. Examples of this kind of radiation are sound waves, visible light, and microwaves as earlier shown in Figure 3.1 above. It has extremely low frequency radiation with very long wave lengths (on the order of a million meters or more) and frequencies in the range of 100 Hertz or cycles per second or less. The following are the properties and benefits of non-ionizing radiation (EPA, 2013):

- Microwave radiation with wavelengths that are about 1 hundredth of a meter long and have frequencies of about 2.5 billion Hertz is commonly use for telecommunications and heating food.
- Infrared radiation is used for warming food in the restaurants.
- Radio waves are used for broadcasting and have wave lengths between 1 and 100 meters and frequencies in the range of 1 million to 100 million Hertz.

3.7 Natural and Artificial Ionizing Radiation Contributions

Natural radiation comes from many sources including more than 60 naturally-occurring radioactive materials (NORM) found in the soil, water and air. Radon, a naturally-occurring gas, emanates from rock and soil and is the main source of natural radiation. Every day, people inhale and ingest radionuclide from air, food and water. Also there is natural radiation from cosmic rays, particularly at high altitude. Consequently, an average of 80% of the annual dose that a person receives of background radiation is due to naturally occurring terrestrial and cosmic radiation sources (WHO, 2012). According to Martin (2006), the natural radiation environment consists of cosmic rays and naturally radioactive materials for which some of the materials are cosmogenic, others are primordial, and others exist naturally because of the radioactive transformation of substances produced by these processes. However, the radiological significance of NORM and radiation sources is closely linked to the physical behaviour of the materials in the source and how they change with time. MRL (2014) reported 85% of annual radiation and DME (2005) noted 88% of annual radiation as shown in Figure 3.6 below. According to WHO (2012), the most common artificial sources of ionizing radiation today are X-ray machines, while other medical devices, use radiation for diagnosis or treatment, then nuclear power generation.

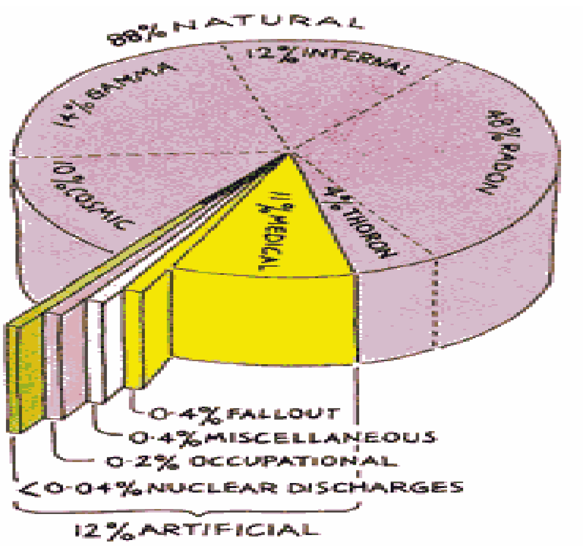


Figure 3.6: Various contributors to the total radiation dose (DME, 2005; Southworth, 2011)

3.8 Health Effects of Ionizing Radiation

Ionizing radiation transfers energy into the body tissue and may thereby interfere in the structure of molecules. In living organisms, this energy transfer may disturb or destroy cellular functions (somatic effect – fatal and nonfatal cancer) or it may change the genetic code of cells (hereditary effect). However, concerning the probability of cell changes, two effects can be distinguished either deterministic or stochastic (IAEA, 1996a). For deterministic, the severity of the effects is proportional to the dose (with threshold) and for stochastic effects the probability but not the severity is proportional to the dose (Frischknecht *et al*., 2000; DME, 2005; UNSCEAR, 2000; Tsoulfanidis, 1995). Accordingly deterministic (acute) effects will occur only if the radiation dose is substantial, such as in accidents. Stochastic effects (cancer and hereditary effects) may be caused by damage in a single cell. As the dose to the tissue increases from a low level, more and more cells are damaged and the probability of stochastic effects occurring increases (UNSCEAR, 2000). Radiobiological and clinical studies have shown that deterministic effects only occur above threshold, doses with dose limits and reference values used in radiological protection which are above 100 mSv. However, for low dose range of less than 100 mSv, only genetic and carcinogenic effects are expected. Although, possible radiation effect of doses less than 100 mSv cannot generally be discovered by epidemiology. Similarly, an individual cancer which may have been caused by ionizing radiation cannot be distinguished from cancers which originate from other unknown causes since there is no specific signature existing for radiation-induced cancer. Therefore epidemiology can probably not clarify the connection between cancer induction and radiation in the low dose range (Streffer, 2010). In addition, other health effects may occur in infants as a result of exposure of the embryo or foetus to radiation. These effects include a greater likelihood of leukaemia and for exposure above various threshold doses during certain periods of pregnancy, severe mental retardation and congenital malformations may arise (IAEA, 1996a; NEA, 1994). According to Wahl and Berkeley (2010), exposure to high levels of radiation is known to cause cancer. But the effects on human health from very low doses of radiation such as the doses from background radiation are very hard to determine because there are so many other factors that can mask or distort the effects of radiation. For example, among people exposed to high radon levels, cigarette smokers are much more likely to get lung cancer than non-smokers. Lifestyle choices, geographic locations, and individual sensitivities are difficult to account for when trying to understand the health effects of its radiation. According to DME (2005) studies have shown that the effect of radiation is dependent on many factors including:

- the type of radiation (alpha, beta or gamma)
- the amount received
- the rate at which it is received
- which part of the body is exposed

- whether the exposure is chronic (regular, low doses) or acute (short time, high dose)
- the age of the irradiated person

Biological effects of radiation are typically classified into two categories (USNRC, *n.d*). The first category consists of exposure to high doses of radiation over short periods of time producing acute or short term effects (Deterministic) while the second category represents exposure to low doses of radiation over an extended period of time producing chronic or long term effects (Stochastic). The high doses tend to kill cells, while low doses tend to damage or change them. High doses can kill so many cells that will lead to damage of tissues and organs. This may result to a rapid whole body response often called the Acute Radiation Syndrome (ARS).

3.8.1 Acute Respiratory Syndrome

ARS is an acute illness caused by irradiation of the entire body or most part of the body by a high dose of penetrating radiation in a very short period of time usually a matter of minutes (CDCP, 2006; TR, 2011; Akashi *et al*., 2006). It is sometimes referred to as radiation toxicity or radiation sickness. According to UWEHS (2006) and Heslet *et al*. (2012), ARS represents the signs and symptoms which result from large doses of radiation – generally over 100 rads (1 Sievert) delivered to a major portion of the body. This type of injury occurs only when the dose is received over a short period of time and the total effect may vary from mild and transient illness to death. The following are the stages in the ARS (Heslet *et al*. 2012; Akashi *et al*., 2006; CDCP, 2006):

3.8.1.1 Prodrome

This is the initial phase of the syndrome, and is usually characterized by nausea, vomiting and malaise (SurvivalIQ, 2008). According to Heslet *et al*. (2012), the prodromal phase usually occurs in the first 48 hours, but may develop up to 6 days after exposure.

3.8.1.2 Latent Stage

During the latent stage, which may be likened to the incubation period of a viral infection, the subjective symptoms of illness may subside, and the individual may feel well. However, changes may be taking place within the blood-forming organs and elsewhere which will subsequently give rise to the next aspect of the syndrome.

3.8.1.3 Manifest Illness Stage

This phase reflects the clinical picture specifically associated with the radiation injury. Among the possible signs and symptoms are loss of hair (epilation), fever, infection, haemorrhage, severe diarrhoea, prostration, disorientation, and cardiovascular collapse. Observation of the foregoing phenomena in a given individual is largely dependent upon the radiation dose received.

3.8.1.4 Recovery or Death

With this stage, according to CDCP (2006) and UWEHS (2006), the recovery process lasts from several weeks to two years. Most patients who do not recover will die within several months of the exposure. Hence, in most cases, bone marrow cells will begin to repopulate the marrow. Hence, there should be full recovery for a large percentage of individuals from few weeks up to two years after exposure but death may occur in some individuals at (1.2 Sv).

3.8.2 Deterministic Effects

A short-term dose is the threshold for causing immediate radiation sickness in a person of average physical attributes, but would unlikely cause death above 1000 mSv (Hall, 2012). Accordingly, the damage may result in cell death or modifications that can affect the normal functioning of organs and tissues. Most organs and tissues of the body are not affected by the loss of even considerable numbers of cells. However, if the number lost becomes large, there will be observable harm to the organ or tissue and therefore to the individual. But only if the radiation dose is large enough to kill a large number of cells will such harm occur. Therefore, this type of harm occurs in all individuals who receive an acute dose in excess of the threshold and is called deterministic.

3.8.3 Stochastic Effects

If the cell is not killed but only modified by the radiation damage, the damage in the viable cell is usually repaired. If the repair is not perfect, the modification will be transmitted to daughter cells and may eventually lead to cancer in the tissue or organ of the exposed individual (Shapiro, 2002). However, if the cells are concerned with transmitting genetic information to the descendants of the exposed individual, hereditary disorders may arise. Such effects in the individuals or in their descendants are called stochastic.

3.9 Radiation Exposure

Generally radiation exposures can be divided into three categories namely high level, medium and low level exposure:

3.9.1 High-level:

This is the radiation exposure that causes massive damage to the body and cannot repair affected cells fast enough. Also, with a dose that may quickly kill the exposed person such as the one from atomic weapons. However, high level of exposure in some cases within a controlled situation can be beneficial. Such as cancer therapy where concentrated beams of radiation are directed to affected areas of the body to destroy cancer cells. High level radiation doses are doses of more than 1000 mSv. According to USNRC (2011), high radiation doses tend to kill cells, while low doses tend to damage or alter the genetic code DNA of irradiated cells. High doses can kill so many cells that will make tissues and organs to be damaged immediately. This in turn may cause a rapid body response ARS. The higher the radiation dose, the higher the probability of death. This syndrome was observed in many atomic bomb survivors in 1945 and emergency workers responding to the 1986 Chernobyl nuclear power plant accident. Approximately 134 plant workers and fire-fighters battling the fire at the Chernobyl power plant received high radiation doses of 800 to 16,000 mSv and suffered from ARS. Out of these, 28 died within the first three months from their radiation injuries. Two more patients died during the first days as a result of combined injuries from the fire and radiation.

3.9.2 Medium-Level radiation exposure:

This type does not kill the exposed person, but may cause damage to reproductive cells or other body cells. Cells which have been permanently damaged or changed may go on to produce abnormal cells when they divide. Under such circumstances, these cells may become cancerous. However, the cancer may take many years to appear. The doses are of the order of hundreds of mSv. Mosse (2012) noted that there is no direct evidence of negative influence of low radiation doses on heredity and that all human investigations in populations from regions with high radiation background have revealed no genetic effects and no harmful consequences for health and lifespan. But according to UNSCEAR (2000), radiation exposure has the potential to cause hereditary effects in the offspring of persons exposed to radiation and such effects were once thought to threaten the future of the human race by increasing the rate of natural mutation to an inappropriate degree. However, radiation induced hereditary effects have yet to be detected in human populations exposed to radiation, although they are known to occur in other species. But it is associated with most forms of leukaemia and with cancers of many organs, such as lung, breast and thyroid gland, but not with certain other organs, such as the prostate gland. Therefore, a small addition of radiation exposure would produce an exceedingly small increase in the chances of developing an attribute to cancer. Moreover, radiation-induced cancer may manifest itself decades after the exposure and does not differ from cancers that arise spontaneously or are attributable to other factors. According to Cunningham and Cunningham (2011a) the process of the fittest individuals passing their traits as encoded in a species DNA to the next generation more successfully is called natural selection. Every organism has a dizzying array of genetic diversity in its DNA. Consequently, it has been demonstrated in experiments and by observing natural populations that changes to the DNA coding sequence of individuals occur, and that the changed sequences are inherited by offspring. Therefore, random recombination and mistakes in replication of DNA strands during reproduction as well as exposure to ionizing radiation and toxic materials are the main causes of genetic mutations.

While sometimes a single mutation has a large effect, but evolutionary change is mostly brought about by many mutations accumulating over time.

3.9.3 Low-level radiation exposure:

This is as a result of natural background radiation or radiation at mines where radioactive ores are dealt with. It may also result in damage to reproductive cells or in cancer. Low-level radiation doses are in the tens of mSv. They spread out over long periods of time but do not cause an immediate problem to the organ. The effects of low radiation doses to the cell may not be observed for many years. According to Cunningham and Cunningham (2011b), ionizing radiation has long been recognized as a human carcinogen. However, it is thought that very low radiation exposure may stimulate DNA repair along with enzymes that destroy free radicals and protects against certain cancers.

3.10 The Associated Health Effects of Radiation

The long-term effects of radiation are those which may manifest themselves years after the original exposure (UWEHS, 2006). It is emphasized that there is no unique disease associated with the long-term effects of radiation. But it is necessary to observe large populations of irradiated persons in order to measure this kind of increase and employ bio statistical and epidemiologic methodology. In addition, the situation is further complicated by the incubation period of radiation-induced diseases which may go unrecorded unless the study continues for many years. Despite the above difficulties, many epidemiologic investigations of irradiated human beings have provided convincing evidence that ionizing radiation may indeed result in an increased risk of certain diseases long after the initial exposure. Therefore, these effects observed were somatic damage, which may result in an increased incidence of cancer, embryological defects, cataracts, and life span shortening and genetic mutations, which may have an adverse effect for generations after the original radiation damage. This information was supplemented from animal experimentation which demonstrates these same effects. For low levels of radiation exposure, the biological effects are so small that they may not be detected. The body has repair mechanisms against damage induced by radiation as well as by chemical carcinogens (USNRC, 2011; Hall, 2012). Consequently, biological effects of radiation on living cells may result in three outcomes:

- Injured or damaged cells repair themselves, resulting in no residual damage
- Cells die, much like millions of body cells do every day, being replaced through normal biological processes
- Cells incorrectly repair themselves resulting in a biophysical change.

The development of cancer is mostly associated with the radiation exposure based on populations exposed to relatively high levels of ionizing radiation such as Japanese atomic bomb survivors, and recipients of selected diagnostic or therapeutic medical procedures.

Cancers associated with high-dose exposure (greater 0.5 Sv) include leukaemia, breast, bladder, colon, liver, lung, oesophagus, ovarian, multiple myeloma, and stomach cancers. Although radiation may cause cancers at high doses and high dose rates, currently there are no data to establish unequivocally the occurrence of cancer following exposure to low doses and dose rates – as below 100 mSv. Figure 3.7 below shows the radiation health effects at different exposure levels.

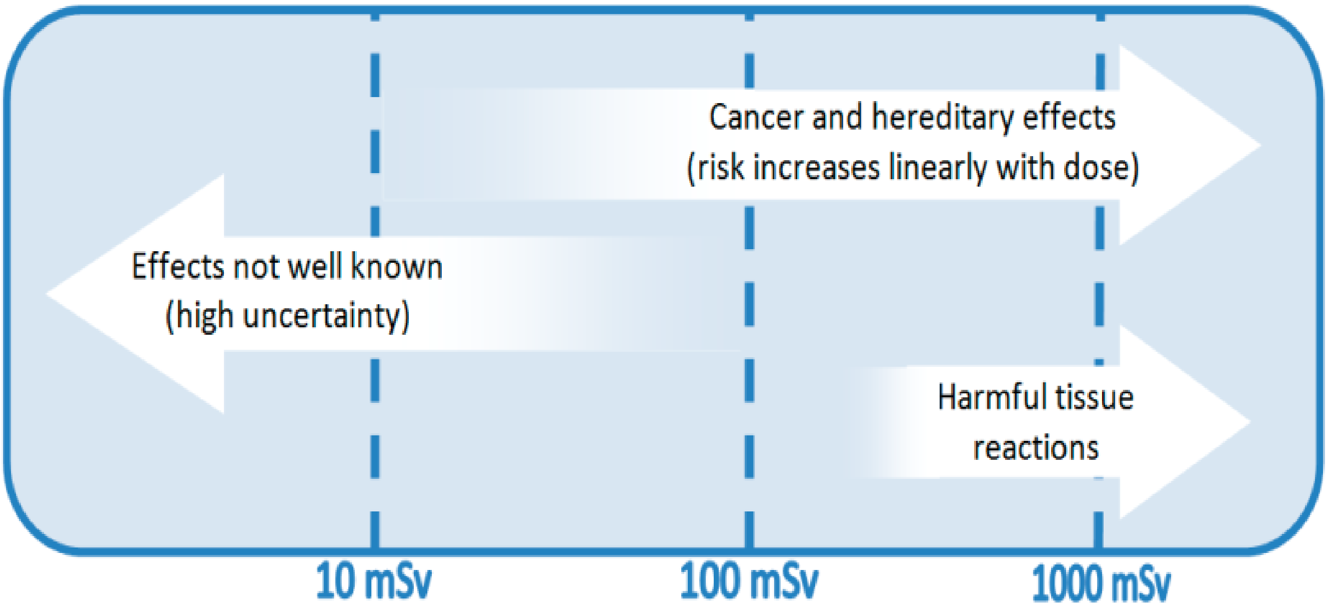


Figure 3.7: Radiation health effects at different exposure levels (ARPANSA, 2014)

3.11 Dose Limits

The purpose of a system of dose limits is to ensure that the radiation dose received by any person other than an accidental exposure or a deliberate exposure as in medical diagnosis is below threshold for any deterministic effect and the probability of any stochastic effect is small enough and acceptable to the individual and to the society (McGill, 2014). However, the system of radiation dose limits in use in most countries is based on the recommendations of the International Commission on Radiological Protection (ICRP).

3.11.1 Occupational Exposure

This is the exposure incurred at work (Valentin, 2002; Lindel *et al*., *n.d.*) as the result of situations that can reasonably be regarded as being the responsibility of the operating management. The maximum permissible dose for occupational exposure is 20 mSv per year averaged over five years (100 mSv in 5 years) with a maximum of 50 mSv in any one year (Botkin and Keller, 2011; Tsoulfanidis, 1995; Shapiro, 2002; IAEA, 2004; Gonzalez, 2002; Chen, 2014; McGill, 2014). According to IAEA (2004), the average dose overall to occupationally exposed workers from artificial sources is less than 1mSv in a year. Hence, the average in the nuclear industry tends to be little higher than this, but for the medical staff is slightly less. This steeply decline in the last decade was primarily because of the widespread introduction of ICRP recommendations and the IAEA Basic Safety Standard (BSS). Therefore, with the exception of mining, the average doses for most types of occupational exposure from artificial sources including nuclear industry are now below 2mSv per year. However, with occupationally exposed to natural radiation, about 1/5 of the people considered, work in shops, offices, schools and other premises in a radon-prone areas and the average dose for such workers is almost 5mSv per year (See Figure 3.8) below. The variations of Radon noticeably from day to day were because of the way buildings were heated and ventilated.

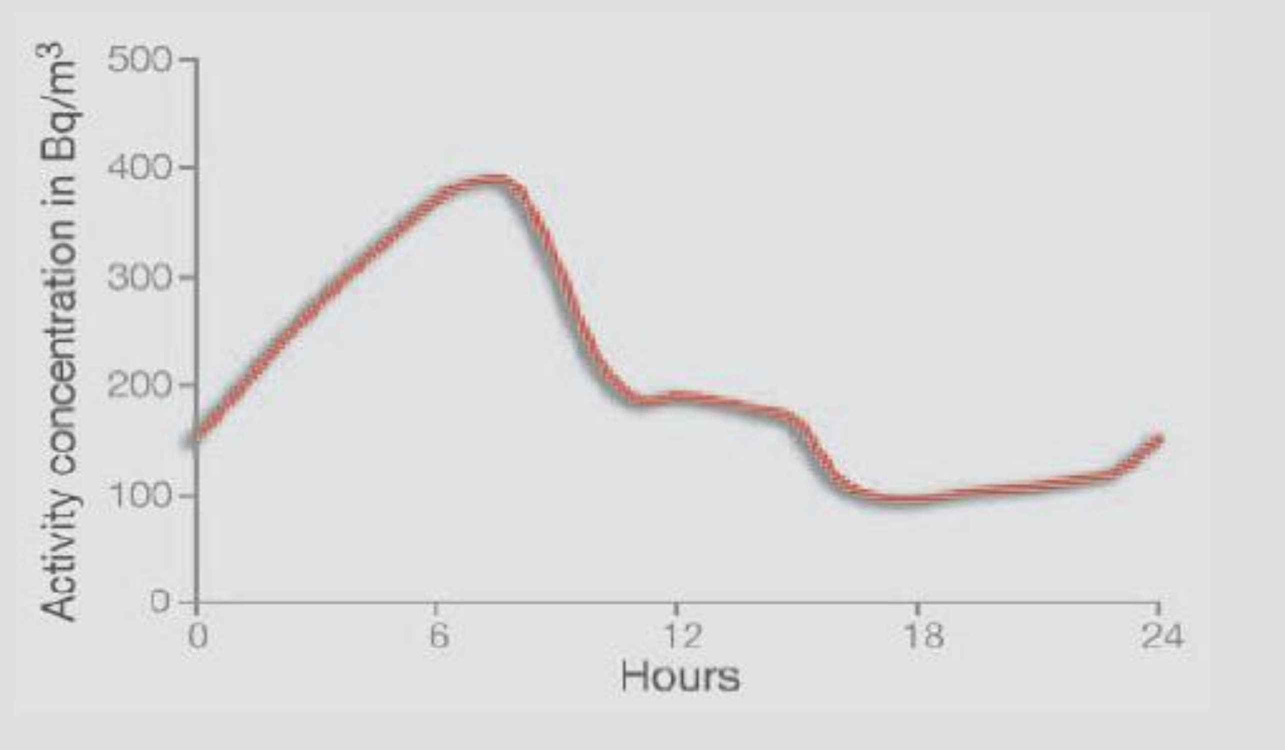


Figure 3.8: Variations in indoor Radon Concentration in a house with moderate levels (IAEA, 2004)

3.11.2 Public Exposure

The recommended radiation exposure for public is 1 mSv per year averaged over five years and this value exclude medical exposure (Chen, 2014; Gonzalez, 2002; IAEA, 2004; McGill, 2014; Shapiro, 2002). According to Gonzalez (2002), in the case of prospective situations that are expected to affect members of the public, what is controlled is the additional dose to the background dose that the public is expected to receive as a result of the introduction of a new activity. Table 3.5 shows likely effects of whole-body radiation doses with individual's dose limits.

Table 3.5: Radiation Level Vs Health Effects (Hall, 2012)

S/n	Radiation Doses	Likely Effects
1	10,000 mSv (10 Sv)	A short-term and whole-body dose would cause immediate illness, such as nausea and decreased white blood cell count, and subsequent death within few weeks. Between 2 and 10 Sv in a short-term dose would cause severe radiation sickness with increasing likelihood of fatality.
2	1,000 mSv (1 Sv)	A short-term dose is the threshold for causing immediate radiation sickness in a person of average physical attributes, but would unlikely cause death. Above 1000 mSv. Severity of illness increases with dose and if it is for a long period they are unlikelihood of health effects, but this may create some risk that cancer will develop many years in the future.
3	250 mSv	Maximum short-term dose allowable for workers controlling the Fukushima accident.
4	Above and about 100 mSv	The probability of cancer (rather than the severity of illness) increases with dose. The estimated risk of fatal cancer is 5 of every 100 persons exposed to a dose of 1000 mSv (i.e. if the normal incidence of fatal cancer were 25%, a 1000 mSv dose would increase it to 30%).
5	50 mSv	This is the highest dose which is allowed by regulation in any one year of occupational exposure. It is the lowest dose at which there is any evidence of cancer being caused in adults. However, dose rates greater than 50 mSv/yr arise from natural background levels in several parts of the world but do not cause any visible harm to local populations.
6	20 mSv/yr averaged over 5 years	The limit for radiological personnel such as employees in the nuclear industry, uranium or mineral sands miners and hospital workers (who are all closely monitored).
7	10 mSv/yr	The maximum actual dose rate received by any Australian uranium miners.
8	3-5 mSv/yr	The typical dose rate (above background) received by uranium miners in Australia and Canada
9	3 mSv/yr (approx)	The typical background radiation from natural sources in North America, including an average of 2 mSv/yr from Radon in air.
10	2.5 mSv /yr (approx)	The typical background radiation from natural sources, including an average of 0.7 mSv/yr from Radon in air. The minimum dose received by all humans anywhere on Earth is about 1.5 mSv/yr.
11	0.3-0.6 mSv/yr	The typical range of dose rates from artificial sources of radiation, mostly medical.
12	0.05 mSv/yr	This is the design target for maximum radiation at the perimeter fence of a nuclear electricity generating station. In practice the actual dose is less.

3.12 Radiation Protection

Radiation protection has its origins early in the twentieth century. It is the term applied to concepts, requirements, technologies and operations related to protection of people such as radiation workers, members of the public, and patients undergoing radiation diagnosis and therapy against the harmful effects of ionizing radiation (NEA, 1994). Furthermore, radiation benefits were first recognized in the use of X-rays for medical diagnosis, later with the discoveries of radiation and radioactivity. The rush in exploiting the medical benefits led fairly to the recognition of the risks and induced harm associated with it. In those early days, only the most obvious harm resulting from high doses of radiation, such as radiation burns were observed and protection efforts were focused on their prevention, mainly for practitioners rather than patients. Although the issue was narrow, this led to the origin of radiation protection as a discipline. Subsequently, it was gradually recognized that there were other, less obvious, harmful radiation effects such as radiation-induced cancer, for which there is a certain risk even at low doses of radiation. This risk cannot be completely prevented but can only be minimized. Therefore, the balancing of benefits from nuclear and radiation practices against radiation risk and efforts to reduce the residual risk has become a major feature of radiation protection. According to ILO (2014), the purpose of radiation protection is to provide an appropriate level of protection in preventing occurrence of harmful deterministic effects and stochastic effects such as cancer and hereditary effects to humans without unduly limiting the beneficial actions giving rise to radiation exposure. Chen (2014) noted that radiation protection program elements include signage and posting; dose limits for the general public; occupational dose program; area surveys; sealed source inventory and leak testing; ordering, receiving, and opening of packages; patient dosage determination and preparation; minimization of contamination and spills; waste decay in storage and disposal; reporting; record keeping; and audits of the radiation protection program. Radiation protection standards in any country are set by government authorities and in the Republic of South Africa, The National Nuclear Regulator is mandated with that responsibility which generally is in line with recommendations by the ICRP, taking into account social and economic factors with the requirement to keep exposure as low as reasonably achievable (Hall, 2012).The authority of the ICRP comes from the scientific standing of its members and the merit of its recommendations. Therefore, radiation protection for practices is founded on a conceptual framework (See Figure 3.9), which was proposed by ICRP and involves three principles: justification, optimization and limitation (IAEA, 1996b; NEA, 1994; Valentin, 2002; Lindel *et al*., *n.d*.; AGDOH, 2012).

- **Justification**: No practice will be adopted except if its introduction will produce positive net benefit to the exposed individuals or to society to offset the detriment it causes. The detriment is not necessarily confined to radiation, but may include other social and economic considerations as well.

- **Optimization**: Once a practice has been justified and adopted, it is necessary to consider how best to use resources in reducing the radiation risk to individuals and the population. For any particular source, the broad aim is that the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposure which is not certain – potential exposure should all be kept as low as reasonably achievable, economic and social factors being taken into account.

- **Limitation**: The exposure of individuals resulting from a combination of all relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposure. These are aimed at ensuring that no individual is subject to radiation risks deemed to be unacceptable. Limits provide a clearly defined boundary of individual risk for application of the more subjective procedures of justification and optimization.

3.12.1 ALARA (As Low as Reasonably Achievable) Concept

ALARA is a concept for radiation protection that urges licensees to make a reasonable effort to maintain individual and collective radiation exposure as low as possible. This means that the institutional operational dose limit for any radiological activity needs to be more restrictive, if possible, than the occupational dose limit. ALARA can be achieved by designing processes, implementing procedures, and using engineering controls to minimize radiation exposure (Chen, 2014). According to IAEA (2010), the aim of Radiation Protection is to establish an appropriate level of protection for people and the environment against detrimental effects of radiation exposure without unduly limiting the desirable human actions that may be associated with such exposure.

3.12.2 Radiation Protection Framework

The conceptual framework for radiation protection covers basically the simple guidance on protection against X-rays that was issued in the 1930s up to the very comprehensive system of protection which now covers practically all existing sources of human exposure, which comprises of artificial and natural as shown in Figure 3.9 below (NEA, 1994):

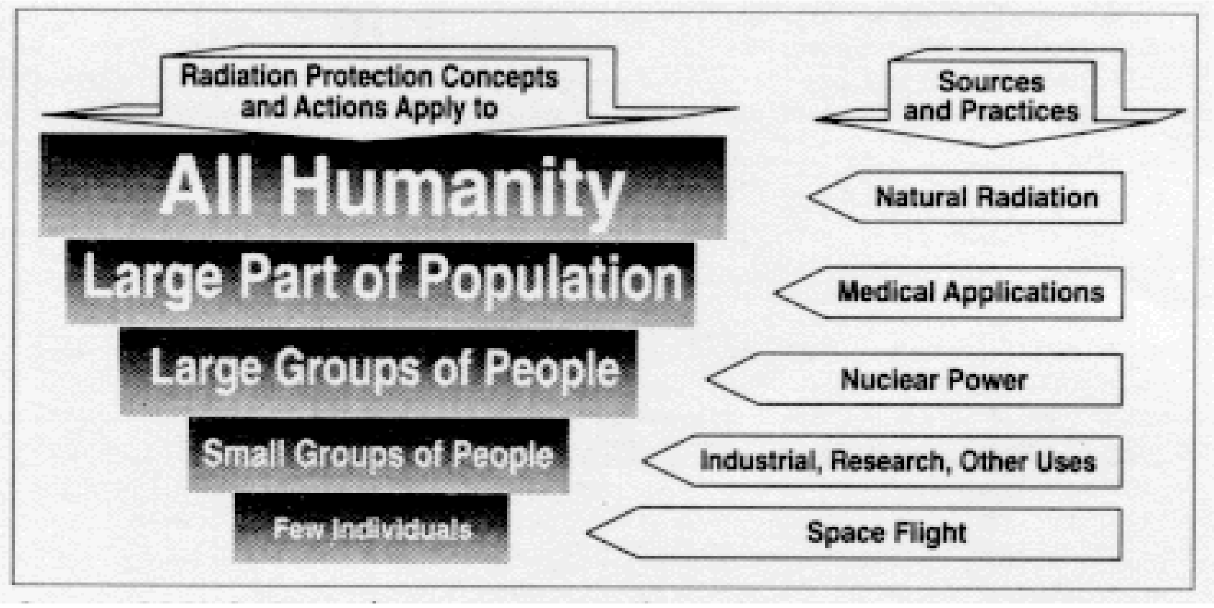


Figure 3.9: Scope of Radiation Protection (NEA, 1994)

According to IAEA (2004) approaches to protection against ionizing radiation has been consistent throughout the world due to the existence of a well established and internationally recognized framework such as UNSCEAR, ICRP and IAEA.

3.12.2.1 UNSCEAR

The UNSCEAR regularly reviews the natural and artificial sources of radiation in the environment to which people are exposed, the radiation exposure due to those sources and the risks associated with the exposure. It reports to the UN General Assembly on frequent basis.

3.12.2.2 ICRP

The ICRP is a non-governmental scientific organization founded in 1928 which derives its authority from the scientific view of its members and recommendations. It regularly published recommendations for protection against ionizing radiation. Its estimates are on the bases of the probability of fatal cancer mainly on studies of the Japanese survivors of the atomic bombs and the assessment by UNSCEAR.

3.12.2.3 IAEA

The IAEA has statutory function to establish safety standards in collaboration with other relevant international organizations. It relies on the work of UNSCEAR and ICRP to achieve this objective. Hence, providing the application of these standards at the request of countries (member states) using various mechanisms such as provision of services and training.

3.12.3 Radiation Exposure

Radiation exposure may be classified into either internal or external (WHO, 2012)

3.12.3.1 Internal exposure

This type of exposure occurs when a radionuclide is inhaled, ingested or otherwise enters into the bloodstream through injection or wounds. This type of exposure is eliminated from the body either through treatment or spontaneously through excreta (Tsoulfanidis, 1995). According to DME (2005), the following precautions can be taken to reduce exposure to internal radiation:

- Minimizing dust in the work place by proper watering, washing down and by good ventilation.
- Wearing appropriate respiratory protection devices in areas where dust is inevitable.
- Ventilation of areas where Radon or Thoron (isotope of radon- radon 220) may build up. This does not normally apply in open cut mines where even a slight wind will disperse the radon.

- Keeping work areas clean: Surface contamination is the start of a pathway that can lead to radioactive materials being re-suspended in the air and inhaled, or transferred from dusty or unclean surfaces to the mouth or by ingestion.

3.12.3.2 External exposure

This can either be due to contamination or irradiation. The external contamination occurs when airborne radioactive material such as dust, liquid, aerosols is deposited on the skin or clothes while for irradiation is such as X-ray. Similarly, DME (2005) noted that it is the radiation that comes from a radioactive source that is outside the body. Therefore, external radiation usually refers to gamma rays, since alpha particles and beta particles do not travel very far in air.

3.12.4 Precautionary Measures of Radiation Protection

The three precautionary measures against external radiation sources are time, distance and shielding (Hall, 2012; EPA, 2012; NU, 2010; Shapiro, 2002)

3.12.4.1Time

By decreasing the amount of time spent near a source of radiation, the less the amount of radiation exposure received. According to SurvivalIQ (2008) and Shapiro (2002), the longer time exposed to a radioactive source, the greater the dose that will be received (radiation dosages are cumulative). Therefore, it is recommended to spend as much short time as possible in a radioactive environment. Consequently, radioactivity decreases or decays over time. This concept is known as radioactive half-life. Thus, a radioactive element decays or loses half of its radioactivity within a certain time. The rule of thumb for radioactivity decay is that it decreases in intensity by a factor of ten for every sevenfold increase in time following the peak radiation level. According to NDT (2014), equation 3.3 can be used to make a simple calculation to determine the dose that will be or has been received in a radiation environment.

$$\text{Dose} = \text{Dose Rate} \times \text{Time}$$

Therefore;

$$\text{Time} = \frac{\text{Dose}}{\text{Dose Rate}} \qquad (3.3)$$

3.12.4.2 Distance

Radiation intensity decreases sharply with distance, according to an inverse square law (UOM, 2014; NU, 2010; SurvivalIQ, 2008; Maher, 2006; Martin, 2006; Shapiro, 2002; AGDOH, 2012). The farther away from a radiation source, the less exposure received. Therefore, the closer it is to the source, the greater chances of bodily damage. According to NU (2010), remote handling tools may be necessary for sources with high-energy beta particles such as Phosphorus-(P-32), high gamma exposure rates such as Caesium-(Cs-

137) and Sodium- (Na-22). It can either be forceps, tongs, vial racks, trays or anything that will put distance between the individual and the source. According to Joseph and Phalen (2006), despite the advances in radiation protection, such as collimators, cones, and positive beam limiting devices, distance is still the best tool for radiation protection and remains the most common method of protecting personnel, visitors, and adjacent patients from ionizing radiation use. This phenomenon of inverse square law which states that the intensity (concentration) of x-ray photons or gamma radiation decreases inversely as the area the beam covers increases is shown in Figure 3.10 below (Joseph and Phalen, 2006) which can also be expressed in equation 3.4 below (NDT, 2014):

Inverse Square Law

$$\frac{I1}{I2} = \frac{D2^2}{D1^2} \qquad (3.4)$$

Where;

I_1 = Intensity 1 at D1
I_2 = Intensity 2 at D2
D_1 = Distance 1 from source
D_2 = Distance 2 from source

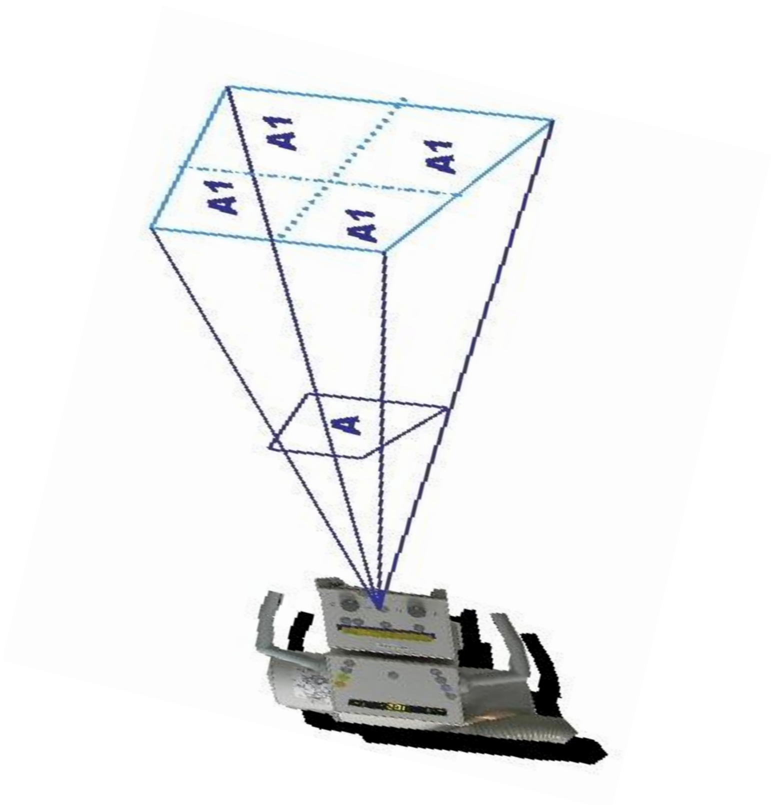


Figure 3.10: A point Source from x-ray tube (Joseph and Phalen, 2006)

Figure 3.10 above is an illustration of a typical x-ray tube used to produce a point source of x-rays. As the radiation exits the tube, it diverges to cover an increasingly larger area as the distance from the source increases. When "A" is smaller, the radiation is more concentrated than in an equal area "A1" which is some distance from "A." Each square A1 is the same size as "A" but only 1/4 the number of photons occupies it because of the divergence of the radiation with increasing distance. However, it should be noted that the inverse square law only applies to electromagnetic point source radiation such as gamma or x-rays, and not to particulate radiations like alpha and beta particles. Particulate radiation does not follow the physical principles of the inverse square law because their distance of travel is limited to only a few millimetres for alpha particles, and a few centimetres for beta particles, then their kinetic energy is reduced to zero delimiting their ionization potential. This is because particulate radiation has mass and charge, which are properties that electromagnetic radiation does not possess. Therefore, moving a couple of feet away from the source of particulate radiation is usually enough protection (Joseph and Phalen, 2006).

3.12.4.3 Shielding

This is the method of placing some material such as concrete or lead in-between radiation source (Hall, 2012). Shielding decreases exposure. However, proper shielding can result in an exponential reduction of dose for gamma emitters and a near-total reduction for beta emitters. Consequently, shielding design may be simple or may involve complex calculations but all that depends on the type of radiation, the energy and frequency of emission, the configurations of source and room, and the occupancy factors (NU, 2012). Therefore, in planning stages of any experiment or clinical procedure the selection of appropriate shielding materials is highly recommended. Shultis and Faw (2005) have noted that shielding design and shielding analysis are complementary activities. In design, the source is identified and a target dose goal is specified. The task is to determine the nature of the shielding required to achieve the goal. While in analysis, the source and shielding are identified and the task is to determine the consequent dose. Specific shielding designs are related to the shielding formula used to protect personnel, patients, and visitors from ionizing radiation (Joseph and Phalen, 2006). According to Martin (2006), shielding is an important aspect of radiation protection and radiation control. Therefore, the features of shields and their design, use and effectiveness warrant specific consideration. Similarly, various materials, placed between a source and a receptor can affect the amount of radiation transmitted from the source to the receptor. Such effects are due to attenuation and absorption of the emitted radiation in the source, material used for the encapsulation, or the shielding barrier. However, radiation shielding is a very complex discipline for many radiation sources and for many geometric configurations in which they may occur. In medical radiology setting two values are useful in determining shielding; the linear attenuation coefficient and the mass attenuation coefficient. These are the most common methods used to measure the ability of an absorber to absorb radiation (Joseph and Phalen, 2006). The linear attenuation coefficient is the fraction of the number of photons removed from the radiation field per centimetre of absorber through which it passes. Generally, it is expressed as a percentage constant such as 10%, with a function like the decay constant and can be adjusted to whatever percent desired. Figure 3.11 shows the application of the formula:

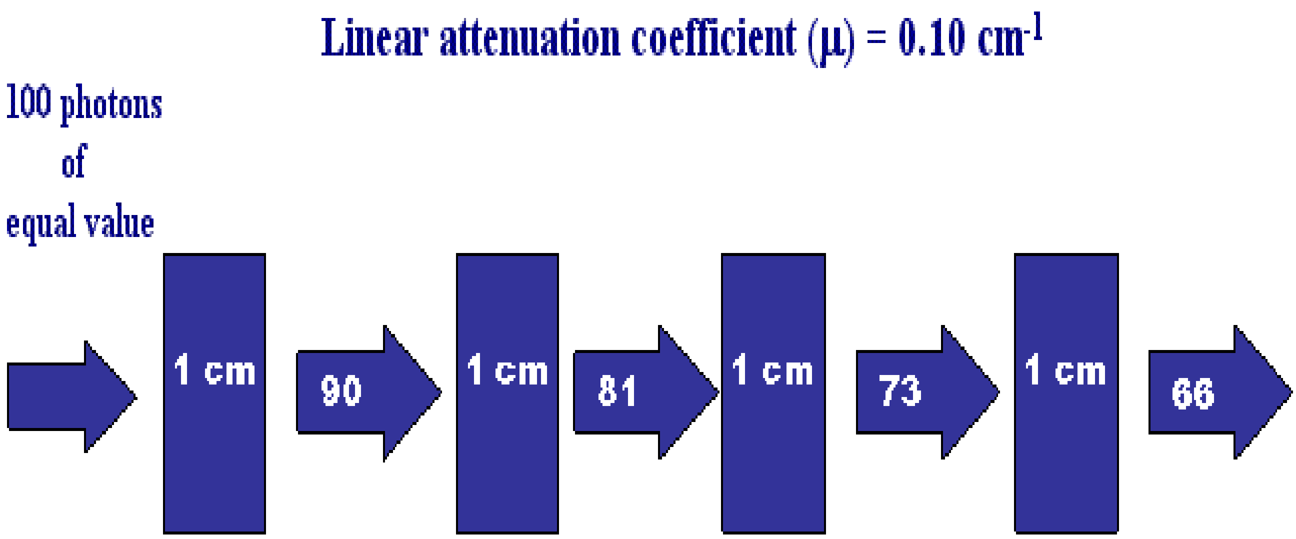


Figure 3.11:The linear attenuation Coefficient (Joseph and Phalen, 2006)

As shown above (Figure 3.11), the desired percent was set at 10% which means that 10% of attenuation was provided by a constant one centimetre thickness of material. If a beam of 100 photons passing through a 1 cm thickness of material, 10% will absorb approximately 10 of them, and if another thickness is added it will absorb 9 more, and so on until the beam is completely reduced. Therefore, for shielding purposes, a high linear attenuation coefficient material is selected. However, the mass attenuation coefficient is not useful in medical shielding but it is covered here because it represents a measurement that does not change based on the physical state of the absorber material. Therefore the shielding formula in equation 3.5 is more useful because it contains attenuation data for shielding any type of radiation and thickness of an absorber.

Shielding Formula

$$I = Io e^{-\mu x} \quad (3.5)$$

I = Radiation intensity after shielding

I_o = Radiation intensity before shielding

e = Logarithm base e (2.178)

µ = Linear attenuation coefficient

x = thickness of shielding material in centimetre (s)

3.12.4.3.1 Half-Value Layer (Shielding)

A more pragmatic approach of understanding shielding is the concept of the half value layer (HVL). The more subatomic particles in a material, the greater the likelihood that interactions will occur and the radiation will lose its energy. Therefore, the denser a material is, the smaller the depth of radiation penetration. Materials such as depleted uranium, tungsten and lead have high subatomic particles, and are therefore very effective in shielding radiation. Concrete is not as effective in shielding radiation but it is a very common building material and so it is commonly used in the construction of radiation vaults. Each material has its own specific HVL thickness, not only is the HVL material dependent, but it is also radiation energy dependent. This means that for a given material, if the radiation energy changes, the point at which the intensity decreases to half its original value will also change as shown in Table 3.6 and Table 3.7 below. The following are some HVL values for various materials commonly used in industrial radiography and X-ray (NDT, 2014).

Table 3.6: HVL when Radiation is from Gamma Source (NDT, 2014)

	Half-Value Layer, mm (inch)				
Source	Concrete	Steel	Lead	Tungsten	Uranium
Iridium-192	44.5 (1.75)	12.7 (0.5)	4.8 (0.19)	3.3 (0.13)	2.8 (0.11)
Cobalt-60	60.5 (2.38)	21.6 (0.85)	12.5 (0.49)	7.9 (0.31)	6.9 (0.27)

From Table 3.6, the HVL of lead for cobalt 60 is 12.5 mm. This means that a given quantity of radiation from a cobalt 60 field that strikes an absorber with a HVL of 12.5 mm lead or equivalent would be reduced in intensity by half (Joseph and Phalen, 2006). Accordingly, the HVL is independent of the amount of radiation that passes through it, it simply reduces the intensity of a radiation field when wearing a lead apron or lead gloves by half; but does not stop it completely no matter how many half value layers are interposed. All lead shields should be considered as barriers having the quality of a half value layer allowing a small quantity of ionizing radiation to pass through. However, radiation that passes through an attenuator having reduced energy and intensity will most likely be absorbed in the tissues of the wearer. The adding of half value layers reduces radiation intensity with each gradation, so that the amount of radiation exposure to the person behind successive half value layers is minimized.

Table 3.7: HVL when Radiation is from X-ray Source (NDT, 2014)

	Half-Value Layer, mm (inch)	
Peak Voltage (kVp)	Lead	Concrete
50	0.06 (0.002)	4.32 (0.170)
100	0.27 (0.010)	15.10 (0.595)
150	0.30 (0.012)	22.32 (0.879)
200	0.52 (0.021)	25.0 (0.984)
250	0.88 (0.035)	28.0 (1.102)
300	1.47 (0.055)	31.21 (1.229)
400	2.5 (0.098)	33.0 (1.299)
1000	7.9 (0.311)	44.45 (1.75)

3.12.4.3.2 Shielding Materials

The control and prevention of radiation from causing physical harm to workers or their surroundings is an important part of operating equipment that emits potentially hazardous rays. Preserving both human safety and structural material that may be compromised from radiation exposure are vital concerns, as well as shielding sensitive materials, such as electronic devices and photographic film. However, the process of regulating the effects and degree of penetration of radioactive rays varies according to the type of radiation involved. Indirectly ionizing radiation, which includes neutrons, gamma rays, and x-rays, is categorized separately from directly ionizing radiation, which involves charged particles (Thomasnet, 2014). Different materials are better suited for certain types of radiation than others, as determined by the interaction between specific particles and the elemental properties of the shielding material.

3.12.4.3.3 Shielding Properties

There are several factors that influence the selection and use of radioactive shielding materials. Considerations such as attenuation effectiveness, strength, resistance to damage, thermal properties, and cost efficiency can affect radiation protection in numerous ways. For example, metals are strong and resistant to radiation damage, but they undergo changes in their mechanical properties and degrade in certain ways from radiation exposure. Likewise, concretes are strong, durable, and relatively inexpensive to produce, but become weaker at elevated temperatures and less effective at blocking neutrons. However, radiation shielding is based on the principle of attenuation, which is the ability to reduce a wave's or ray's effect by blocking or bouncing particles through a barrier material (Thomasnet, 2014). Hence, charged particles may be attenuated by losing energy to reactions with electrons in the barrier, while x-ray and gamma radiation are attenuated through photoemission, scattering, or pair production and Neutrons can be made less harmful through a combination of elastic and inelastic scattering, which most neutron barriers are constructed with materials that encourage these processes. According to Shapiro (2002), one basic difference between beta and gamma shielding is that Beta particles are charged ionizing particles and have a maximum range. Thus a shield built to stop beta particles from a particular radionuclide will stop the particles from any source consisting of that nuclide, regardless of the source strength. On the other hand, a gamma shield always allows a fraction of the gamma photons to get through, since they are uncharged ionizing particles. The fraction decreases, of course, as the thickness of the shield increases.

3.12.4.3.4 Gamma and X-ray Shielding

Every gamma ray has a finite probability of passing all the way through a medium through which it is travelling (Shapiro, 2002). However, the probability that a gamma ray will penetrate through a medium depends on many factors, which includes: the energy of the gamma ray, the composition of the medium and the thickness. If the medium is dense and thick enough, the probability of penetration may be practically zero. Most radionuclide's have good chance of emerging and being detected outside the body. Therefore, suitable gamma-ray emitters are powerful tools for studying body function. It is then very important to note that it is the electrons to which the energy is transferred by the gamma photons that actually produce damage in the medium – by subsequent ionization and excitation of the atoms. Once a photon liberates an electron, the subsequent events depend only on the properties of the electron and not on the gamma photon that liberated it. The ejection from an atom by a photon of an energetic electron, with energy of 1 MeV for instance, is only a single ionization. The electron, in slowing down, will produce tens of thousands of ionizations and excitations, and the damage produced will depend on the number and spatial distribution of these ionizations and excitations, rather than on the single ionization produced by the gamma photon. Thomasnet (2014) noted that high-density materials are more effective than low-density alternatives for blocking or reducing the intensity of radiation. However, low-density materials can compensate for the disparity with increased thickness, which is as significant as density in shielding applications. Lead is particularly well-suited for lessening the effect of gamma rays and x-rays due to its high atomic number. This number refers to the amount of protons within an atom, so a lead atom has a relatively high number of protons along with a corresponding number of electrons. These electrons block many of the gamma and x-ray particles that try to pass through a lead barrier and the degree of protection can be compounded with thicker shielding barriers. However, it is important to remember that there is still potential for some rays making it through the shielding, and that an absolute barrier may not be possible in many situations. According to Martin (2006), three groups of people are considered for protection in the use of x-rays: the patient, workers who perform examinations and members of the public. Most of who can be presumed to be only occasionally exposed when attending to patients. However, shielding is placed around x-ray units and x-ray rooms to maintain exposures of workers and members of the public below prescribed limits and at levels as low as reasonably achievable (ALARA) within these limits. Accordingly, the first consideration in protecting patient is to ensure that there is necessity of the examination – a study should not be prescribed unless it is medically justified either ensuring the use of optimal techniques that will help in minimizing the number of x-rays taken. Secondly, is to ensure that quality radiographs that contain the requisite diagnostic information are obtained by using properly calibrated and maintained x-ray equipment, kept at optimal operating condition by quality control procedures. The other elements for patient protection from medical x-rays are based on good practices, some of which are (Martin, 2006; Shapiro, 2002):

- To confine the field size to the regions being examined through proper collimation and shielding, especially for the reproductive regions.
- Using the maximum distance practicable between the x-ray source and the patient.
- Using the highest x-ray tube voltage practicable and proper filtration of the x-ray beam to give the minimum absorbed dose consistent with producing a satisfactory radiograph.
- Paying particular attention to the film processor, especially ensuring accurate processing temperature and the quality and strengths of process chemicals.
- Using fast film/screen combinations and short exposure times.
- Planning of all exposures carefully to minimize retakes.

3.12.4.3.5 Alpha and Beta Shielding

While density remains an important characteristic for blocking alpha and beta radiation, thickness is less of a concern. A single centimetre of plastic is sufficient for shielding against alpha particles. In some cases, lead is ineffective in stopping beta particles because they can produce secondary radiation when passing through elements with a high atomic number and density. Instead, plastic can be used to form an efficient barrier for dealing with high-energy beta radiation (NU, 2010; Thomasnet, 2014). When negatively charged beta particles hit a high-density material, such as tungsten, the electrons are blocked, but the target which the barrier is intended to protect can actually become irradiated.

3.12.4.3.6 Neutron Shielding

Accordingly, lead is quite ineffective for blocking neutron radiation, as neutrons are uncharged and can simply pass through dense materials. Materials composed of low atomic number elements are preferable for stopping this type of radiation because they have a higher probability of forming cross-sections that will interact with the neutrons. Hydrogen and hydrogen-based materials are well-suited for this task. Compounds with a high concentration of hydrogen atoms, such as water, form efficient neutron barriers in addition to being relatively inexpensive shielding substances. However, low density materials can emit gamma rays when blocking neutrons, meaning that neutron radiation shielding is most effective when it incorporates both high and low atomic number elements. The low-density material can disperse the neutrons through elastic scattering, while the high-density segments block the subsequent gamma rays with inelastic scattering.

3.13 Conclusion

We provided in this Chapter the basic understanding on the activities involving radiation exposure, such as the production and use of radiation sources, radioactive materials and the operation of nuclear installations, including the management of radioactive waste and the risks associated with radiation exposure. Since the benefits to be gained outweighed tremendously the demerit and consequently the demand for its applications and by-products for radiation and radioactive substances continue to increase globally, it is very essential that the risks due to its exposure must be restricted and protected against by the application of radiation safety standards, nuclear techniques, health effects of radiation and techniques for the safe design and operation of radiation sources. In Chapter 4, we highlight on the design of nuclear energy sustainability having in mind the protection of life, property and the environment from the harmful effects of ionizing radiation.

CHAPTER FOUR

DESIGN FOR SUSTAINABLE DEVELOPMENT WITH NUCLEAR SOURCES

4.1 Introduction

The sustainability of nuclear sources is discussed in this chapter. It is factual that many countries currently are facing energy crisis because the electricity required to grow the economy and drive local development is inadequate. Traditional energy solution has relied heavily on fossil fuel for power generation which is becoming unsustainable. Increasing frequency of global warming induced extreme events such as droughts and floods are undermining the generation capacity of hydropower generation, which has also come under pressure because of its negative impacts on people and ecosystems (Chiejina, 2012). According to WNA (2013), the world's population will continue to grow for several decades while energy demand and the proportion supplied by electricity is likely to increase faster. Therefore, there is need for more large-scale grid-supplied power, especially in urbanised areas, over the next several decades. The criteria for any acceptable energy supply will continue to be cost, safety, and security of supply, as well as environmental considerations. Usually there are cost implications in addressing these effects based on the current climate change debate. Hence, supplying low-cost electricity with acceptable safety and low environmental impact will depend substantially on developing and deploying reasonably sophisticated technology which will include both large-scale and small-scale nuclear energy plants that can be harnessed directly to industrial processes such as hydrogen production or desalination, as well as in generating electricity. However, with the discoveries of fertile Thorium fuel cycles that offer attractive features, including lower level of waste generation, less dangerous, less expensive, more accessible and more environmentally friendly option for nuclear fuel supply as against Uranium fuel cycle that most of the present reactors were built on. And also with the latest innovation of fast breed reactors (FBR) and High Temperature Reactors (HTR) which offer more efficient use of uranium resources and the ability to burn actinides which are otherwise the long-lived component of high-level nuclear wastes (Oyedepo*,* 2012). The analysis of nuclear energy characteristics within a sustainable development framework shows that the approach adopted by the nuclear energy sector is generally consistent with the fundamental sustainable development goal of passing on a range of assets to future generations while minimizing environmental impacts (NEA, 2014). Similarly, GEA (2012) has noted that energy is essential for human development. Hence, energy systems are a crucial entry point for addressing the most pressing global challenges of the 21st century, including sustainable economic, and social development, poverty eradication, adequate food production and food security, health for all, climate protection, conservation of ecosystems, peace, and security. Yet, more than a decade into the 21st century, current energy systems do not meet these challenges. According to Echávarri

(2014), recent studies have shown that new nuclear power plants can compete favourably with alternatives such as gas or coal-fired plants. Apart from the rising prices of fossil fuels which reinforce the competitiveness even more, the main factors that contribute to the competitiveness are based on the new designs which include cost-effectiveness of the concepts, enhanced technical performance such as longer lifetimes, higher energy availability and better fuel utilisation. The advanced light water reactors currently available on the market are designed for 60 years of operation at an average availability factor of 90%, thereby making better use of the energy content of natural uranium by generating 15% less waste. Therefore, nuclear energy could make a major contribution to diversification, security of energy supply and the reduction of greenhouse gas (GHG) emissions in a cost-effective way.

4.2 Sources of Electricity Generation in South Africa

The most common way to generate electricity throughout the world is by temperature and pressure steam from boiling water (CCEI, 2014). However, many different fuels can be used to heat the water including wood, coal, oil and natural gas. In a nuclear generating plant for instance, a process called nuclear fission creates the heat by splitting uranium atoms. In recent years, generation from these traditional fuels has been supplemented with a growing list of emerging technologies that use the sun, wind and even biomass to produce electricity. Primary among these technologies are wind turbines and photovoltaic or solar cells. Fuel cells are also emerging as possible energy sources for homes, businesses and automobiles. These new technologies are both costly and limited in their capacities. In South Africa, the most abundant source of energy is coal with a low quality, low heat value and high ash content. Therefore, Eskom relies on coal fired power stations to produce 85.62% (Figure 4.1) of its electricity that uses over 90 million tons of coal per annum. However, coal mining in South Africa is relatively cheap compared to the rest of the world and these low costs have had an important effect on the nation's prosperity and potential for development. Eskom's generation division has 13 coal-fired power stations with an installed capacity of 37 745 MW (See Figure 4.1 and Table 4.1) (Eskom, 2012***)***. Also, in the country's generating plant mix is Africa's first nuclear power station at Koeberg with an installed capacity of 1 910 MW of power and total net output of 1 8 30 MW. As part of the generation plant mix, are two conventional hydroelectric power stations and two hydro pumped storage schemes of 2000 MW combined capacity. These stations are used when there is a sudden increase in the demand for electricity which cannot immediately be met by the base load stations. Also, there are two smaller old open cycle gas turbine stations with total capacity of 2426 MW that uses kerosene and two new ones that uses diesel finally, three wind turbines with total capacity of 3MW***.*** According to the Power utility, the company is currently looking into the resource availability of wave power along the east and west coastline of the country. The process is to capture wave data and manipulate the data to determine the possibility of investing money into a new generation technology. Once the resource assessment has been completed and the results are positive, the company will be doing laboratory tests on different ocean energy conversion technologies. These tests will provide an edge to choose the best technology to be used on their coastlines.

Table 4.1: South Africa Electricity Generation by Source (Eskom, 2012)

S/N	Sources	Generated Capacity in MW
1	Coal Fired	37745
2	Nuclear	1910
3	Hydro (Conventional)	600
4	Hydro (Pumped)	1400
5	Gas Fired	2426
6	Wind farm	3
	Total	**44084**

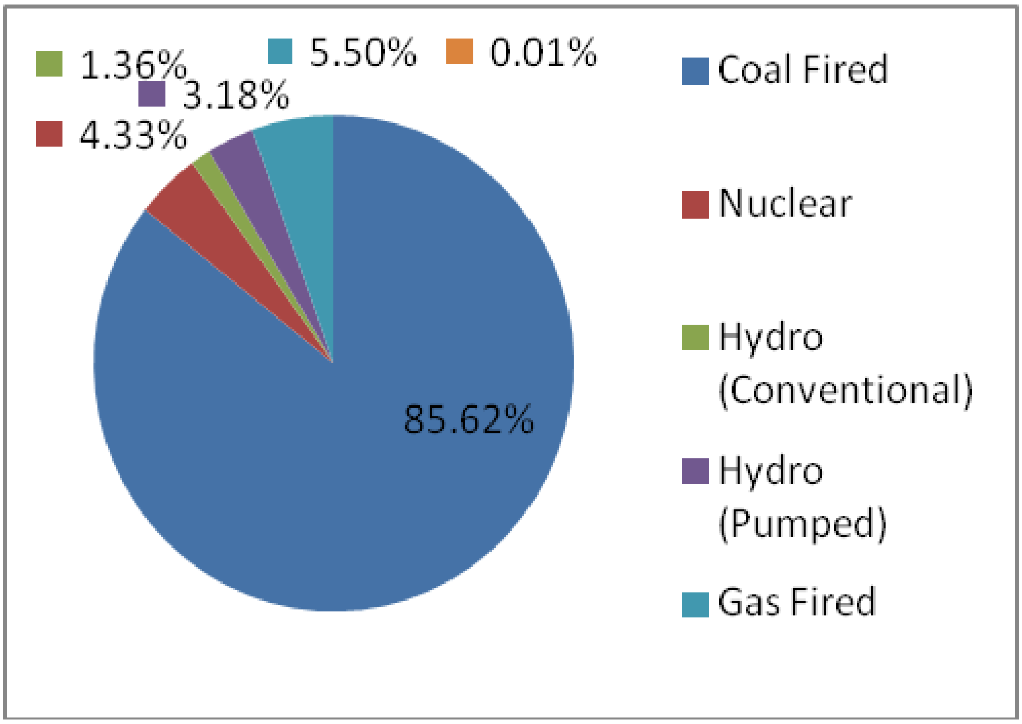


Figure 4.1: South Africa Electricity Generation by Source (Eskom, 2012)

According to Mooley and van Weele (2013), South Africa currently has a well-developed energy supply and production system, but the challenge is to maintain and expand to support her growing economy. It is also characterized by the duality of low production costs but high environmental impacts as a consequence of a heavy reliance on large coal reserves and other imported fossil fuels. In fact, 70% of primary energy and 90% of electricity are derived from coal. Unfortunately, the energy intensity and reliance on fossil fuel derived energy, translates into relatively high GHG emissions such as carbon dioxide (CO_2) whether measured either per capita or by intensity. This heavy reliance on energy is also increasingly becoming a liability as energy prices raise to compensate for the progressive internalization of the environmental and social costs of generating the energy. Accordingly, South Africa is the 27th largest economy in the world, but the 12th largest CO_2 emitter mainly because the energy intensive economy is largely dependent on carbon-based fuels. As the world takes steps to cost the negative effects of carbon, South Africa is likely to face challenges in reducing emissions. However, it will have to find ways of improving both the water and energy efficiency of industry. The energy sector is critical to South Africa's economy, because it contributes approximately 15% to the country's Gross Domestic Product (GDP) and therefore underpins the rest of the economy. As the economy continues to grow, energy is increasingly becoming a key focus. Therefore, a transformation of the energy sector is regarded as one of the major requirements through which equitable economic growth and sustainable development can be achieved.

4.3 Co_2 Emission in South Africa

South Africa's emissions stand at 1.49% of total global CO_2 emissions as shown in Figure 4.2 below (Urban Earth, 2012). China is the greatest contributor to CO_2 emissions, while the US is in the second position. (This estimate was CO_2 emissions from energy consumption only and did not include other GHGs). The graph below contrasts South African CO_2 emissions with the 5 top global carbon emitters.

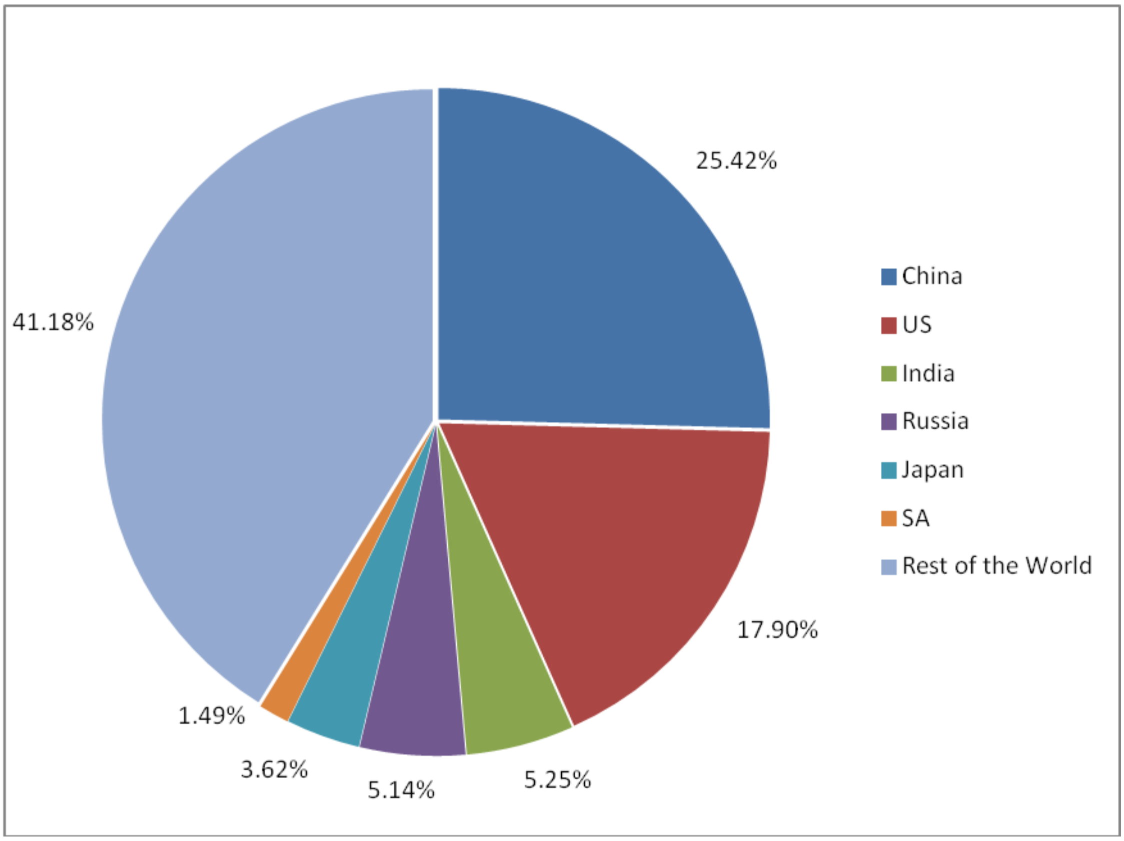


Figure 4.2: South Africa CO2 Emissions compared to top global emitters (Urban Earth, 2012)

4.3.1 CCS in South Africa

CCS is a set of technologies that can greatly reduce CO_2 emissions from new and existing coal- and gas-fired power plants and large industrial sources (EPA, 2013). CCS is a three-step process that includes capturing the CO2 from power plants or industrial processes, transporting the captured and compressed CO_2 (usually in pipelines) and underground injection and geologic sequestration (also referred to as its storage) into deep underground rock formations. These formations are often a mile or more beneath the surface and consist of porous rock that holds the CO_2. Overlying these formations are impermeable, non-porous layers of rock that trap the CO_2 and prevent it from migrating upward. After the capture, it is compressed and then transported to a site where it is injected underground for permanent storage also known as sequestration. However, it is commonly transported by pipeline, but it can also be transported by train, truck, or ship. According to CCSA (2014), CCS uses established technologies to capture, transport and store carbon dioxide emissions from large point sources, such as power stations and it also have an important role to play to ensure manufacturing industries, such as steel and cement, can continue to operate, without the associated emissions. Hence, it is a key tool in tackling climate change, providing energy security, creating jobs and economic prosperity. Similarly, the principal rationale behind any effort to sequester carbon is to mitigate the progression and further impact of climate change. Given its high mitigation potential, the technology is often regarded as particularly relevant which along China are seen as critical actors in any global mitigation scenario. India and Brazil are already the world's fifth- and seventh-largest emitters in absolute terms; while South Africa has one of the highest emissions rates per capita (Rom'an, 2011). In the country's national climate change response, the South African government gave a commitment to invest on clean coal technologies and efficient technologies where coal is still used, backed by stringent thermal efficiency and emissions standards for coal-fired power stations. As part of the commitment, South Africa then recognizes the need to move towards a low-carbon society by December 2009, committed at Copenhagen to reduce 34% of GHG emissions by 2020 and 42% by 2025 on condition that it received the necessary finance, technology and support from the international community. In view of this, the development of CCS has been declared a national research priority and the government was instrumental in setting up the South African Centre for Carbon Capture & Storage (SACCCS) in March 2009. According to SACCCS (2014) more than ninety percent of South Africa's power is generated from coal and other industries e.g. the synfuel industry also uses large quantities of coal, which is resulting in the release of over 400 million tonnes of CO_2 annually. Therefore, the government then committed SACCCS to reduce CO_2 emissions and to investigate the feasibility of CCS in South Africa or alternatively, improving energy efficiency and switching to non-fossil fuel based power generation as an essential if necessary in addressing the problem. However the existing energy infrastructure has a life expectancy of about fifty years and the impact of replacing this infrastructure prematurely would be damaging to the economy. The capture of CO_2 at the point of release and the deep underground storage (CCS) thereof will help to decrease CO_2 emissions. CCS technology is a way of bridging the gap from today until the existing energy infrastructure is replaced with non-fossil fuel based power generation. Therefore, IEA (2014) asserts that coal-fired power plants and heavy industries such as cement and iron/steel are responsible for the majority of GHG and particulate emissions worldwide. Combining these processes with CCS can significantly reduce GHG emissions. Despite the advantages, successful implementation of CCS is dependent on geographical, environmental, legal and cost considerations. Successful deployment of CCS is critically dependent on comprehensive policy support. A policy approach focusing on funding, costs and risks, subsidies/penalties, and technology support will move CCS from the pilot stage to widespread deployment. However, Norway - Mission to the UN (2009) believes that if the world is to achieve necessary climate goals, it is essential that developing countries make use of climate-friendly technology. Coal-fired power plants may account for nearly half of the world's power production in 20 years from now. CCS technology can help to reduce emissions from these plants by as much as 85-95 percent. To make these possible, developing countries need to develop the necessary policies and legislation. According to Kharecha and Hansen (2013), human caused climate change and air pollution remain a major global scale problems and these are mostly attributed to fossil fuel burning. Mitigation efforts for these problems should be undertaken concurrently in order to maximize effectiveness. Such efforts can be accomplished largely with currently available low-carbon and carbon-free alternative energy sources like nuclear power and renewable, as well as energy efficiency improvements. Likewise, without nuclear power, it will be even harder to mitigate human-caused climate change and air pollution. This is fundamentally because historical energy production data reveal that if nuclear power never existed, the energy would have almost certainly been supplied by fossil fuels which cause much higher air pollution related mortality and GHG emissions per unit. According to Kharecha and Hansen (2013) using historical production data, we calculate that global nuclear power has prevented an average of 1.84 million air pollution related deaths and 64 gigatonnes of CO2-equivalent (GtCO2-eq) GHG emissions that would have resulted from fossil fuel burning. On the basis of global projection data that take into account the effects of the Fukushima accident, we find that nuclear power could additionally prevent an average of 420 000 − 7.04 million deaths and 80 −240 GtCO2-eq emissions due to fossil fuels by midcentury, depending on which fuel it replaces. By contrast, we assess that large scale expansion of unconstrained natural gas use would not mitigate the climate problem and would cause far more deaths than expansion of nuclear power. Also, Markandya and Wilkinson (2007) noted that nuclear power has one of the lowest levels of GHG emissions per unit power production and one of the smallest levels of direct health effects, yet there are understandable fears about nuclear accidents, weapons uses of fissionable material and storage of waste. Nonetheless, it would add a substantial further barrier to the achievement of urgent reductions in GHG if the current 17 percent of world electricity generation from nuclear power were allowed to decline.

4.4 Issues on environmental degradation

Environmental degradation is the deterioration in environmental quality from ambient concentrations of pollutants and other activities and processes such as improper land use and natural disasters (OECD, 2001). According to Wikipedia (2014) and Wordpress (2005), it is the deterioration of the environment through depletion of resources such as air, water and soil; the destruction of ecosystems and the extinction of wildlife. It is defined as any change or disturbance to the environment perceived to be deleterious or undesirable. Similarly, environmental problems can be regional, such as acid rain or forest fires, or international, such as climate change or ozone layer loss. Or they can be national in character, such as overfishing, deforestation, overgrazing, soil erosion, over mining, biodiversity loss, and the loss of cultural heritage. Consequently, severe environmental degradation can affect a country's macroeconomic performance over the long run. If not dealt with appropriately and early, environmental problems could eventually impose a heavy burden on an economy and hamper growth (Gandhi, 1998). Topical issues on environmental degradation include:

1. Ozone layer depletion
2. Acid rain
3. Global warming
4. Consequences of radioactive waste

4.4.1 Ozone layer

The ozone layer is responsible for absorbing the ultraviolet rays and thereby preventing them from passing through the atmosphere of Earth. Ozone is a molecule containing three oxygen atoms (O_3). It is blue in colour and has a strong odour. Normal oxygen, which we breathe, has two oxygen atoms and is colourless and odourless. Ozone is much less common than normal oxygen. Out of each 10 million air molecules, about 2 million are normal oxygen (EPA, 2010). The ozone layer absorbs a portion of the radiation from the sun, preventing it from reaching the planet's surface. Most importantly, it absorbs the portion of ultraviolet type B light called UV-B which has been linked to many harmful effects, including various types of skin cancer, cataracts, and harm to some crops, certain materials, and some forms of marine life. This means that the effects of ozone depletion are not limited to humans only, as it can affect animals and plants as well. Therefore, ultraviolet rays of the Sun are associated with a number of health and environmentally related issues. According to AGBOM (2004), chlorofluorocarbon (CFC) contains chlorine, fluorine and carbon atoms. Hence, the UV radiation breaks oxygen molecules (O_2) into single oxygen atoms and the chlorine atom which is then free to attack another ozone molecule again. Therefore, the chain reaction continues as shown in equations 4.1. However, the overall effect is a decrease in the amount of ozone.

$$\begin{aligned} CFCl_3 + \text{UV Light} &= CFCl_2 + Cl \\ Cl + O_3 &= ClO + O_2 \\ ClO + O &= Cl + O_2 \end{aligned} \tag{4.1}$$

4.4.2 Acid Rain

Acid rain is a broad term referring to a mixture of wet and dry deposition (deposited material) from the atmosphere containing higher than normal amounts of nitric and sulphuric acids (EPA, 2012). Accordingly, the chemical forerunners of acid rain formation result from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) resulting from the combustion of fossil. Therefore, acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds. The result is a mild solution of sulphuric acid and nitric acid.

4.4.3 Global Warming

The increase in the average temperature of the Earth's atmosphere and its oceans, a gradual change that is believed to be permanently changing the Earth's climate (Livescience, 2012). However, the scientific consensus on climatic changes related to global warming is that the average temperature of the Earth has risen between 0.4 and 0.8 °C over the past 100 years. The increased volumes of CO_2 and other GHG released by the burning of fossil fuels, land clearing, agriculture, and other human activities, are believed to be the primary sources of the global warming that has occurred over the past 50 years. Scientists from the Intergovernmental panel on climate, carrying out global warming research have recently predicted that average global temperatures could increase between 1.4 and 5.8 °C by the year 2100. Changes resulting from global warming may include rising sea levels due to the melting of the polar ice caps, as well as an increase in occurrence and severity of storms and other severe weather events.

4.4.4 Consequences of radioactive waste management

There are a number of pervasive myths regarding both radiation and radioactive wastes. Some lead to regulation and actions which are counterproductive to human health and safety (WNA, 2012). Over the years, many views and concerns have been expressed in the media, by the public and other interested groups in relation to the nuclear industry and in particular its waste. For instance, questions have been raised about whether nuclear power should continue when the issue of how to deal with its waste has apparently not yet been resolved. Some of the views and concerns are as follows:

- The nuclear industry still has no solution to the 'waste problem', so cannot expect support for construction of new plants until this is remedied.
- The transportation of this waste poses an unacceptable risk to people and the environment.
- Plutonium is the most dangerous material in the world.
- There is a potential terrorist threat to the large volumes of radioactive wastes currently being stored and the risk that this waste could leak or be dispersed as a result of terrorist action.
- Nuclear wastes are hazardous for tens of thousands of years. This clearly is unprecedented and poses a huge threat to our future generations.
- Even if put into a geological repository, the waste might emerge and threaten future generations.
- Man-made radiation differs from natural radiation.
- Nobody knows the true costs of waste management. The costs are so high that nuclear power can never be economic.

- The waste should be disposed of into space
- Nuclear waste should be transmuted into harmless materials.

4.4.4.1 International challenges on radioactive waste management

One of the most difficult problems associated with nuclear power is the disposal of wastes produced during mining, fuel production, and reactor operation (Cunningham and Cunningham, 2012). Hence, how these wastes are managed may ultimately be the overriding obstacle to nuclear power. Presently, enormous and abandoned mine tailings in all uranium producing countries represent serious waste disposal problems. For instance 1,000 tons of uranium fuel typically generates 100,000 tons tailings and 3.5 million litres of liquid waste and there are approximately 200 million tons of radioactive waste in piles around mines and processing plants especially in the USA. This material is carried by the wind and washes into streams, contaminating areas far from its original source. In addition to these, there are 100,000 tons of low level wastes from contaminated tools, clothing, building materials and 77, 000 tons of high level wastes. The high-level wastes consist mainly of spent fuel rods from commercial nuclear power plants and assorted wastes from nuclear weapons production. While they are still intensely radioactive, spent fuel assemblies are stored in deep, water-filled pools at the power plants. These pools were originally intended only as temporary storage until the wastes were shipped to reprocessing centres or permanent disposal sites. Secondly, most nuclear power plants are built near rivers, lakes or sea coasts and extremely toxic radioactive materials could spread quickly over large areas if leakages occur. And the old NPP after their useful life of 30 yrs for older generations and 40-60 yrs for new generations which require decommissioning. Most parts of the decommissioned plant are radioactive; this may include the reactor, pipes and even the meter thick steel reinforced concrete containment building. The contaminated waste from decommissioned plants constitutes serious environmental problem.

4.4.4.2 South Africa's Radioactive Waste Disposal Facility (Vaalputs)

Vaalputs hosts the radioactive waste disposal facility managed by South African Nuclear Energy Corporation (NECSA).The need to have this facility was identified in the mid-1970 when the country was planning her NPP at Koeberg. By 1980 a countrywide survey of potential disposal sites was undertaken and finally resulted in the selection of the present Vaalputs site. The site covers 10, 000 hectares and was acquired and prepared by NECSA on behalf of the State. Figure 4.4 shows the aerial view of the disposal trenches. It was issued an operating license for Low and Intermediate Radioactive waste disposal by National Nuclear Regulator (NNR) since 1986 (NECSA, 1985). However, in South Africa radioactive waste is produced by the nuclear fuel cycle. But there is also waste due to decommissioning of NECSA nuclear fuel production facilities which was shutdown since 1997, waste from NECSA's Safari research reactor at Pelindaba which produces spent fuel, operational waste from radioisotopes production activities at NECSA and iThemba LABS and NORM waste from mining, minerals processing, industries and the medical sector are classified as NECSA waste while operational waste from Koeberg NPP are referred to as Eskom waste. Accordingly, all the surface stored radioactive waste at Pelindaba will be moved to a centralized storage facility on site called the Pelstore. Hence, the spent fuel from the Safari reactor, the radioactive waste from Hot Cell Complex and Isotope production are presently stored in a pipe store facility at Pelindaba. Also, historical waste, consisting of combinations of low and intermediate level waste as well as spent radiation sources are presently stored in covered trenches at Thabana on the Pelindaba site (NECSA, 2012) while Eskom Koeberg operational waste (low and intermediate level waste) is stored temporally at Koeberg before being transferred to Vaalputs for final disposal. Vaalputs is located approximately 100 km south-east of Springbok in the Northern Cape Province as shown in Figure 4.3 on the location map.

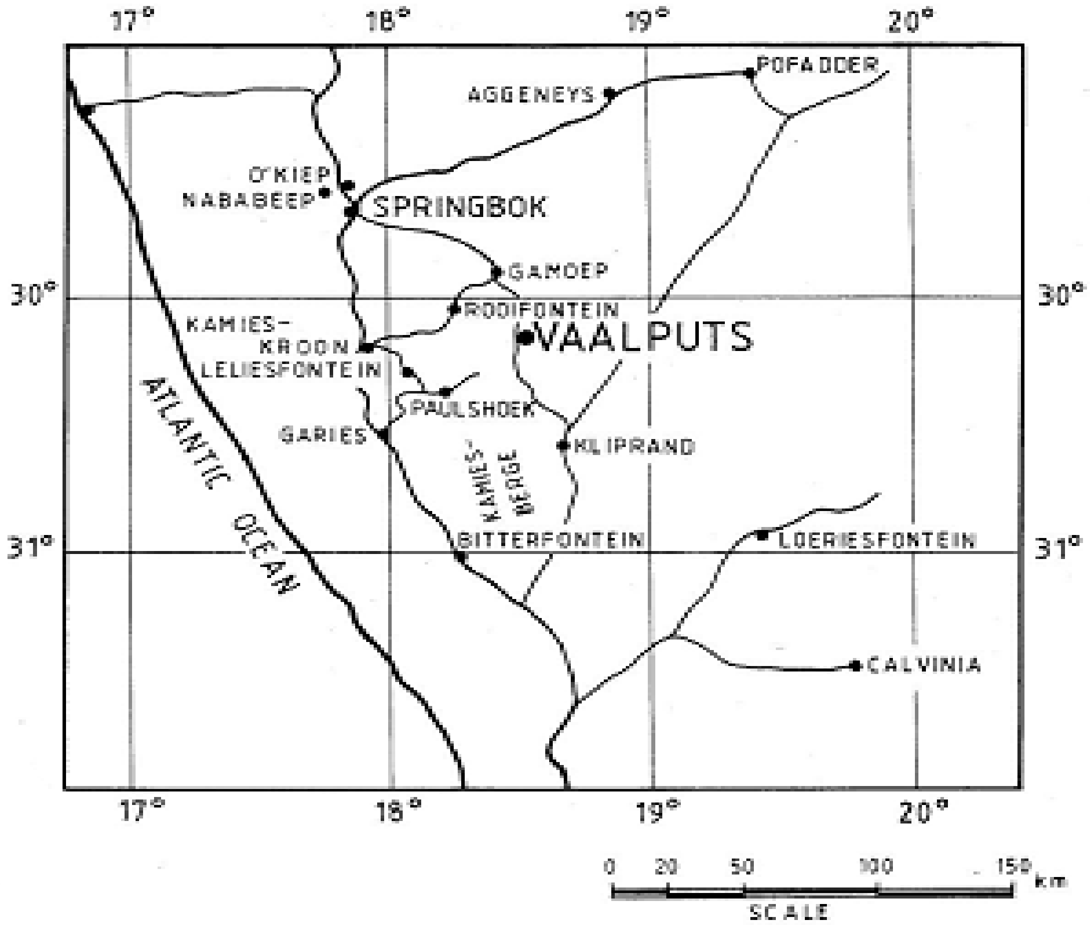


Figure 4.3: Location of Vaalputs (NECSA, 1985)

Figure 4.4: Aerial view showing disposal trenches (NNR, 2011)

4.4.4.3 United States Radioactive Waste Disposal Facility (Yucca Mountain)

In an effort to find a solution to the permanent storage problem in US for instance, the congress in 1987 amended the Nuclear Waste Policy Act, directing the Energy Department (USDOE) to exclusively study Nevada's Yucca Mountain, a remote desert location, as the site for a potential repository for geologic disposal of used nuclear fuel (NEI, 2014). After two decades of site studies, the federal government filed a construction license application in 2008 for a repository at Yucca Mountain. However, President Obama in 2010 stopped the Yucca Mountain license review and empanelled a study commission to recommend a new policy for the long-term management of used fuel and high-level radioactive waste. One of the recommendations of the Commission was a stakeholder participation which involves interaction with national, interest groups, states, communities and tribes that would directly be within the operation of the facilities (BRC, 2012). This will promote public confidence, commitment in the safety of disposal of such waste and spent fuel. Since this was lacking from beginning, it led to the shutdown of the facility.

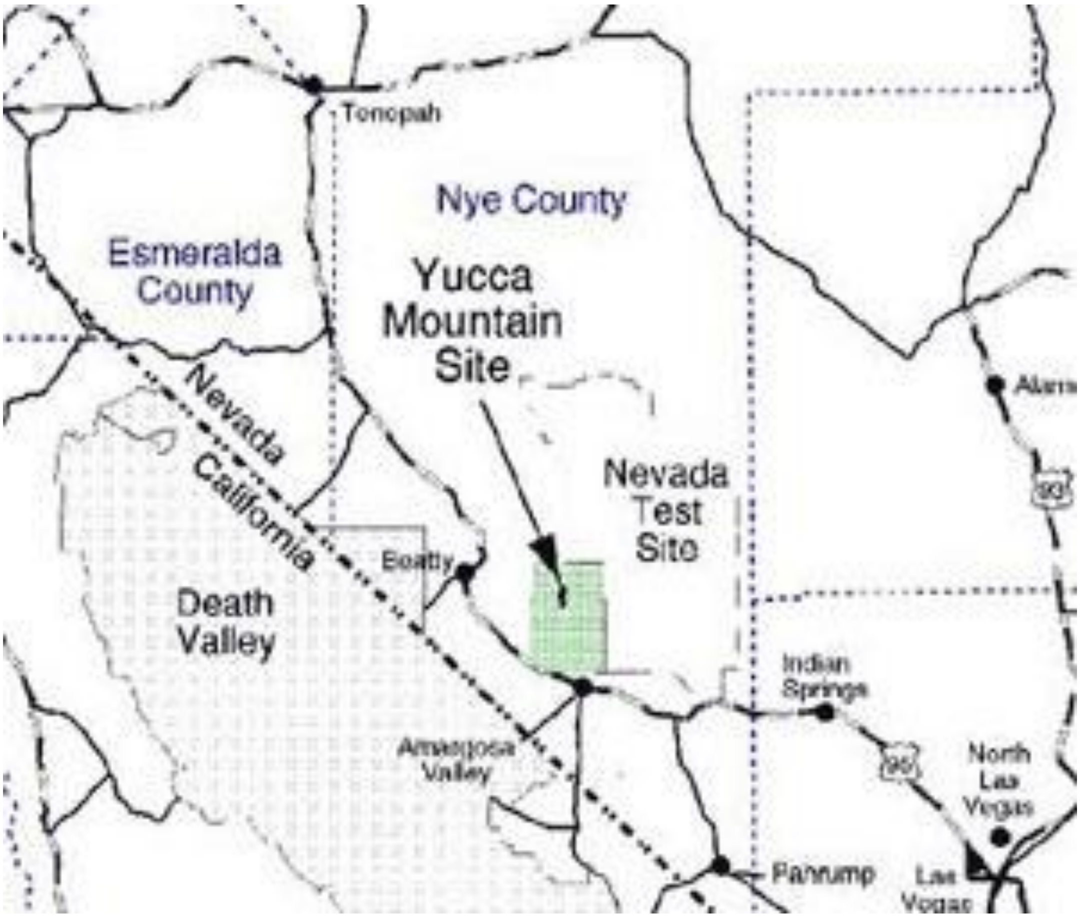


Figure 4.5: Location of Yucca Mountain (U.S.NRC, 2012a).

Fig 4.5 above shows the location of Yucca Mountain, in relation to major highways; surrounding counties, cities, and towns in Nevada and California; the Nevada Test Site; and Death Valley National Park. Yucca Mountain is located on Federal land in Nye County in southern Nevada, approximately 160 km (100 miles) northwest of Las Vegas (U.S.NRC, 2012a).

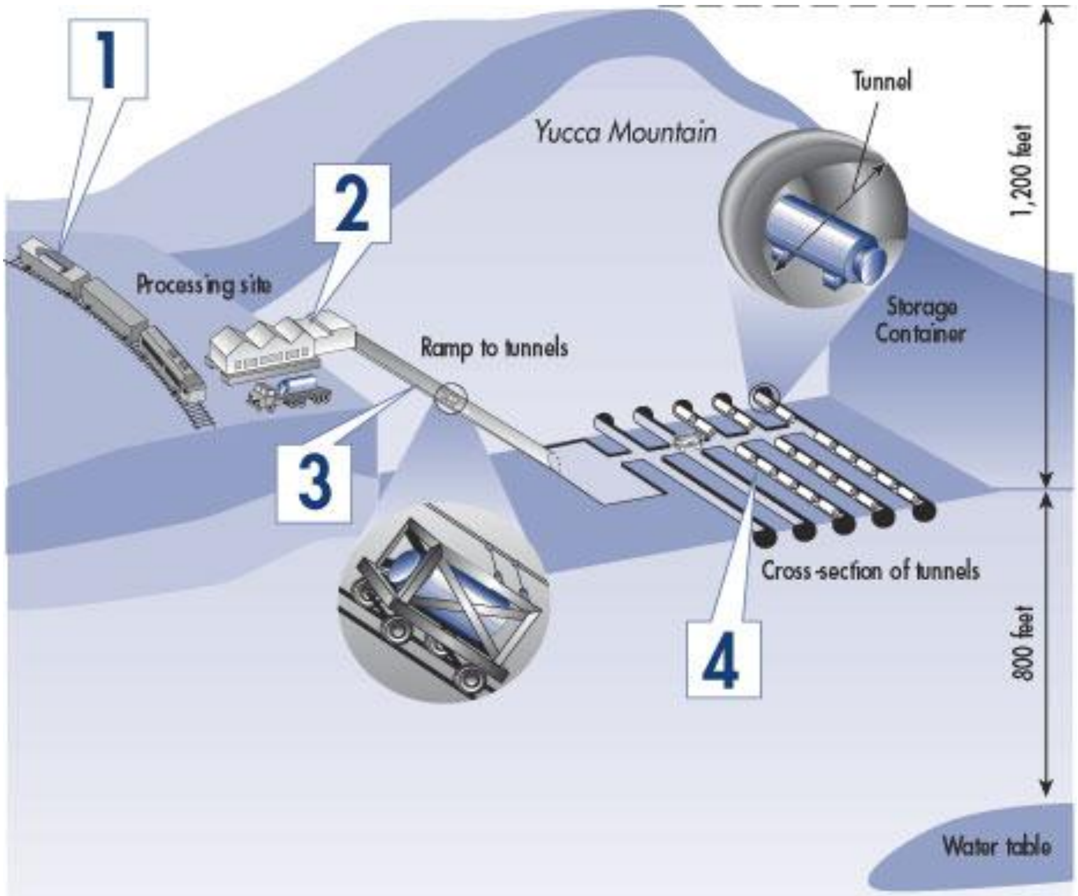


Figure 4.6: Conceptual Design of Yucca Mountain Disposal Plan (U.S.NRC, 2012b)

Fig 4.6 is the Conceptual Design of Yucca Mountain Disposal Plan showing Canisters of waste, sealed in special casks, being shipped to the site by truck or train at Point 1. Then at Point 2 shipping casks are removed, and the inner tube with the waste is placed in a steel, multilayered storage container while at Point 3, an automated system sends storage containers underground to the tunnels. And finally at Point 4 containers are stored along the tunnels on their side.

4.5 Environmental Protection and Sustainable Development

Environment is defined differently by different authors. Environment is basically defined as everything that surrounds us or inclusively as the complex set of physical, geographic, biological, social, cultural and political conditions that surrounds an individual or organism that ultimately determines its form and the nature of its survival (Robert, 2010). While according to OECD (2003) environmental protection refers to any activity that maintains or restores the quality of environmental media through preventing the emission of pollutants or reducing the presence of polluting substances in environmental media. Therefore, environmental protection encompasses the careful use of land, air, water, minerals, plants and animal resources and other natural resources so that they are not destroyed. The modern concept of Sustainable development however was most clearly articulated in 1987 through the publication of a United Nations report entitled our “common future”, also known as the Brundtland report (Drexhage and Murphy, 2010). It defines Sustainable Development as the “development which meets the needs of the present without compromising the ability of future generations to meet their own needs”. The concept of sustainable development needed strengthening by an International legal framework and this was accomplished in June, 1992 In Rio-De-Jeneiro, Brazil at the United Nations Conference on Environment and Development also known as the Earth Summit. At this summit, it was agreed and accepted that development, as striven for with the unrestricted increase in material wealth, has placed mankind’s survival at risk because it exceeded the earth’s capacity as an ecosystem. Therefore, five agreements emerged from the summit which was referred to as Earth summit:

- The Rio Declaration on Environment and Development – a series of principles defining the rights and responsibilities of States.
- Agenda 21 - a comprehensive program of action for global action in all areas of sustainable development.
- Convention on Biological Diversity.
- The statement of forest Principles - a set of principles to underlie the sustainable management of forests worldwide.
- The United Nations Framework Convention on Climate Change (UNFCC).

The Rio-Declaration states that the right to development must be fulfilled so as to equitably meet developmental needs of present and future generations (UNESCO (1992). Accordingly, it is this linking of the environment and development which is expressed by the term “Sustainable Development” which is an increase of a country’s wealth production (gross income), that does not entail parallel reduction or degradation of its natural capital but preserved and passed onto future generations unscathed. However, environmental protection requires effective planning and is guided by seven principles:

4.5.1 Trust doctrine principle:

In the Common Law of jurisprudence, a trust is "the legal relationship between one person having an equitable ownership in property and another person owning the legal title to such property." In the context of the Public Trust Doctrine, the legal title is vested in the state (country) and the equitable title in the public. Thus the state is responsible as trustee to manage the property in the interest of the public (Bento, 2009).

4.5.2 Precautionary principle (Halt adverse projects):

The precautionary principle” is a notion which supports taking protective action before there is complete scientific proof of a risk; which means, action should not be delayed simply because full scientific information is lacking. The “precautionary principle” or precautionary approach has been incorporated into several international environmental agreements, and some claim that it is now recognized as a general principle of international environmental law (WTO, 2014).

4.5.3 Principle of intergenerational equity (Sustainable development):

The Rio Declaration recognized a number of principles of equity. However, foremost of these are the principles of inter- and intra-generational equity (Millar, 2014). Inter-generational equity is defined as meaning that the present generation should ensure that the health, diversity and productivity of the environment are maintained or enhanced for the benefit of future generations.

4.5.4 Principle of intra-generational equity (Access to all):

The conservation of access principle provides that each generation should give its members equitable rights that access the legacy of past generations and should conserve this access for future generations (Millar, 2014).

4.5.5 Subsidiarity principle (Consult):

The subsidiarity principle is designed to ensure that decisions are taken as closely as possible to the citizen. In areas which do not fall within its exclusive competence, the community shall take action, in accordance with the principle of subsidiarity, only if and in so far as the objectives of the proposed action cannot be sufficiently achieved by the member States and can therefore, by reason of the scale or effects of the proposed action, be better achieved by the Community (Paul, 1994).

4.5.6 Polluter pays principle:

The ‘polluter pays principle’ states that whoever is responsible for damage to the environment should bear the costs associated with it (Cordato, 2001).

4.5.7 User pays principle:

The user-pay principle requires that users pay the full economic costs of the goods and services they consume. Equity, efficiency and water conservation are promoted by the application of the user-pay principle (Hanke, 1987).

4.6 International Environmental Institutions

In order to safeguard the environment, the following International institutions were established, which include:

4.6.1 United Nations Environmental Programme (UNEP):

UNEP acts as a catalyst, advocate, educator and facilitator to promote the wise use and sustainable development of the global environment (UNEP, 2003). Accordingly, it is the principal United Nations (UN) body in the field of the environment with the role as the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the UN system and serves as an authoritative advocate for the global environment. It therefore assists Governments and the international community in general to identify environmental problems of regional or global significance, to build and disseminate the knowledge base concerning the identified problems, facilitates in building international consensus on measures to address such problems and promotes the implementation of such measures through the promotion of international cooperation etc.

4.6.2 United Nations, Educational, Scientific and Cultural Organization (UNESCO):

It's the intellectual agency of the United Nations in mobilizing for education so that every child has access to quality education as a fundamental human right and as a prerequisite for human development (UNESCO, 2012)

4.6.3 Organization for the prohibition of Chemical Weapons (OPCW):

The OPCW is the implementing body of the Chemical Weapons Convention (CWC), which entered into force in 1997 working together to achieve a world free from chemical weapons. They share the collective goal of preventing chemistry from ever again being used for warfare, thereby strengthening international security (OPCW, 2010).

4.6.4 Comprehensive Nuclear Test Ban Treaty Organization (CTBTO):

The comprehensive Nuclear-Test Ban Treaty (CTBT) bans nuclear explosions by everyone, everywhere: on the earth surface, in the atmosphere, underwater and underground. It makes it very difficult for countries to develop nuclear bombs for the first time, or for countries that already have them, to make more powerful bombs. It also prevents the huge damage caused by radioactivity from nuclear explosions to humans, animal and plants (CTBTO, 2010).

4.6.5 International Atomic Energy Agency (IAEA):

The IAEA is the world's centre of cooperation in the nuclear field. It was set up as the world's "Atoms for Peace" organization in 1957 within the UN family. The agency works with its member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies (IAEA, 2014).

4.6.6 International Institute for Environment and Development (IIED):

IIED is one of the world's most influential international development and environment policy research organizations founded in 1971 by economist Barbara Ward, who forged the concept and cause of sustainable development (IIED, 2014).

4.6.7 Centre for our common future (Brundtland Commission):

Formally known as the World Commission on Environment and Development (WCED), the Brundtland Commission's mission is to unite countries to pursue sustainable development together (Wikipedia, 2014).

4.6.8 International Union for the Conservation of Nature (IUCN):

The International Union for Conservation of Nature is the world's oldest and largest global environmental organization founded in 1948. Today, it is the largest professional conservation network which is the leading authority on environment and sustainable development (IUCN, 2014).

4.6.9 United Nations Commission on Sustainable Development (CSD):

The CSD was established by the UN General Assembly in December 1992 to ensure effective follow-up of UN Conference on Environment and Development (UNCED), also known as the Earth Summit. At the UN Conference on Sustainable Development (Rio+20), member States agreed to establish a high level political forum that will subsequently replace the Commission on Sustainable Development (CSD, 2014).

4.7 Conventions and Agreements

The agency above facilitates environmental protection through the following conventions and agreements (UNEP, 2003):

4.7.1 Rio Conventions:

4.7.1.1 Convention on Biological Diversity (CBD) (1992–1993):

The CBD entered into force on 29 December 1993 with 3 main objectives:

- The conservation of biological diversity.
- The sustainable use of the components of biological diversity.
- The fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

4.7.1.2 United Nations Framework Convention on Climate Change (UNFCC) (1992–1994):

This incorporates the Kyoto Protocol with the following key objectives:

- Stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.
- And with KP, it commits industrialized countries to stabilize GHG emissions based on the principles of the Convention. It only binds developed countries because it recognizes that they are largely responsible for the current high levels of GHG emissions in the

atmosphere, which are the result of more than 150 years of industrial activity.

4.7.1.3 United Nations Convention to Combat Desertification (UNCCD) (1994–1996):

- The UNCCD is the sole legally binding international agreement linking environment and development to sustainable land management.
- This convention is to forge a global partnership to reverse and prevent desertification/land degradation and to mitigate the effects of drought in affected areas in order to support poverty reduction and environmental sustainability.

4.7.1.4 Transboundary Watercourses and International Lakes (Water Convention) (1992–1996):

Water Convention is intended to strengthen national measures for the protection and ecologically sound management of transboundary surface waters and groundwater. The Convention obliges Parties to prevent, control and reduce transboundary impact, use transboundary waters in a reasonable and equitable way and ensure their sustainable management.

- **Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1989–1992):**

  The objective of the Basel Convention is to protect human health and the environment against the adverse effects of hazardous wastes. The provisions of the convention centre on the following principal aims:

  i. The reduction of hazardous waste generation and the promotion of environmentally sound management of hazardous wastes, wherever the place of disposal.
  ii. The restriction of transboundary movements of hazardous wastes except where it is perceived to be in accordance with the principles of environmentally sound management.
  iii. A regulatory system applying to cases where transboundary movements are permissible.

4.7.1.5 Rotterdam Convention on the Prior Informed Consent Procedures for Certain Hazardous Chemicals and Pesticides in International Trade (1998-2004):

The objectives of the conventions are:

- To promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm.

- To contribute to the environmentally sound use of those hazardous chemicals, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export and by disseminating these decisions to Parties.

4.7.1.6 Stockholm Convention on Persistent Organic Pollutants (COP) (2001–2004):

The objective of the Stockholm Convention is to protect human health and the environment from persistent organic pollutants. The Stockholm Convention on Persistent Organic Pollutants is a global treaty to protect human health and the environment from chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of humans and wildlife, and have harmful impacts on human health or on the environment.

4.8 Sustainability in FBR and HTR

Fast reactors use the uranium-238 as well as the fissile U-235 isotope used in most reactors and if they are designed to produce more plutonium than they consume, they are called FBR (WNA, 2012). It can also burn long-lived actinides which are recovered from used fuel out of ordinary reactors. Therefore, several countries have R&D programs for improved Fast Neutron Reactors (FNR). So far, there has been progress on the technical front, but the economics of FNR still depends on the value of the plutonium fuel which is bred and used, relative to the cost of fresh uranium. Also there is international concern over the disposal of ex-military plutonium; therefore there are proposals to use fast reactors as burners for this purpose. In both respects the technology is important for long-term considerations of world energy sustainability. According to IAEA (2013), several countries are engaged in intense R&D programmes for the development of fast reactors innovative GENIV concepts as discussed earlier in Chapter 2. However, the technology relies upon a closed fuel cycle, which means that spent fuel is reprocessed after its initial use in a reactor. Instead of sending the spent fuel into storage and eventually long-term disposal, the materials are reused, particularly, the fertile material that is not fissionable, but it can be converted into fissionable material by exposure to radiation in a reactor. Once converted into fissile material, it will be consumed in the chain reaction. This conversion from fertile to fissionable material significantly improves nuclear fuel efficiency. Therefore, fast reactors can thus be used to breed more fissile material than they consume or to burn nuclear waste or for a combination of these two tasks and they offer significant benefits in making nuclear energy production more sustainable. Hence, the fast breeder technology has the potential to make the production of energy from uranium 100 times more efficient than with the existing thermal reactor, reducing the amount and toxicity of radioactive waste, as well as the heat emanating from the waste and also shortening the waste's hazardous lifetime span (Monti, 2013). Accordingly, with the fast reactors operating in a closed fuel cycle, using currently new uranium resources would be able to provide energy for thousands of years as well as easing concerns about waste. More so, fast reactors are versatile and flexible technology that promises to create or breed more fuel by converting nuclear waste into fissile material. Hong *et al*. (2006) have noted that the HTR innovation concept is an advanced reactor concept also that can meet the energy and environmental needs of future generations as defined under the GENIV Initiative. It is suitable for burning Plutonium most effectively, as well as to minimize the amount of it to be disposed. And with the use of a Thorium based fuel cycle, would produce a small amount of toxic fuel waste or long-lived radiotoxic waste, both of which contribute substantially to anxieties about disposal of nuclear waste. International interest has been growing in HTR technology in recent years due to a growing recognition of the potential of HTR designs to provide high efficiency, cost effective electricity generation appropriate for the conditions in developing countries, and in the longer term to provide a source of process heat. Additionally, the Thorium based fuel cycles not only produce electricity, but also replace the Plutonium with denatured uranium which could be used in other reactors in the future.

4.9 Sustainability in Coal and Gas-Fired Power Plants

There is no perfect energy source. Each and every one has its own advantages and compromises (Siegel, 2012). However, the least destructive form of clean coal is underground coal gasification (UCG). This is where the coal is left in the ground and converted to gas by chemical means and then sucked up to the surface where it is burnt. Most of these projects include capturing the CO_2 and then sequestering it. According to WCA (2014) coal plays a vital role in electricity generation worldwide. A coal-fired power plant currently fuel 41% of global electricity and constitutes 85% of the power generation output of Republic of South Africa (Eskom, 2012). The country's coal resources were estimated at around 34 billion tonnes – 95% of African coal reserves and 4% of world reserves. Coal provided an estimated 72% share of the country's total primary energy supply in 2007 and accounts for about 85% of electricity generation capacity (Zero, 2014). However, coal is also a major feedstock for the country's synthetic fuel industry. Energy supply is therefore heavily carbon-intensive. Hence, the demand for energy is rising and the country is meeting this challenge by building more coal power plants as part of its developmental strategy for electricity supply between 2010 and 2030 which includes 9.6GW from nuclear power, 6.3GW from coal (in addition to 10GW already under construction), 17.8GW from renewable and 8.9GW from imported hydro and gas turbines. With this strategy, by 2030, South Africa's electricity generation capacity will increase from 260 TWh to 454 TWh. In as much as coal is in abundant supply with concentration in industrialized countries, relatively inexpensive with high load factor and mature industry, it has a lot of demerits to the environment as highlighted in Table 4.2 below:

Table 4.2: Comparison between Coal and Nuclear (Cohen, 1986)

<table>
<tr><th>S/N</th><th>Coal</th><th>Nuclear</th></tr>
<tr><td>1</td><td>The most abundant dangerous gas emitted in coal burning is sulphur dioxide, discharged at a rate of a ton every five minutes. According to a National Academy of Sciences study commissioned by a U.S. Senate Committee, the annual releases from a single plant results in 25 deaths, 60,000 cases of respiratory disease, and $25 million in property damage.</td><td rowspan="6">The waste from a nuclear plant is different from these coal-burning wastes in two very spectacular ways. The first is in the quantities involved. The second spectacular difference is that the nuclear wastes are radioactive, providing a health threat due to the radiation they emit, whereas the principal danger to health from coal wastes arise from their chemical activity</td></tr>
<tr><td>2</td><td>Another type of gaseous pollutant from coal burning is nitrogen oxides, best known as the principal pollutant from automobiles. The reason for cars having expensive pollution control equipment and requiring lead-free gasoline. A single plant emits as much nitrogen oxide as 200,000 automobiles.</td></tr>
<tr><td>3</td><td>Then there is the smoke, which consists of tiny solid particles. There is a widespread impression that the smoke from coal burning has been largely eliminated, but this is true only of the large particles that provide visible dirt. The situation is much less favourable regarding the smaller particles that are far more harmful because they can get past the body's defences and reach the deep lung.</td></tr>
<tr><td>4</td><td>Another class of pollutant released in the burning of coal is Polycyclic hydrocarbons, a type of chemical that can cause cancer and genetic defects in later generations; the best known of these is benzpyrene, which is believed to be the principal cancer-causing agent in cigarette smoke.</td></tr>
<tr><td>5</td><td>Then there is the ash, the bulk solid material produced at a rate of 1000 pounds per minute, which is, in its disposal, responsible for some very difficult environmental problems, and for some serious long-term health effects.</td></tr>
<tr><td>6</td><td>There is uranium and thorium, naturally radioactive materials which serve as sources of radon gas with health effects, exceeding those of all radioactivities's released from nuclear plants.</td></tr>
<tr><td>7</td><td>A more realistic comparison would be on the basis of simple, cheap, and easy disposal techniques. For coal burning this would be to use no air pollution control measures and simply release the wastes without inhibition.</td><td>For nuclear waste, a simple, quick, and easy disposal method would be to convert the waste into a glass, a technology that is well in hand-and simply drop it into the ocean at random locations.</td></tr>
<tr><td>8</td><td>The consequences of release of air pollution, as given above, are 25 fatalities per year from each plant.</td><td>The waste produced by one power plant in one year would eventually cause an average total of 0.6 fatalities; Incidentally, this disposal technique would do no harm to ocean ecology.</td></tr>
</table>

4.9.1 Underground Coal Gasification in South Africa

UCG is a method of converting coal still in the ground into a combustible gas which can be used for industrial heating, power generation or the manufacture of hydrogen, synthetic natural gas or diesel fuel (WorldCoal, 2014; Lincenergy, 2011). The basic UCG process involves drilling two wells into the coal mine, one for injection of the oxidants (water/air or water/oxygen mixtures) and another well some distance away to bring the product gas to the surface. Hence, the coal at the base of the first well is then heated to temperatures that would normally cause the coal to burn. According to WorldCoal (2014), through careful regulation of the oxidant flow, the coal does not burn but rather separates into the syngas which is then drawn out of the second well. Therefore, UCG turns this resource into high value products by providing clean power, liquid fuels, syngas, fertilisers and other chemical feedstock. The technology also allows countries that are endowed with coal to fully utilize their resource from otherwise unrecoverable coal deposits in an economically viable and environmentally safe way thereby presents the opportunity to reduce emissions as there are fewer surface emissions. However, it could also have synergies with Carbon Capture and Storage (CCS) as the CO_2 could be stored in the coal cavity after gasification. Accordingly, there has been significant renewed interest in UCG technology in recent time (WorldCoal, 2014):

- China has about 30 projects in different phases of preparation that use UCG.
- India plans to use UCG to access an estimated 350 billion tonnes of coal. In 2007 India compiled a 93-page status report on UCG that highlighted interest from many of the country's biggest companies.
- South African companies Sasol and Eskom both have UCG pilot facilities that have been operating for some time, giving valuable information and data.
- In Australia, Linc Energy has the Chinchilla site, which first started operating in 2000. Carbon Energy has completed a successful 100 day commercial scale study in Bloodwood, Creek, Australia in 2008.

Currently, coal provides much of South Africa’s primary energy needs and UCG as a potential clean coal technology enables mitigation of the environmental consequence of this dependence while its alternatives are being developed (Eskom, 2014). Modularity is shown by the fact that Eskom’s demonstration plant gas turbine is in the same size range as those proposed for the envisaged commercial plant. The mining and gas treatment modules will also be sized similarly to their commercial plant successors. This modularity will assist in reducing scale-up risk and in expediting the technology uptake. Accordingly, UCG enables utilization of substantial coal resources that are not yet mined in South Africa, which has obvious primary energy inventory advantages. There are also advantages due to the broader geographic spread of such coal. This significantly improved mining efficiency of UCG, as compared to other conventional underground coal mining technologies. It also has obvious primary energy inventory advantages as well as safety advantages as people do not need to work underground. UCG effectively shortens the coal value chain by reducing the number of steps between mining the energy resource and generating electricity. This has obvious advantages for the cost of electricity as well as additional less obvious advantages for safety and the environment (due to the absence of handling and transportation of solids). According to Kolber (2013), Eskom would start work on larger scale on the UCG plant at its Majuba power station, in Mpumalanga, as soon as environmental approvals were received. Accordingly, the power utility ran a small-scale pilot successfully for two years, co-firing the Majuba power station with gas and coal, the next step of the project would make use of a larger gasifier to feed larger amounts of gas into Majuba. Moreover, during this second phase of the pilot study, the gas supplied to Majuba would still be co-fired with coal, with the third phase planned to only use gas that would be put into a gas turbine. Thus, the project has been a success so far and UCG presents a big opportunity for South Africa as it opens up the possibility to exploit coal reserves that were previously not utilized. Furthermore, with UCG, the coal at Majuba, as well as many other deposits that may be too fragmented and not economical to mine using traditional methods will now be possible thereby significantly increasing South Africa's coal reserves.

4.10 Conclusion

We have quite acknowledged so far that the environmental resources available to man, animals, plants and the entire ecosystem is very vulnerable and requires strategic planning to carter for our generation and subsequent ones unborn. To achieve this, we need to imbibe the concept of sustainable development and nuclear energy is the answer as it does not contribute to environmental pollution as coal and gas fired power plants. In addition to safeguarding the environment from degradation, we highlighted some of the international established institutions with their main objective of protecting the environment and promote sustainable development. Accordingly, to further enhance the sustainability, in Chapter 5, we introduced the design concept on safety, security and safeguard in any nuclear facility as an essential tool in protecting life, property and environment against the effect of ionizing radiation.

CHAPTER FIVE

NUCLEAR SAFETY, SECURITY AND SAFEGUARD DESIGN

5.1 Introduction

This chapter discusses the design priorities in any nuclear facility. Obviously, due to the need and interest in development of nuclear energy capabilities, the potential for malicious use of nuclear and radioactive materials has expanded and heightened. This increase in the nuclear power programs will likely include the construction of a variety of nuclear facilities that could become new potential targets for terrorists and other dangerous actors. According to Boureston and Semmel (2010), an international Symposium held at Vienna, Austria between March 30 to April 3, 2009 noted availability of credible evidence that terrorists are interested in acquiring and using nuclear material to build a rudimentary nuclear explosive device, and in constructing a radiological dispersal device that could be used to sabotage nuclear facilities or places where radioactive substances are used, stored, or transported. Also, the physical protection against the theft or unauthorized use of nuclear material and against the sabotage of nuclear material and facilities by individuals or groups of persons has become a matter of increased concern nationally and internationally (Carmona, 2005). Similarly, as a result of a GHG emission and the need to increase energy demand, a global trend to introduce nuclear power into both developed and emerging countries has been growing. This also increases concern from the international society about the consequences and impact on the non-proliferation regime. Therefore, introducing non-proliferation mechanisms in an efficient and effective manner will require not only a balance between peaceful use of nuclear energy and nuclear non-proliferation, but also inter-cooperation among the 3S practices and implementation (Rojavin *et al*., 2011). Therefore, fostering a 3S understanding and culture will be important for establishing a stable foundation from which to successfully implement and sustain nuclear energy programs and maintain their public acceptance. Though nuclear industry maintains very high safety standards, the potential for an unintentional reactor malfunction and release of radioactive materials into the environment represents a significant risk. This risk is also associated with the medical use of radioactive materials, as well as storage and transport of spent nuclear fuels.

5.2 Physical Security and Protection

The Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225) document of IAEA has long been considered as the internationally accepted standard for nuclear physical protection, and the practical complement to the Convention on the Physical Protection of Nuclear Material. However, it is not a legally binding instrument as such, but it is given legally binding effect in some bilateral nuclear safeguards agreements that prescribe Information Circular (INFCIRC/225) as the standard to be applied to nuclear material supplied under such agreements (Everton *et al*., 2010). The physical protection which is also referred to as physical security consists of a variety of measures to protect nuclear facilities and material against sabotage, theft, diversion, and terrorist attacks. The United States Nuclear Regulatory Commission (USNRC) and its licensees use a graded approach for physical protection, consistent with the significance of the facilities or material to be protected. In so doing, the USNRC establishes the regulatory requirements and assesses compliance, and licensees are responsible for providing the protection (USNRC, 2013). Accordingly, the nuclear facilities that require physical protection include nuclear reactors, fuel cycle facilities, and spent fuel storage and disposal facilities.

5.2.1 Physical Protection System (PPS)

A PPS integrates people, procedures, and equipment for the protection of assets or facilities against theft, sabotage, and terrorist attacks. Hence, the design of an effective PPS requires a methodical approach in which the designer weighs the objectives of the PPS against available resources and then evaluates the proposed design to determine how well it meets the objectives. Without this kind of careful assessment, the PPS might waste valuable resources on unnecessary protection or, worse yet, fail to provide adequate protection at critical points of the facility (Xu *et al*., 2014; Garcia, 2008; NSSPI, 2014). However, theft, sabotage, and terrorist attacks at a facility may be prevented in two ways: by deterring the adversary or by defeating the adversary. Deterrence occurs by implementing measures that are perceived by potential adversaries as too difficult to defeat. It makes the facility an unattractive target, so the adversary abandons or never attempts an attack. Examples of deterrents are the presence of security guards in parking lots, adequate lighting at night, posting of signs, and the use of barriers, such as bars on windows. These are features that are often implemented with no additional layers of protection in the event of an attack. Therefore, deterrence can be very helpful in discouraging attacks by adversaries. However, it is less useful against an adversary who chooses to attack anyway. According to Bakr and Hamed (2009), the ultimate goal of a PPS is to prevent the accomplishment of overt or covert malevolent actions. Typical objectives are to prevent sabotage of critical equipment, deter theft of assets or information from within the facility, and protect people. A PPS must accomplish its objectives by either deterrence or a combination of detection, delay and response. Fig 5.1 below is a design and evaluation process for PPS. The process starts with determining objectives, then designing a system to meet the objectives. It ends with an evaluation of how well the system performs compared to the objectives.

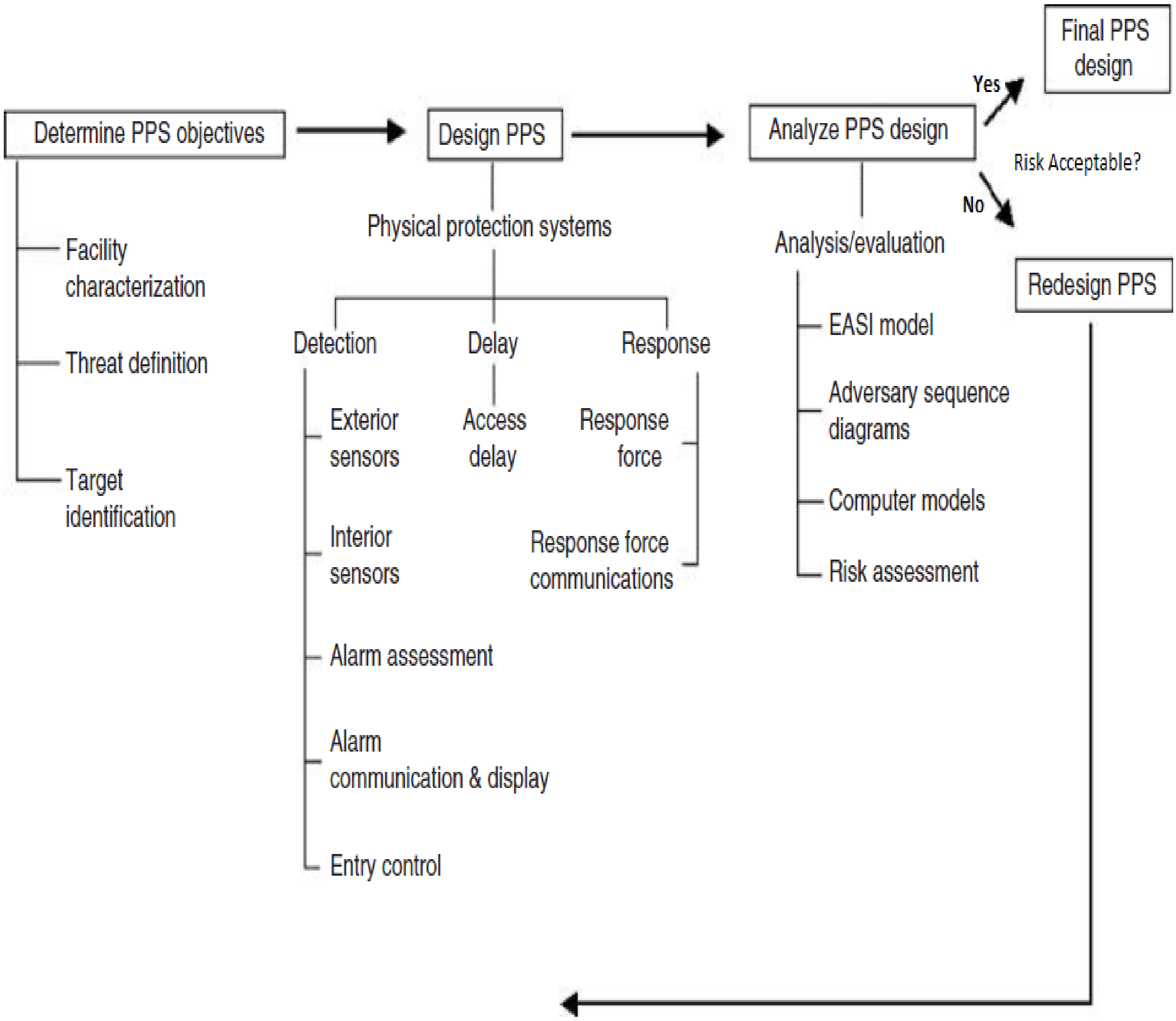


Figure 5.1: Design and evaluation process for physical protection systems (Garcia, 2008; NSSPI, 2014)

Adversaries can be classified into three categories, outsiders, insiders and outsiders working in collusion with insiders (IAEA, 2008; Garcia, 2008). Accordingly, each class of adversary with the full range of tactics of deceit, force, stealth, or any combination of these should be expected. Deceit is the attempted defeat of a security system by using false authorization and identification, force is the overt, the forcible attempt to overcome a security system and stealth is any attempt to defeat the detection system and enter the facility covertly. For any given facility there may be several threats, such as a criminal outsider, a disgruntled employee, competitors, or some combination of these, so the PPS must be designed to protect against all of these threats. Therefore, the best option in designing a new PPS is to combine such elements as fences, barriers, sensors, procedures, communication devices, and security personnel in order to achieve the protection objectives necessary. The overall design should meet its objectives within the operational, safety, legal, and economic constraints of the facility. The primary functions of a PPS are detection, delay and response by security personnel and an effective PPS must accomplish these objectives by either deterrence or a combination of detection, delay and response (Garcia, 2008).

Detection: This is the discovery of an adversary action, which includes sensing of covert or overt actions. The measures of effectiveness for the detection function are the probability of sensing adversary action and the time required for reporting and assessing the alarm.

Delay: Delay can be accomplished by personnel, barriers, locks, and activated delays. It is the slowing down of adversary progress. Response personnel can be considered elements of delay if they are in fixed and well-protected positions.

Response: This consists of the actions taken by the response team to prevent adversary success. This may include both interruption and neutralization. Interruption is defined as a sufficient number of response personnel arriving at the appropriate location to stop the adversary's progress while Neutralization describes the actions and effectiveness of the responders after interruption. Figure 5.2 below is the graphical view on the function of PPS:

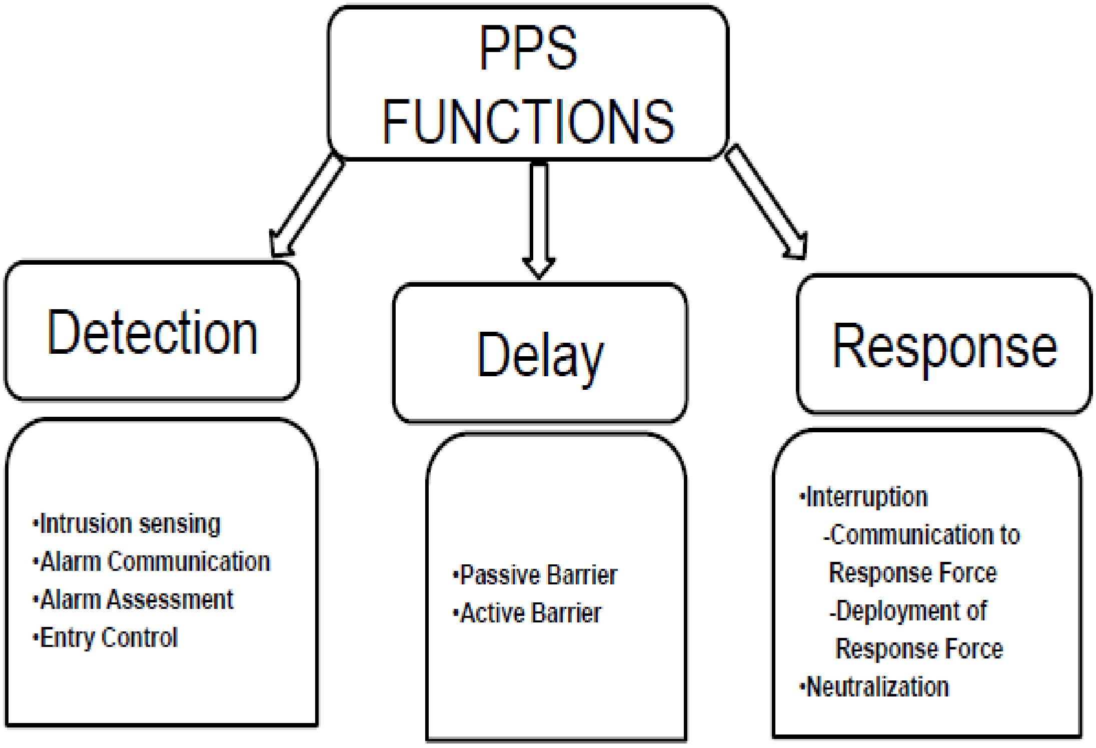


Figure 5.2: Functions of Physical protection System (Brayon, n.d.)

Similarly, according to IAEA (1999) and (NSSPI) (2014), a country's objectives for physical protection system are as follows:

- To establish conditions which would minimize the possibilities for unauthorized removal of nuclear material and/or for sabotage ; and

- To provide information and technical assistance in support of rapid and comprehensive measures by the country to locate and recover missing nuclear material and to cooperate with safety authorities in minimizing the radiological consequences of sabotage.

5.2.2 Concept and requirements of PPS design

According to Gandhi and Kang (2013), design concepts traditionally applied to nuclear safety such as defence in depth, single failure criteria, redundancy and diversity; fail safe criteria, passive systems are also applicable to nuclear security as well. These safety designs and systems can potentially reinforce protection against malicious acts. Therefore, application of these concepts to nuclear security means that would-be perpetrators of nuclear sabotage must compromise several layers of safeguards in order to cause radiological release. However, it is the responsibility of every country to establish and maintain the risk associated to the removal and sabotage of nuclear materials and facilities and this can be achieved through the risk management of physical protection regime which involves assessing the threat and the potential consequences of malicious acts, then developing a legislative, regulatory framework which ensures that appropriate and effective physical protection measures are put in place (IAEA, 2011a). The fundamental principles of risk management for physical protection design are as follows:

- Defence in depth
- Security Culture
- Quality Assurance
- Confidentiality
- Contingency

5.2.2.1 Defence in depth

Defence in depth in nuclear security is based on the PPS, which serves to detect, delay and respond effectively in attempts to harm a nuclear facility, nuclear material accounting system and to protect, control against insider and outsider threats. According to Kim and Kang (2012) the concept of defence in depth applies as much in nuclear security as to nuclear safety. At the design level of nuclear facilities, defence in depth relates to physical protection that reflects the concept of several layers (IAEA, 2011a) and methods of protection such as structural, technical, personnel and organizational that may need to be circumvented by an adversary in order to achieve his objectives. For instance, an incidence of Fukushima Nuclear Power Plant disaster which occurred March 11 2011, resulting in a meltdown of three of the plant's six nuclear reactors was as a result of insufficient defence in depth provisions for tsunami hazards. The failure occurred when the plant was hit by a tsunami triggered by the magnitude 9.0 Tōhoku earthquake. The tsunami waves overwhelmed the defences of the Fukushima Dai-ichi facility, which were only designed to withstand tsunami waves of a maximum of 5.7 m high as against the larger waves that impacted the facility estimated to be over 14 m high (IAEA, 2011b). Therefore, a prime aspect of the principle of defence in depth however is the successive layers of protection that must be independent to each other and be sufficient to prevent harm occurring which should cover all layers of protection: management systems and cultures, site selection, design incorporating safety margins, diversity and redundancy with appropriate attention to quality and reliability requirements, operating systems, accident and emergency arrangements.

5.2.2.2 Security Culture

IAEA (2012) and Khripunov (2012) have defined nuclear security culture as the assembly of characteristics, attitudes and behaviour of individuals, organizations and institutions which serves as a means to support and enhance nuclear security. A literature review revealed that there is no accepted ways of measuring security culture that can be used outside narrow domains such as the nuclear industry and the security culture to organizational performance (Malcolmson, 2009). However, specific research on security culture has been limited, but relationships do exist between security culture and organizational security metrics. Therefore, understanding and then enhancing the security culture within organizations where security is a critical success factor is likely to lead to those organizations being better able to achieve their primary goals and maintain their reputation. However, there are six groups of actors responsible for the proper development of security culture (CNND, 2013), these are: countries, organizations, managers in organizations, personnel, public and the international community who fulfil the different tasks relevant for the realization of nuclear security culture through dialogue and coordination.

5.2.2.3 Quality Assurance

The quality assurance (QA) comprises all planned and systematic actions that are necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service (USNRC, 2013). However, the attributes of a QA program include procedures, recordkeeping, inspections, corrective actions, and audits. The QA program is an interdisciplinary management tool that provides a means for ensuring that all work is adequately planned, correctly performed and assessed. According to IAEA (1996), it includes the organizational structure, functional responsibilities, levels of authority and interfaces for those managing, performing and assessing the adequacy of work providing a systematic approach for accomplishing work with the ultimate goal of doing the job right the first time.

5.2.2.4 Confidentiality

This is the concept and the property that information is not made available or disclosed to unauthorized individuals, entities, or processes (IAEA, 2011a). Accordingly, computer security objectives are commonly defined as protecting the confidentiality, integrity and availability attributes of electronic data or computer systems and processes. Therefore by identifying and protecting these attributes in data or systems that can have an adverse impact on the safety and security functions in nuclear facilities, the security objectives can be achieved. Otherwise, there will be an impact on the organization, which may take various forms, such as breaches of nuclear security, impaired safety, and impaired operation of the activities, loss of customer confidence or financial losses.

5.2.2.5 Contingency

Contingency plan can be seen as a sort of upstream radiological emergency plan designed to secure a site before mitigation actions are taken (Gandhi and Kang, 2013). It is also referred to as disaster planning. According to Krupa (2003), statistics provided by Price Waterhouse Coopers reveals that 90 percent of all companies that experience a computer disaster with no pre-existing survival plan go out of business within 18 months. However, if a flood, fire, or hurricane occurred at an organization's site, one would hope employees at this facility know what to do. More importantly, if there was unrecoverable damage to systems, there should be a contingency plan that gives accurate instruction on how to recover from disaster in a specific amount of time.

5.3 Safety, Security and Safeguard

The quest for nuclear power should be welcomed from the perspectives of achieving energy security and combating global warming, but this should not be without reservation because great number of nuclear reactors could increase problems and risks in terms of safety, security, and safeguards, and careful consideration must be given to these three aspects when introducing nuclear power generation to alleviating these (Endo, 2009). Therefore, the 3Ss stand out as the major prerequisites for the peaceful use of nuclear energy. Safety was the first to gather interest internationally and to be systematically established, followed by safeguards. Nuclear security is to a certain degree included in the concepts of safety and nuclear non-proliferation, but it has come to be treated as an independent concept.

5.3.1 Nuclear safety

The main principle of safety regulation is to protect the population and the environment from radiation and other hazards caused by the operation of NPP and other nuclear facilities at all stages of life cycle, as well as storage, transportation and radioactive materials utilization including spent nuclear fuel and radioactive waste – at the same time safety is adherence limits of radiation exposure to personnel, population and environment, and abidance by established rules, regulations and safety standards (IAEA, 2014). Nuclear Safety concerns both the risks of radiation under normal conditions and those arising risks from incidents or due to loss of control over the operation of nuclear reactor, chain reaction, radioactive source or any other source of radiation. Therefore, safety main aim is on the transparency of the information and this is due to the necessity of sharing feedback on experience, and thereby to prevent occurrences of incidents or accidents at one nuclear power plant from being repeated at others. According to Endo (2009), nuclear safety can be divided by focus into the safety of plant design and operation and the safety of material handling, and by phenomenon into safety for the prevention of radioactive exposure and safety for the prevention of critical accidents.

5.3.2 Nuclear Security

Nuclear security means measures designed to address the risks associated with theft and trafficking in nuclear and radiological materials, sabotage of nuclear facilities, and the danger of terrorists acquiring and using it for a nuclear weapon (CNND, 2013). The global advances in recent time on nuclear security are still inadequate. Therefore, effective nuclear security must be of a concern globally. This is quite necessary because a major nuclear security incident would have far-reaching consequences. Doyle (2008) noted that the security of nuclear materials is the responsibility of the country that possesses them and they have a variety of approaches to this task. There are no legally binding requirements for maintaining high level standards of security, nor is there any multinational authority that inspects and evaluates the effectiveness of nuclear safeguards in each country. However, there is a Convention on the Physical Protection of Nuclear Material to which nearly all countries with nuclear materials are party. These countries agree to follow technical guidelines for adequate physical protection of nuclear materials during storage and transportation. IAEA provides these guidelines to all countries through its document on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/ Rev.4) but does not require inspections or enforcement of the convention. According to Amano (2013), the risk that nuclear or other radioactive material could be used in criminal or intentional unauthorized acts remains a matter of concern internationally and continues to be regarded as a threat to international security. Therefore, it is well recognized that the responsibility for nuclear security rests entirely with each country and that appropriate and effective national systems for nuclear security are vital in facilitating the peaceful use of nuclear energy and enhancing global efforts to combat nuclear terrorism. Significant growth is however anticipated over the coming years in the use of nuclear applications in general and nuclear power programmes in particular by several countries.

Global Nuclear Security Architecture

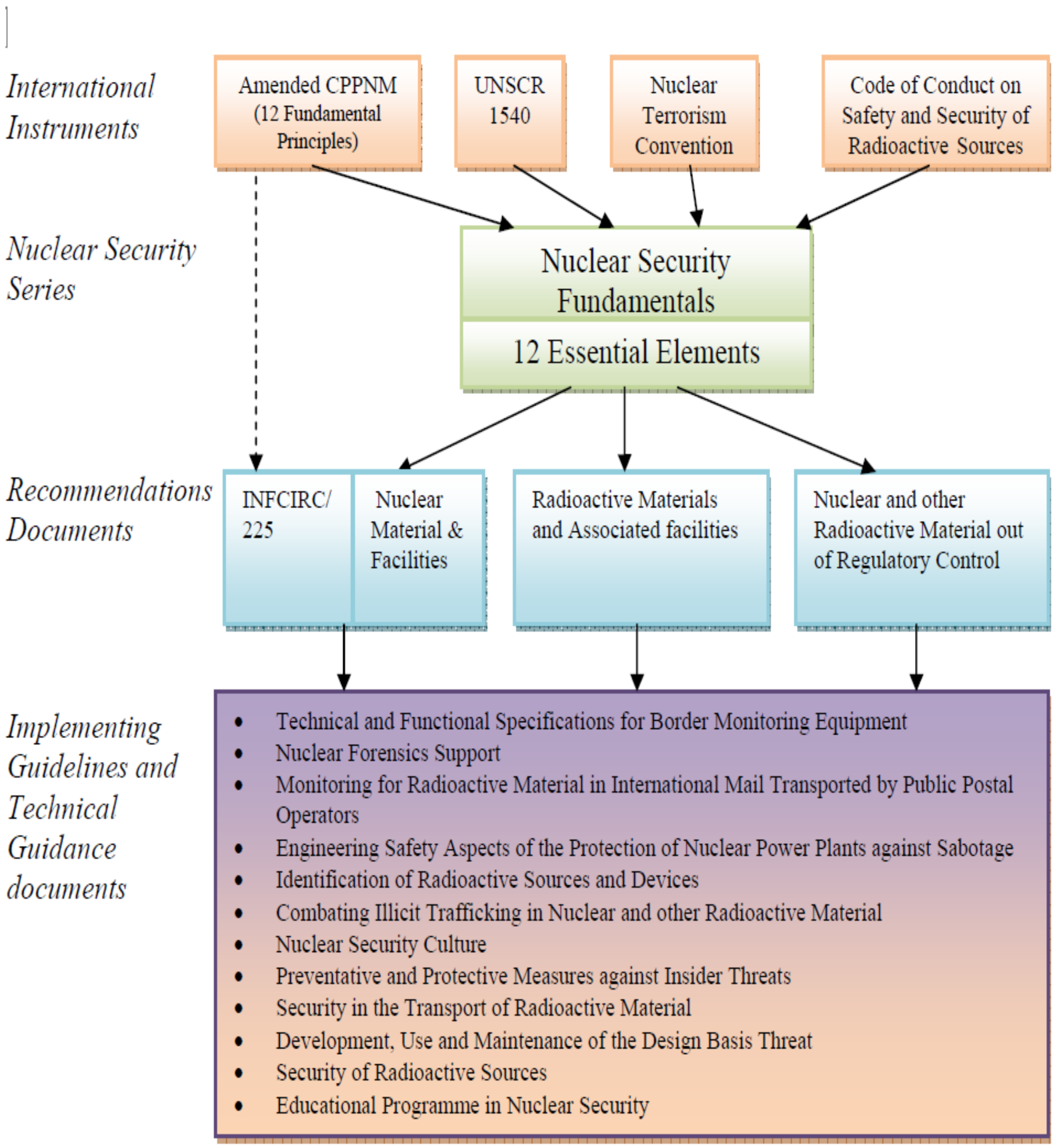


Figure 5.3: The Global Nuclear Security Regime (Everton et al., 2010; CNND, 2013)

Globally, nuclear security is less well developed than nuclear safeguards and nuclear safety. The three main elements of the nuclear security regime are national laws and regulations (international agreements), instruments and institutions (ad hoc) and voluntary cooperative measures. As in Figure 5.3 above, the following are the main global components (Everton *et al*., 2010; CNND, 2013):

- The Convention on the Physical Protection of Nuclear Material (CPPNM) (1980) which applies primarily to the protection of nuclear material in international transport and the CPPNM Amendment (2005) which extends the convention's application to protection of nuclear material in domestic use and of facilities against sabotage.

- The International Convention for the Suppression of Acts of Nuclear Terrorism (ICSANT) (2007).
- United Nations Security Council Resolution (UNSCR) 1540 (28 April 2004).
- IAEA guidance documents: INFCIRC/225/Rev.5, INFCIRC/153 and various multilateral, regional and bilateral agreements and initiatives. However, the Physical Protection of Nuclear Material (INFCIRC/225) and its subsequent amendments to Rev.4 are IAEA documents on guidelines and recommendations to protect nuclear facilities and nuclear materials against intentional cases of theft, sabotage or mishandling during transportation. But Rev.5 update is designed to cope with emerging threats to nuclear materials especially nuclear terrorism with new standards for nuclear security in compliance to CPPNM – 2005. Therefore, the reason for the review was the desire to harmonize the structure of Rev.5 with the amended CPPNM which is the parallel development in physical protection standards through the IAEA's Nuclear Security Series and to accommodate the changed in threat environment following the terrorist attacks on the United States in 2001. While INFCIRC/153, according to (Parsick and Sanborn (1994), is an IAEA guidance document for Non Proliferation Treaty (NPT) verification which serves as an element of a special nuclear materials production cut-off convention. Its safeguards objective is the ability to detect diversion which is achieved by verifying country's nuclear material accounting system. However, a non-nuclear weapons country signatory to the NPT must periodically report of all transfers and inventories of nuclear material to the IAEA for which it will verifies the reports by auditing the records and by independent observations, including measurements of the material presented to the inspectors.
- The Fundamental Principles of Physical Protection of Nuclear Material and Nuclear Facilities.

For an effective and appropriate nuclear security regime however, the 12 essential elements that should be reasonably and practically applied are as follows (IAEA, 2013b):

- State responsibility:

  It is the responsibility of a country to meet the objective of the country's nuclear security regime thereby establishing, implementing, maintaining and sustaining a nuclear security regime applicable to nuclear material, other radioactive material, associated facilities, and associated activities under its jurisdiction.
- Identification and definition of nuclear security responsibilities:

  Various responsibilities such as regulatory bodies and those competent authorities related to border control and law enforcement should be identified and defined for appropriate integration and coordination of responsibilities for the sake of oversight to ensure the continued appropriateness of the nuclear security regime.
- Legislative and regulatory framework:

Establish competent authorities, including regulatory bodies, with adequate legal authority to fulfil their assigned nuclear security responsibilities.

- International transport of nuclear material and other radioactive material:
  Ensuring that nuclear material and other radioactive material are adequately protected which extends to the international transport thereof, until that responsibility is properly transferred to another country.
- Offences and penalties including criminalization:
  To define appropriately under nuclear security regime measures for offences or violations under domestic laws or regulations for criminal or intentional unauthorized acts involving or directed at nuclear material, other radioactive material, associated facilities or activities.
- International cooperation and assistance:
  A nuclear security regime provides cooperation and assistance between countries directly or through IAEA or other international organizations by either assistance or cooperation in providing timely information as appropriate to affected countries concerning criminal or intentional unauthorized acts involving nuclear and radioactive material.
- Identification and assessment of nuclear security threats:
  The nuclear security regime ensures identification and assessment of nuclear security threats, both internal and external including their credibility, regardless of whether the targets are within or outside the country's jurisdiction.
- Identification and assessment of targets and potential consequences:
  A nuclear security regime ensures that targets under the country's jurisdiction are identified, assessed and it's up to date maintained to determine if protection from nuclear security threats is required should the targets be compromised.
- Use of risk informed approaches:
  A nuclear security regime uses risk informed approaches in the conduct of nuclear security related activities that are based on a graded approach and defence in depth such as in the allocation of resources for nuclear security systems and nuclear security measures.
- Detection of nuclear security events:
  A nuclear security regime ensures that nuclear security systems and nuclear security measures are in place at all appropriate organizational levels to detect and assess nuclear security events and to notify the relevant competent authorities so that appropriate response actions can be initiated.
- Planning, preparedness and response to a nuclear security event:
  A nuclear security regime ensures that relevant competent authorities and authorized persons are prepared to respond appropriately, at local, national, and international

levels to nuclear security events by developing arrangements and response plans and periodically exercising, testing, and evaluating the plans for effectiveness by relevant competent authorities and authorized persons with the aim of ensuring timely implementation of comprehensive measures.

- Sustaining a nuclear security regime:
  A nuclear security regime ensures that each competent authority, authorized person and other organizations with nuclear security responsibilities contribute to the sustainability of the nuclear security regime and this can be achieved by developing, implementing and maintaining appropriate and effective integrated quality management systems in nuclear security matters.

The need for effective nuclear security has been widely recognized. So far, three Nuclear Security Summits (NSS) have been held. One was on 12–13 April 2010 in Washington, DC and the second was 26–27 March 2012 in Seoul. The third was at Hague, Netherlands on 24 and 25 March 2014 (CNND, 2013). Likewise, the Nuclear Security Series are International Atomic Energy Agency (IAEA) publications relating to the prevention and detection of, and response to, theft, sabotage, unauthorized access and illegal transfer or other malicious acts involving nuclear material and other radioactive substances and their associated facilities.

5.3.3 Safeguard

IAEA safeguards are an essential component of the international security system (DOS, 2014). The primary role of the department is to deter the proliferation of nuclear weapons in two ways: by providing credible assurances that country's are honouring their international obligations, thus helping to build international confidence, and by being able to detect early any misuse of nuclear material or technology, thereby alerting the world of potential proliferation. In achieving this, it applies various technical measures to verify the correctness and the completeness of the declarations made about their nuclear material and activities. Accordingly, safeguards by design is an approach whereby international safeguards requirements and objectives are fully integrated into the design process of a nuclear facility, from initial planning through design, construction, operation, and decommissioning. This process is not unique to international safeguards but represents good project management to include safeguards requirements in the overall design and construction process. By including awareness of all regulatory issues, including international agreements that concern international safeguards, project management can schedule consideration at the appropriate time and level of detail and subsequently reduce the project risk (IAEA, 2013a). Therefore, it is important to understand that nuclear safeguards are a means of reassurance whereby non-nuclear-weapons states demonstrate to others that they are abiding by their peaceful commitments. They prevent nuclear proliferation in the same way that auditing procedures build confidence in proper financial conduct and prevent embezzlement. Their specific objective is to verify whether declared nuclear material remains within the civil nuclear fuel cycle and is being used solely for peaceful purposes or not. Also, non-nuclear-weapons state parties to the non proliferation treaty (NPT) agree to accept technical safeguards measures applied by the IAEA. These require that operators of nuclear facilities maintain and declare detailed accounting records of all movements and transactions involving nuclear material. Almost 900 nuclear facilities and several hundred other locations in 57 non-nuclear-weapons countries are subject to regular inspection (WNA, 2013). Similarly, their records and the actual nuclear material are audited. Inspections by the IAEA are complemented by other measures such as surveillance cameras and instrumentation. The aim of traditional IAEA safeguards is to deter the diversion of nuclear material from peaceful use by maximizing the risk of early detection. At a broader level they provide assurance to the international community that countries are honouring their treaty commitments to use nuclear materials and facilities exclusively for peaceful purposes. In this way safeguards are a service both to the international community and to individual countries, which recognise that it is in their own interest to demonstrate compliance with these commitments. According to Boyer and Schanfein (2008), in the model comprehensive safeguards agreement (CSA) in INFCIRC/153, the technical aim of safeguards as the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection. Therefore the relationship between safety, safeguards and security is safeguards addresses “peace”, nuclear safety as addressing “safety” and nuclear security as spanning both peace and “safety” (Endo, 2009). The term safeguards in relation to peaceful uses referred to institutional, legal, and technical mechanisms to prevent the misuse of nuclear technologies and nuclear materials for military applications. Nuclear technology has dual use technology with both peaceful and military applications. Concerns about the misuse of peaceful applications of nuclear energy were at first focused on the country’s seeking nuclear weapons. The first concepts for restricting nuclear energy to peaceful purposes were proposed in the context of a broad international agreement under the auspices of the newly formed United Nations (Tape and Pilat, 2008).

5.4 Nuclear safety and nuclear security synergy

Nuclear safety refers to the prevention and mitigation of nuclear accidents and the harmful effects of radiation on human health and the environment while nuclear security refers to the physical protection of nuclear materials and equipment from theft or tampering (Alger, 2008). According to IAEA-NSS, (2012), during the Fukushima accident of March 2011 and the connection between nuclear security and nuclear safety, it was considered that sustained efforts are required to address the issues of nuclear safety and nuclear security in a coherent manner that will help to ensure the safe and secure peaceful uses of nuclear energy. Hence, during 2012 Seoul NSS of March 2012, synergy between safety and security was one of the main directions of discussion. Based on the official Seoul Summit Communiqué, safety measures and security measures have in common the aim of protecting human life, health and the environment. Moreover, nuclear security and nuclear safety measures should be designed, implemented and managed in nuclear facilities in a coherent and synergistic manner. According to IAEA (2014), there is no exact distinction between the general terms safety and security. In general, security is concerned with malicious or negligent actions by humans that could cause or threaten harm to other humans while safety is concerned with the broader issue of harm to humans and the environment from radiation, irrespective of the cause. Therefore, safety matters are transparent with the use of probabilistic safety analysis while security matters are confidential and threat based judgment is used. Figure 5.4 shows the Venn diagram for safety nuclear and security synergy.

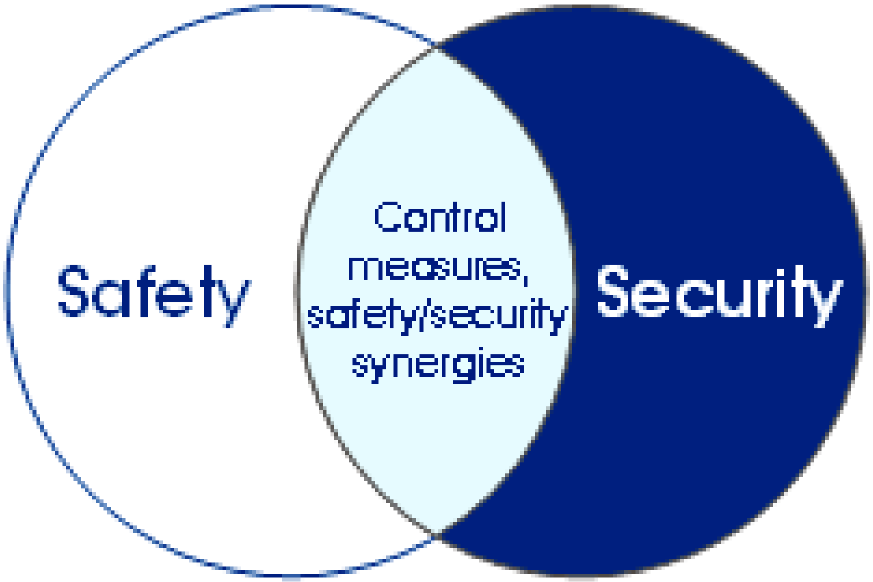


Figure 5.4: Synergy of safety and security (IAEA, 2014; Batra and Nelson, 2012)

There are many common linkages between safety and security as shown in Figure 5.4 above and it is important to treat nuclear safety and security as interrelated subjects, mutually reinforcing and fully integrated (Gandhi and Kang, 2013). Hence, the synergy between the two should be maximized. Consideration should also be given to the facts that although some safety systems can enhance security, at times security systems have been seen to interfere with safety practices and vice versa. Therefore, it is essential that an integrated approach towards nuclear safety and security be adopted. This study describes the similarities and differences between nuclear safety and security. Further, it suggests the ways and methods to increase the synergy between nuclear safety and security. A key difference between nuclear safety and security is intentionality. Accidents related to nuclear safety are unintentional, whereas nuclear security incidents are clearly intentional and undertaken with a specific motive. While safety culture promotes transparency and openness, security culture requires confidentiality. A well developed safety culture requires

that employees share information liberally, but a well developed security culture requires that the employees share information with the relevant authorized personnel only. Safety culture and security culture should not be merged and yet, they should not be set in opposition to each other. Operators should attempt to integrate the safety-security interface into the core operations of nuclear facilities. Safety and security measures must be built into a plant in all its phases, from design and construction, through operation, to decommissioning and dismantlement. According to Kim and Kang (2012), to ensure that nuclear facilities do not endanger the public, it is time to think in terms not of nuclear safety, or nuclear security, but of a combined approach called nuclear safety-security. Although safety and security programs have different requirements, they overlap in key areas and could support and enhance one another. Moreover, nuclear facilities could improve safety-security in technical ways, including more secure emergency electrical supplies, better security for control rooms, and at new plants, reactor containment structures built to survive attacks by terrorist flown airplanes. At the institutional level, regulators could strengthen the safety-security interface by requiring it to be built into the life cycle of nuclear plants, from design to dismantlement. Similarly, INSAG (2010) highlighted that the events taken into account differ in each sphere but safety evaluations focus on risks arising from unintended events initiated by natural occurrences (such as earthquakes, tornadoes, or flooding), hardware failures, other internal events or interruptions (such as fire, pipe breakage, or loss of electric power supply), or human mistakes (such as the incorrect application of procedures, or incorrect alignment of circuits). In the case of security, the risks, or events arising from malicious acts carried out with the intent to steal material or to cause damage. Therefore, security events are based on intelligent or deliberate actions carried out purposely for theft or sabotage and with the intention to circumvent protective measures. Safety and Security should be coordinated from the conceptual stages of development, through infrastructure building, sitting, design, and operation and decommissioning. All systems and procedures should be examined to both safety and security with the aim of ensuring that an optimal balance is achieved. An effective change control process should be put in place to ensure that any proposed changes of design, layout or procedures are thoroughly evaluated to verify that they do not jeopardize safety or security. Therefore, the principle of optimization of protection, applicable to both safety and security, is based on the idea that radiation risks must be kept as low as reasonably as achievable (ALARA), taking social and economic factors into consideration.
According to Kim and Kang (2012), the following areas have been identified in which synergy between safety and security could be maximized:

- Legal and regulatory framework.
- Responsibility.
- Design concepts and criteria.
- Graded approach.

- Operating principles.
- Emergency response.
- Training and education.

5.4.1 Legal and regulatory framework

According to Gandhi and Kang (2013), a legislative and regulatory framework is required to ensure sufficient oversight of installations, deal with potential radiological risks and implement safety as well as security requirements.

5.4.2 Responsibility

The responsibility of a country lies more on the security than the safety related issues and in the assessment of threats and Design Basis Threat (DBT), both of which serve as the basis for the design of the PPS for a nuclear facility. But the prime responsibility of the operator is on the safety of the facility (Gandhi and Kang, 2013).

5.4.3 Design Concepts and Criteria

Nuclear power plants are designed by applying the defence in depth principle for both safety and security. Certain design criteria imposed for safety purposes may serve to reinforce security. As an example, the single failure criterion applied to safety systems requires the nuclear power plant to be designed with a sufficient level of redundancy and/or diversification to ensure that safety functions are maintained even if one set of equipment in the system fails. This design feature is helpful for security purposes as well. Therefore, with the application of this criterion, aggressors must compromise several targets in the nuclear power plant in order to cause a radiological release (INSAG, 2010).

5.4.3.1 Design Basis Threat (DBT)

A postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to ensure public health and safety (USNRC, 2014 ; Kim and Kang, 2012). According to IAEA (2009), a PPS is designed to prevent adversaries from successfully committing a malicious act. To ensure that this objective is met, the designer for physical protection should understand the conditions under which the protection system must perform. A clear description of these threats defines these conditions and is therefore an essential prerequisite for reasonably assured and effective physical protection. Therefore a DBT is a tool that provides a common basis for planning for physical protection by the operator and approval of its physical protection plan by the competent authority for nuclear security.

5.4.3.2 Design Basis Accident (DBA)

According to Sienicki (2011), nuclear power plants are designed to maintain their integrity and performance of safety functions for a bounding set of normal operational events as well as abnormal events that are expected to occur or might occur at least once during the lifetime of the plant. In addition, they are designed to maintain performance of safety functions for a set of DBA that involve failures that are possible but unlikely to occur during the plant lifetime. The plant design incorporates redundant safety systems which meet requirements for inspection and testing to assure their performance when required. An example of a DBA for a LWR is the loss of electrical power from the electrical grid. The plant design includes redundant safety systems to shut down the nuclear chain reaction in the core as well as redundant multiple diesel generators that will start automatically to provide the electricity needs with an electrical power backup from batteries to assure core cooling to remove the decay heat generated in the core.

5.4.3.3 Passive System

From an engineering perspective, the best safety systems are those that require no user intervention to operate (Schultz, 2012). Rather, they are engineered to trip automatically under specific conditions and by the use of only natural forces such as gravity, buoyancy, convection, and conduction to drive flows. Such safety systems are known as passive safety in the nuclear industry. However, these techniques have only recently been included in real reactor designs and only a handful of recently opened nuclear power stations around the world are currently using this technology. Similarly INSAG (2010) also highlighted that the use of passive systems to avoid human errors may make it more difficult for potential aggressors to tamper with these systems. Accordingly, new passive safety systems have been proposed in the advanced reactor designs and by using all passive safety systems, a ten-fold increase in reactor safety is possible that will be safer, simpler systems that are easier to operate and maintain which will reduce significantly the potential for serious human errors and eventually lead to even more economical nuclear power systems (Ishii *et al*., 2003). According to IAEA (2009), another motivation for the use of passive safety systems is the potential for enhanced safety through increased safety system reliability.

5.4.4 Graded Approach

This is a concept of evaluating the threat, its relative attractiveness, nature of the nuclear material and the associated potential consequences (IAEA, 2011a). It is the measure, when implementing nuclear safety and security, to ensure that important safety and security requirements are observed more stringently. Therefore, their requirements should be commensurate with the potential hazard of the facility and proportional measures for prevention and mitigation should be undertaken to minimize radiological risks to society and the environment. These requirements should be applied to siting, design, operation, utilization, modification, training and qualification, emergency preparedness, and regulatory supervision (Gandhi and Kang, 2013).

5.4.5 Operating principles

Coordination is needed in developing operating procedures, especially when conflicts are unavoidable; the matter should be resolved based on the philosophy of minimizing the overall risk to the public (Shokr, *n.d.*). Coordination is necessary so that compensatory measures do not undermine the necessary balance between safety and security (e.g. compromising security surveillance systems during maintenance operation should be avoided). However, verifying the status of the facility on periodical basis is very necessary, which may either results in the need for modernization or refurbishment, updating of procedures and documents, and revision of the safety analysis including DBA or DBT. Similarly, in access control, consideration should be given for the requirements for safety and security. While facilitated access is needed for emergency teams but it may be controlled for security purposes. Some areas within the reactor facility may be subjected to special PPS while it should be possible to be accessed for evacuation of personnel in case of emergency. Likewise, Safety procedures in some cases may slowdown transport of materials, while the duration of transport should be minimized for security purposes.

5.4.6 Emergency Response

The challenges in this area are very similar, regardless of whether the initiating event was on safety or security. The principal aim is to mitigate the event and its radiological consequences, thereafter to address non-radiological issues, through consistent and authoritative provision of information to the public. Coherent initial assessment, crisis and consequence management are needed, which can therefore only be achieved through coordinated and effective preparedness involving all relevant authorities and organizational response. Though, there are different tendencies between safety-related and security-related events (Batra and Nelson, 2012). The most critical type of emergency of a nuclear plant is an off-site emergency where members of the public may get affected and to cope with such an off-site emergency, detailed response plans are required to be put in place. It is also mandatory for the power plant operators to periodically conduct on-site and off-site emergency exercises. No new or existing power plant or radiation facility will be permitted by the regulatory board to operate unless preparedness plans are in place for the postulated emergency scenarios. According to INSAG (2010), security plans for a nuclear power plant should encompass not only the prevention of malicious acts, but also the specification of effective response measures (contingency plans). Similarly, there is an obvious need to ensure that the security plan is compatible with and complementary to the safety plan. Therefore, this is necessary to ensure that coordination is organized among both safety and security responders as part of overall emergency planning.

5.4.7 Training and education.

Training is an essential component in building and sustaining capacity in national nuclear security systems. The IAEA offers a wide variety of international, regional, sub-regional and national training courses and workshops which draw upon international guidelines and recommendations published by the IAEA and international best practices (GNSSN, 2014).

5.5 Nuclear Safety, Security and Safeguard Synergy

Suzuki *et al*. (2010) have noted that the 3S initiative is to raise awareness of 3S worldwide and to assist countries in setting up nuclear energy infrastructures that are essential cornerstones of a successful nuclear energy program. The goals of the 3S initiative are to ensure that countries already using nuclear energy or those planning to use nuclear energy are supported by strong national programs in safety, security, and safeguards not only for reliability and viability of the programs, but also to prove to the international audience that the programs are purely peaceful and that nuclear material is properly handled, accounted and protected for. An inclusion of security and safeguards in conjunction with safety is important for overcoming growing security threats and increasing proliferation risks. It should be noted that coordination between each "S" is lacking because they are developed independently in response to historical events and because they are often regulated by different institutions. Communication between 3S organizations and cultures is deficient. Nuclear safety-related accident information is shared by all countries and safety culture concepts of "safety first" and "defence in depth" are well established. In contrast, incident information for nuclear security events is generally not shared because of the inherent need for secrecy. The human factor greatly contributes to human error in safety, as well as to all nuclear security events, which can be traced to unintentional personal errors as well as deliberate malicious acts. It is incumbent on leadership and management to resolve issues related to complaints about inadequate organizational procedures and management failure. Therefore, establishing strong cultural norms, strict codes of behaviour and enforceable penalties are important for deterring intentional acts by organizations or individuals. According to Kroening, *et al*. (2012), in the design of new or operation of already existed nuclear facilities, there are several equally important elements for each "S", like confinement, containment, and protection of nuclear materials in the form of 3S synergy as shown in Figure 5.5 below. Passive and inherent mechanisms, such as double-entry doors, could satisfy both security and safety objectives, and sharing nuclear facility process data systems could enhance the efficiency of safeguards and safety. Hanks (2013) noted that nuclear reactor containment structures are designed to prevent the release of radioactive materials during an emergency for protecting the public thereby improving safety of the facility. The containment barriers designed into other facilities such as a mixed oxide fuel fabrication (MOX) facility also serves as protection to the public. Moreover, these containment structures provides security barrier to terrorist directed towards taking control of nuclear material that might be used for their activities.

Furthermore, facility containment design information is verified as part of an IAEA safeguards approach, in ensuring that nuclear material is not removed without detection. Accordingly, at the Three Mile Island (TMI) NPP accident of 1979, new techniques for locating radioactive materials disbursed throughout the reactor primary system were developed in order to determine nuclear material accountancy (safeguards) and minimize human exposure to radiation (safety). Security measures were also taken to mitigate malicious acts during removal and transportation of the damaged nuclear fuel.

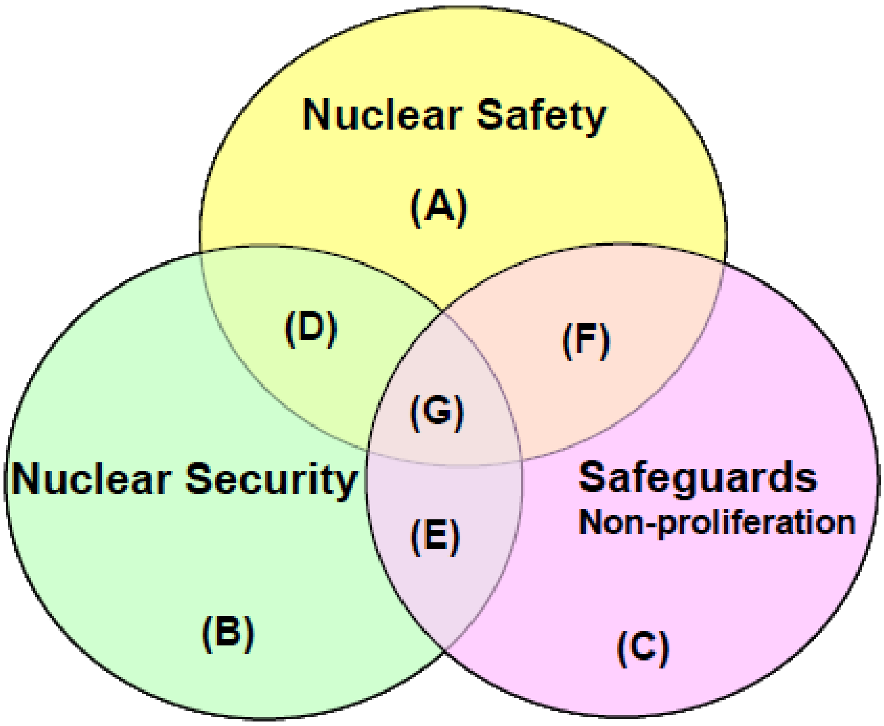


Figure 5.5: The Venn diagram of sets of 3S (Suzuki el at., 2010; Batra and Nelson, 2012; Kroening, et al., 2012)

The relationships between 3S as in Figure 5.5 are shown below:

A = Emergency core cooling system for nuclear power plant

B = Barrier at the facility entrance

C = Authenticated apparatus

D = Double-entry doors to keeping lower pressure than the atmosphere Pressure and prevent radioactive release

E = Management of nuclear material using containment and surveillance by the use of CCTV and guarding troops.

F = Management of nuclear material for criticality and accounting control

G = Possible monitoring camera for multipurpose use, such as joint use of Equipment

Based on the concept of 3S synergy as illustrated in this chapter, Figure 5.6 below is the design of PPS for nuclear facility. It is made of six (6) different layers of protection (A-F) before the source containment.

A = Strong room with the source container (Safeguard)

B = Barrier made of locks to the strong room (Security1)

C = Detection devices made of Access control for authentication to critical Offices with the use of identity cards or any other identification objects (Security 2)

D = Law and Legislation (Safety)

E = Logon password authentication for main office entrance (Security 3)

F = Fence, Security lights and Guard troops (Security 4)

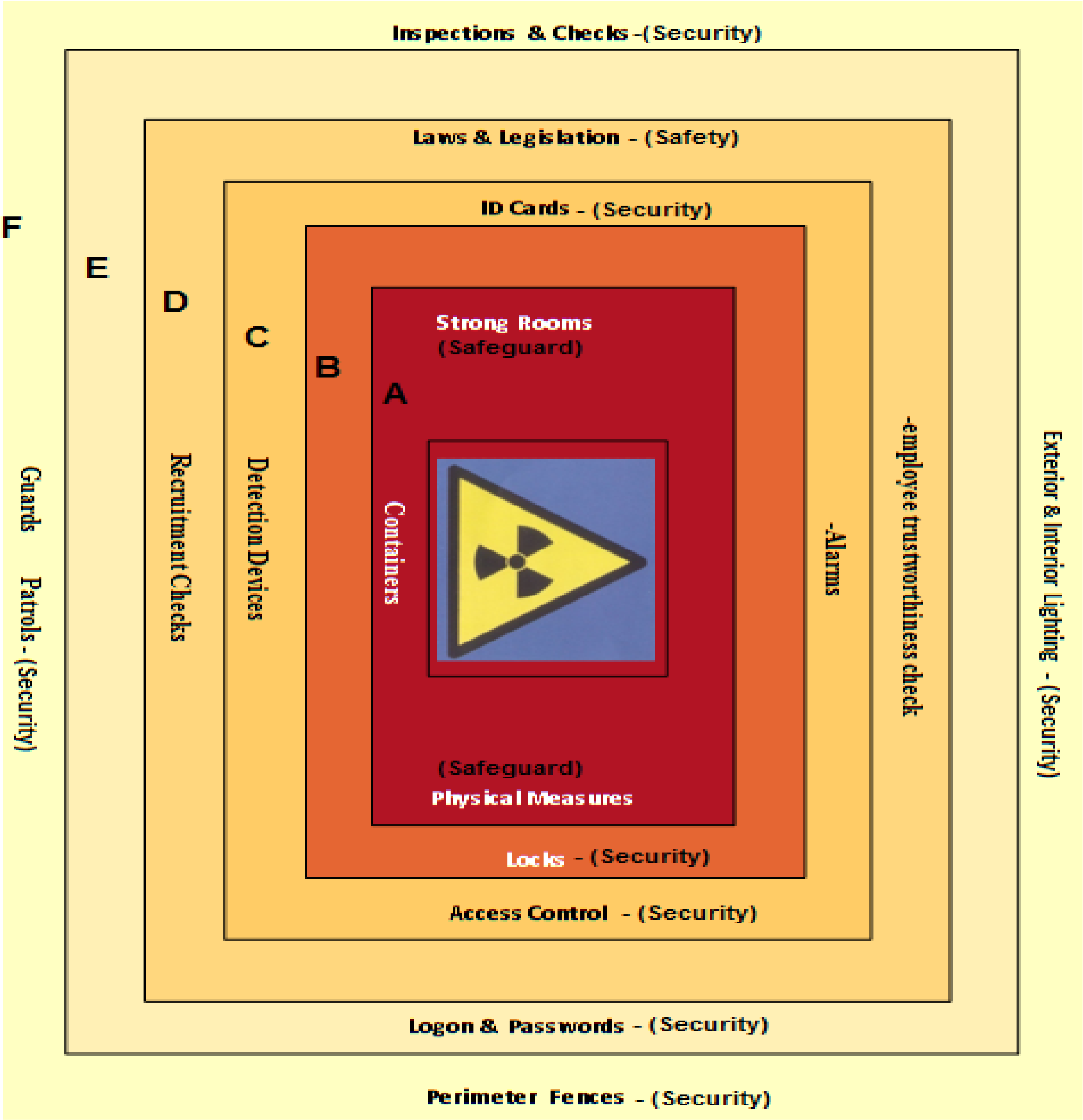


Figure 5.6: PPS Layout for Nuclear Facility

5.6 Conclusion

We have discussed the holistic approach of safety in subjecting the activities of nuclear installations and the radioactive waste management to standards of Safety, Security and Safeguard. And this can be achieved if these three elements, are integrated into the design, installation, operation, maintenance and management of Nuclear and radiological facilities. Consequently, it is advantageous as it enhances the radiation protection of a nuclear facility thereby increasing the level of confidence in the safe operation of nuclear facilities and the danger of terrorism. Thus, as part of the concept in radiation protection, in Chapter 6, we shall examine radiation monitoring system as an indicator for over exposure of ionizing radiation during emergency.

CHAPTER SIX

DEVELOPMENT OF THE RADIATION MONITORING SYSTEM

6.1 Introduction

Widespread application of nuclear science and technology has been the subject of much concern as well as nuclear safety issues. Therefore, to ensure the safety of public life, it is indispensable to improve the emergency system for nuclear accidents and the environment monitoring system for nuclear radiation, so that the occurrence of nuclear accidents and terrorist incidents as well as the resulting hazards can be prevented (Huang and Sun, 2011). The primary purpose of environmental radiation monitoring in the vicinity of NPP is to obtain essential information for the assessment of the station's radiological impact on the neighbouring population as a very important component of a system for demonstrating that the controlled releases of radioactive substances to the environment during normal operation is as designed and in compliance with international safety requirements. Furthermore, it is indispensable in providing timely information for decision making in case of accidental releases. The global practice of environmental radiation monitoring of NPP consist of three phases (RO, 1989):

6.1.1 Pre-operational:

Background radiation monitoring is designed primarily to provide baseline radiological information against any changes caused by the NPP after commissioning and these results need to be obtained prior to the commissioning of the station.

6.1.2 Operational:

This phase of the monitoring is designed to assess the radiological impact on the environment and the population and to demonstrate compliance with the applicable regulations and standards during the operation of the NPP.

6.1.3 Emergency:

Emergency monitoring is designed to provide timely radiological information in case incidents or accidents occurring at the plant that may have off-site consequences.

However, radiation monitoring falls into the following categories: environmental radiation monitoring, personal dose monitoring, surface contamination monitoring, radioactive material monitoring and area process monitor (Kono, 2004). Environmental radiation monitoring measures the spatial gamma-ray dose rate, the concentration of gaseous radioactive material, and the concentration of airborne radioactive material. Accordingly, with the advent in construction of nuclear power facilities, there was an increase in demand for radiation monitoring equipment, which gradually became the largest sector of the market for radiation equipment. According to (Kobayashi *et al*. (2004), the environmental radiation measuring equipments are commonly used for the purpose of measuring and controlling environmental radiation at facilities such as NPPs, research laboratories and hospitals. However, Radiation control at nuclear power facilities is implemented in accordance with various laws and regulations for safety of workers in the facility and local residents (Ooi *et al. n.d*) with the measurement of data being reported publicly and sent to nuclear environmental monitoring facilities administered by local municipalities (Takagi *et al*. 2004). According to Ooi *et al.* (*n.d*), this is to provide the general public with a better understanding on the operation of NPP and to ascertain conditions near the perimeter of a supervised area at an NPP or other facility that uses radiation.

6.2 The Design of Radiation Dose Monitoring System

In a radiation monitoring system, the data signals from radiation detectors installed at each worksite are transmitted to a central control room where radiation control computer processes the data with radiation levels and alarm activation and outputs the data on a display or as a printout (Ooi *et al. n.d)*. However, as radiation control at nuclear power facilities becomes more advanced, monitoring systems are being required to provide improved reliability, labour saving maintenance, inspections, and enhanced monitoring functions. According to Huang and Sun (2011), most of nuclear radiations monitoring systems data collation are usually transferred by wired network. These types of systems have a lot of defects, such as high cost of cable deployment, maintenance problems and poor mobility. In view of this, the thesis proposes a monitoring system based on wireless LAN (IEEE 802.11n) with mesh network topology (See Figure 6.1) below: This comprises the radiation dose collection terminals, the wireless transmission medium and the data processing centre.

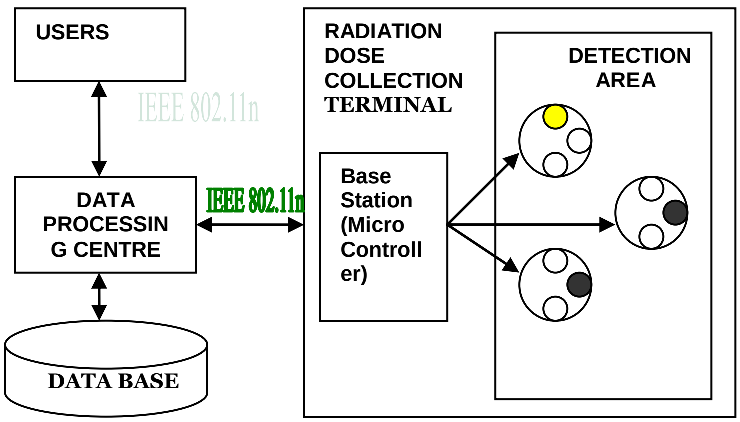


Figure 6.1: The Basic Schema of Radiation Monitoring System (Huang and Sun, 2011)

6.2.1 Nuclear radiation dose collection terminal

From Figure 6.1 above, the nuclear radiation dose collection terminal is responsible for collecting radiation doses real-time made of radiation detector as highlighted below:

6.2.1.1 Radiation Detector

The function of the detector is to produce a signal for every particle entering into it. According to Tsoulfanidis (1995), every detector works by using some interaction of particles with matter. The following are the most commonly used detector types:

- Gas-filled counters (ionization, proportional, Geiger-Muller counters)
- Scintillation detectors
- Semiconductor detectors
- Spark chambers
- Bubble chambers (used with high energy particles)
- Photographic emulsions
- Thermo-luminescent dosimeters (TLDs)
- Cerenkov counters
- Self-powered neutron detectors

From literature, there are three types of gas-filled detectors. The ion chambers, proportional counters, and Geiger-Mueller counters (Glasstone and Dolan, 1997; Buchtela, 1998). They differ mainly in the strength of the electric field applied between their electrodes. However, Geiger-Mueller (GM) tubes are used most frequently for radiation monitoring and contamination control in day-to-day radiochemistry work. According to Shapiro (2002), a GM is a very effective instrument for searching for excessive scattered radiation that must then be evaluated accurately with dose or exposure measuring devices. It is however the best-known and popular radiation detector because it is simple in principle, inexpensive to construct, easy to operate, sensitive, reliable, and very versatile as a detector of ionizing particles. Therefore, it is particularly suitable for radiation protection surveys.

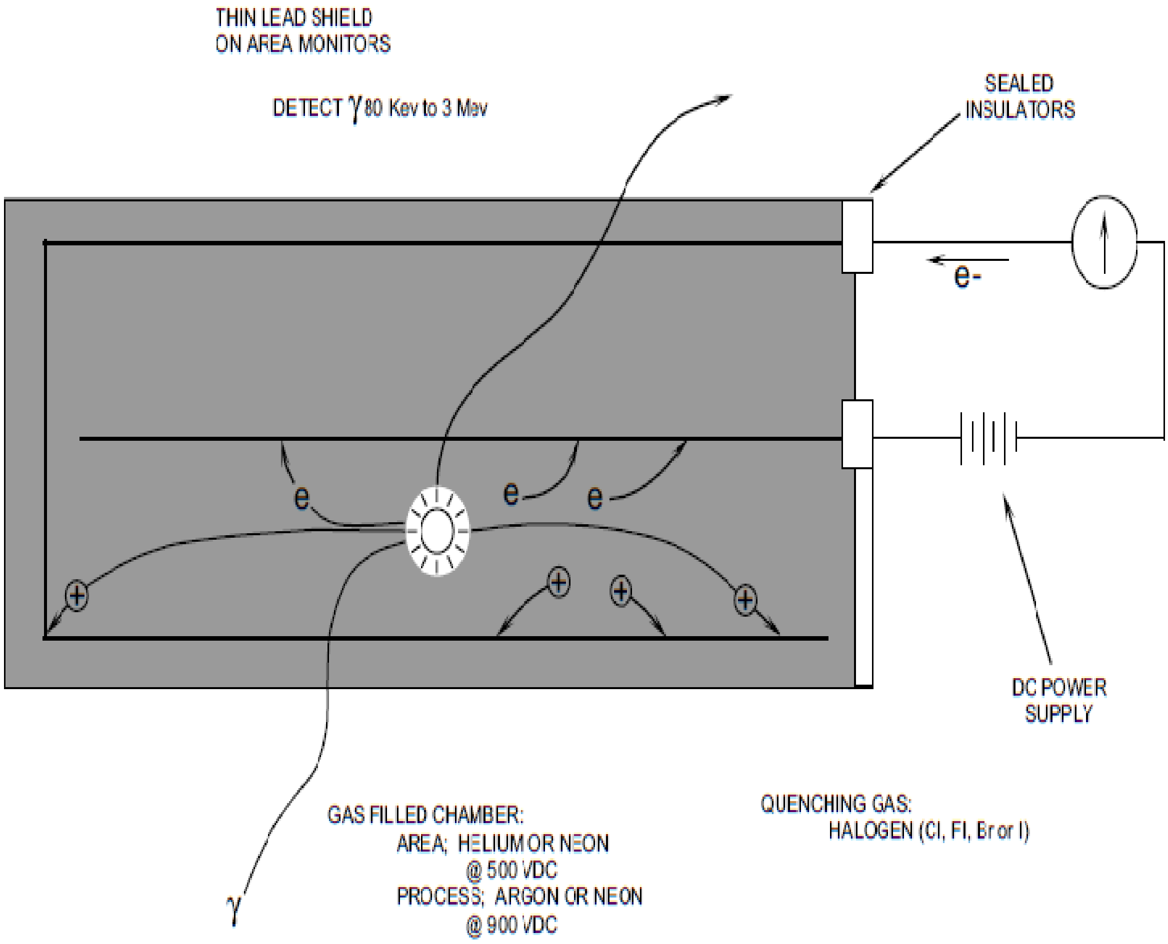


Figure 6.2: Geiger Mueller tube (Shapiro, 2002; Westinghouse, n.d)

As shown in Figure 6.2 above, a gas with molecules having a very low affinity for electrons (for example, helium, neon, or argon) is put into a conducting shell (Shapiro, 2002; Martin, 2006), and a fine wire that is insulated from the shell being mounted at the centre. With connection of a positive high-voltage source between the wire and the shell, a GM is then made. Any incident particle that ionizes at least one molecule of the gas will institute a succession of ionizations and discharges in the counter that causes the centre wire to collect a multitude of additional electrons. This tremendous multiplication of charges, consisting of perhaps 109 electrons, will produce, in a typical GM circuit, a signal of about 1 volt, which is then used to activate a counting circuit. According to Martin (2006), the GM counter is operated in the Geiger region and is characterized by a plateau voltage which produces an avalanche of discharge throughout the counter for each ionizing radiation that enters the chamber. This avalanche of charges produces a pulse, the size of which is independent of the initial ionization, therefore the GM counter is especially useful for counting lightly ionizing radiations such as beta particles or gamma rays and is specially designed to take advantage of this effect. Since it is difficult to make tubes with windows thin enough for alpha particles to penetrate into the gas chamber, GM counters are used mainly for the more penetrating beta and gamma radiations. However, Geiger counters, especially with pancake probes, are very useful for general surveys of personnel contamination, area contamination, and the presence of external radiation fields. Consequently, Glasstone and Dolan (1997) have noted that the Geiger counter and the pocket chamber (or dosimeter), for measurement of gamma and other radiations, are based on the formation of per electrically charged ion pairs in a gas and its consequent ability to conduct electricity. The detection of ionizing radiation has greatly improved since the days of Roentgen, Becquerel, and the Curies. With Geiger counters and other devices ionizations can be detected accurately. As the efficiency of the detector is known, one can determine not only the location of the radiation, but also the amount of radiation present (NRC, 2006). It is important to select an instrument that is appropriate for the radionuclide's used (NU, 2010) and the most common instruments are ratemeters that display counts per unit time, used with either GM detectors or scintillation detectors. The ion chambers, which measure exposure rate, are useful in certain applications. According to Cumo (2010), one widely used type of gas-filled detector is the GM detector, which consists of a sealed tube containing the counting gas, anode, cathode, and a secondary gas to quench the discharge and prevent secondary discharges. The counter is inexpensive, trouble-free, and generally used to measure gross gamma or beta/gamma radiation.

6.2.1.1.1 GQ GMC-320-Plus Radiation Detector

The GQ GMC-320-Plus as shown in Figure 6.3 is used for radiation detection and monitoring both indoor and outdoor, as well as in other similar environments (GQE, 2012). It is an enhanced digital Geiger counter compared to the previous models (See Table 6.1) designed as portable and convenient with audible and visual signals for the level of radiation detected made of automatic data recording. It can continually monitor radiation and log the data each second into internal memory and when connected to a computer with the aid of the software, the radiation history data can be downloaded to the computer for analysis.

Figure 6.3: The GQ GMC-320-Plus Geiger counter (GQE, 2012)

According to GQE (2014), when the radiation passes through the Geiger tube, it triggers an electrical pulse for the Central Processing Unit (CPU) to register as a count in Count per Minute (CPM). With the count rate, the radiation level that will indicate can also be converted to other traditional radiation units such as micro-sievert per hour (uSv/h) or milli-rem per hour (mR/h). Accordingly, with GMC-320 plus, the background radiation reading (in CPM) shows within one minute when turned ON which indicates the nature of background radiation detected at that minute. However, this reading may change from time to time and location to location. Therefore to get accurate reading, average value is required over a longer time frame.

Table 6.1: GQ Geiger counters models and selection criteria (GQE, 2012)

	GMC - 080	GMC - 200	GMC - 280	GMC - 300	GMC – 300E	GMC – 300E Plus	GMC - 320	GMC – 320 Plus	Other
Ready- To- Use		Yes		Yes	Yes	Yes	Yes	Yes	
On board CPU			Yes	Yes	Yes	Yes	Yes	Yes	
Geiger Tube Installed		Yes		Yes	Yes	Yes	Yes	Yes	
LCD display			Yes	Yes	Yes	Yes	Yes	Yes	
Onboard Speaker	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Battery Included	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Battery Type	9V NiMH	9V NiMH	9V NiMH	9V NiMH	9V NiMH	9V NiMH	3.7V Li=Ion	3.7V Li-Ion	
LED Indicator						Yes		Yes	
Audio Data Port	Yes	Yes				Yes		Yes	
USB Data Port			Yes	Yes	Yes	Yes	Yes	Yes	
Audio USB Data cable	Yes	Yes							
Mini USB Cable			Yes	Yes	Yes	Yes	Yes	Yes	
Wall Charger, Power Adapter	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Car Charger, Power Adapter				Yes	Yes	Yes	Yes	Yes	
Internal Flash Memory				64 KB	64 KB	64 KB	1 MB	1 MB	
Internal Data Logger				Yes	Yes	Yes	Yes	Yes	
Real Time Clock			Yes	Yes	Yes	Yes	Yes	Yes	
Electronic Gyroscope							Yes	Yes	
Temperature Sensor							Yes	Yes	
Battery Type Selectable (Charge or Not)						Yes	(by software)	(by software)	

6.2.1.1.2 Features of GQ GMC-320-Plus

The following are the main features of GMC-320-Plus (GQE, 2012):

- Small, portable hand-held
- Audio and visual indication for nuclear radiation detections.

- Dot matrix LCD digital display model with back light.
- USB Data port for connection with computer and GQ Soft Geiger Counter software
- Battery charging feature for charging internal battery.
- USB DC input port for external power input, so that continually monitoring becomes possible.
- Powerful counter circuit is capable for handling high CPM counting.
- High sensitivity tube M4011 installed (user can remove this tube install other tube if needed)
- built-in battery charging circuit
- On-board real-time clock
- On-board temperature sensor
- On-board electronic gyroscope
- Once mega bytes on-board flash memory for history data record
- On-board speaker.
- Accepts both rechargeable and non-rechargeable 3.6V/3.7V battery
- DC power adapter operation
- Text mode provides maximum data information. Example: CPM, Date, Time, Elapsed time, uSv/h, mR/h etc.
- Real-time graphic mode provides visualized real-time radiation changes, so that much easier to observe the data changes. It also displays the CPM rate at same time. In Graphic mode, the ZOOM feature let user to see from lowest to highest graph onscreen.
- Back light Control to set the back light ON, OFF and timeout. So that to save the power.
- Battery charging and battery level indicator.
- Battery type selectable in software. For rechargeable or non rechargeable
- Speaker ON/OFF control.
- Alarm setting. It sets the alarm ON/OFF, alarm type, alarm level.
- Date time set the real-time clock.
- Temperature display in Celsius OR Fahrenheit.
- Swivel display setting. Auto 180 degree swivel display provides a convenience reading when unit upside down.
- Three points calibration. For CPM to uSv/h and mR/h conversion
- Power saving mode let unit keep running at minimum power.
- Data saving mode selection. Let unit record data every second/minute/hour. Up to 7 days history data
- History data searching

- Variable serial communication baud rate

6.2.1.1.3 Justification for GM detector

GM counting tubes had been used during an extensive and remarkable investigation carried out by Russian and Norwegian scientists in the South Ural region near the site of the first weapon grade plutonium production reactor complex in Russia for the determination of beta counting of yttrium-90 after growth to equilibrium with strontium-90 (Strand *et al*. 1999; Buchtela, 1998). According to Buchtela (1998), the measurements for the determination of strontium-90 were carried out in Romania after the Chernobyl accident without previous chemical separation procedures by using GM proportional radiation detector of VA-Z-520 type (Cosma, 2000). Hence, the aluminium plates were used to absorb low-energy beta particles thereby detecting only the high-energy beta radiation of yttrium-90 where the values between 40 and 75 kBq/kg were obtained from sediments and soil.

6.2.2 Wireless Network Platforms

The Wireless connectivity platform is responsible for the data exchange between the collection terminals and monitoring data processing centre. According to GHKSAR (2010), a wireless Local Area Network (WLAN) is a type of local area network that uses high frequency radio waves rather than wires to communicate between network enabled devices and can be operated using three different topologies; infrastructure mode, ad-hoc mode and bridging mode (Akyildiz *et al*. 2005; GHKSAR, 2010). However, the IEEE 802 family of standards (See Table 6.2) has been developed for wireless communications with various networking platforms such as personal area network (PAN), local area network (LAN), metropolitan area network (MAN) and wide area network (WAN) as shown in Figure 6.4 below (Korsah *et al.* 2009; Sidhu *et al*. (2007):

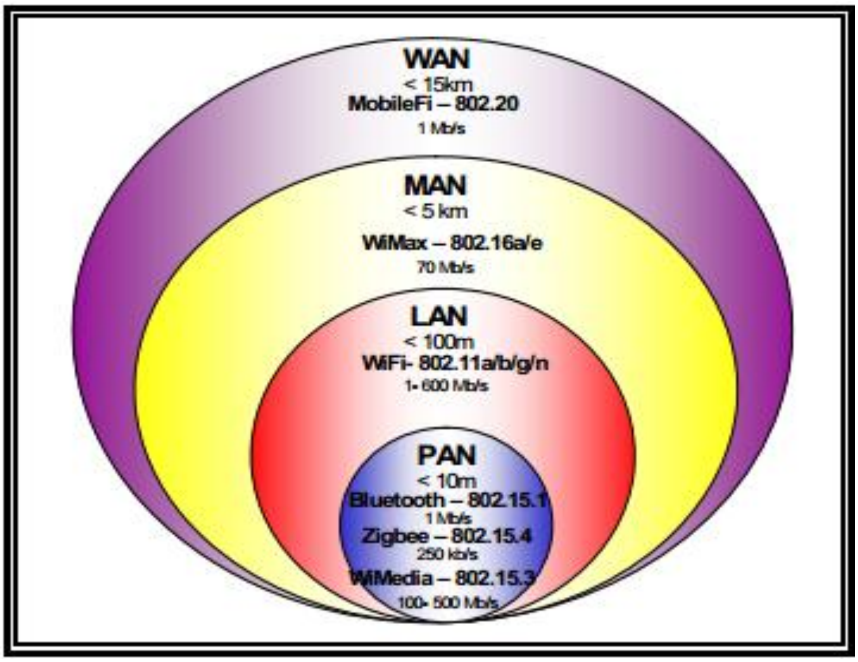


Figure 6.4: Type of Wireless Access (Sidhu et al. 2007; Korsah et al. 2009)

Table 6.2: IEEE Standards for Wireless Communications (Hashemian, 2011)

IEEE Standard	Industry Name	Operational Frequency	Characteristics	Common Application
802.11	Wi-Fi	2.4 GHz 5.7 GHz	High Data Rate Local Area Network	Network /Internet Connectivity
802.15.1	Bluetooth	2.4 GHz	Low Data Rate Personal Area Network	Peripheral Wireless Devices
802.15.3	UWB WiMedia	~5 GHz	High Data Rate Personal Area Network	Video Transmission
802.15.4	Zigbee, ISA100.11a and Wireless Hart ™	868/915 MHz 2.4 GHz	Low Data Rate Personal Area Network	Sensor Networks
802.16	WiMAX	2-11 GHz 10-60 GHz	High Data Rate Wide Area Network	Broadband Wireless Access

6.2.2.1 PAN

The PAN standard, which is governed by IEEE 802.15, is designed to provide a point-to-point wireless connectivity between devices equipped with the same wireless protocol (Bluetooth, ZigBee, or Wi-Media). It is limited in its coverage to the immediate space surrounding a device (e.g., a single room) with a range on the order of 10 m. The bit transfer rate varies from 250 kbit/s to 500 Mbit/s depending on the type of protocol used in conjunction with the communicating devices.

6.2.2.2 LAN

The IEEE 802.11 is LAN standard networks designed for coverage of larger area (on the order of 100 m). However, most LANs are confined to single building or group of buildings. In addition, one LAN can be connected to other LANs to provide much wider coverage using telephone lines as well as wireless transmission. On the other hand, the wireless communication over LANs is accomplished using the wireless fidelity (Wi-Fi) protocol. With this protocol therefore, data can be transmitted at relatively fast rates, varying from 1 to 600 Mbit/s, depending on the IEEE standard being adopted (802.11a, 802.11b, 802.11g, 802.11n) by the network and the communicating devices. The higher data rate is attributed to version 802.11n as a result of using multi-input, multi-output (MIMO) and orthogonal frequency division multiplexing (OFDM) techniques. According to Geier (2010), WLAN can be configured as Ad hoc, Infrastructure or Mesh architectures, depending on requirements of the system.

6.2.2.3 MAN

The MANs can deliver point-to-multipoint communication among devices within a business building or an entire block of business buildings. Hence it can cover a geographic area larger than that covered by an even larger LAN. Such networks are typically found in urban areas where large obstructions typically exist. Therefore, they are capable of covering areas in the range of 5 km and can even extend to wider areas with the use of repeaters. The wireless communication protocol used in conjunction with MANs is the Wi-Max (worldwide interoperability for microwave access), with capability of transmitting data at 70 Mbit/s and possibility of merging technologies from different networking platforms. According to Korsah *et al.* (2009), Wi-Max is a telecommunication technology conforming to the IEEE 802.16 standard and described as a standards-based technology enabling the delivery of wireless broadband access as an alternative to cable and digital subscriber line with the aim in providing broadband access to Internet services throughout the world. Therefore, the technology has the potential for replacing the fibre optic and copper wire backbones of existing networks. Although there may be reluctance in urban environments to switch to wireless infrastructure, where wired infrastructure is already available, there is more of a need for this service within developing countries and rural areas where the resources are not yet available. However, because of the wide coverage range of Wi-Max, extending to 50 km, by using a minimum number of base stations, coverage can be provided to such remote places for a cost much less than installing a copper or fibre optic infrastructure. The capability of its wide coverage is attributed to high transmitter power and the use of directional antennas. Also, by limiting the maximum number of customers to 500 per base station, it is possible to increase the bandwidth provided to each customer, thereby achieving overall high data rate. To achieve wide coverage in Wi-Max, the antennas are normally placed on rooftops, although development is underway to extend coverage to indoor environments. Therefore, both Wi-Max and Wi-Fi provide accessibility to wireless connectivity and the Internet. The Wi-Max is used to transmit data over larger distances (kilometres) to a network infrastructure such as the MAN, while Wi-Fi provides data access through the Internet within a limited region (meters).

6.2.2.4 WAN

The WANs are the result of interconnecting LANs and MANs through routers, repeaters, and even satellites to form even wider geographical areas—in the range of 15 km. Wireless connectivity to WANs is achieved using the Mobil-Fi protocol, which is based on the IEEE 802.20 standard allowing coverage worldwide. This wireless technology extends high-speed wireless access to mobile users with a relatively fast data rate of 1 Mbit/s.

6.2.2.5 Wireless Mesh Network (WMN)

A wireless mesh network is an internet protocol (IP) communications network consisting of wireless nodes organized in a logical mesh topology which can be implemented with various wireless technologies including 802.11, 802.15, 802.16, cellular technologies or combinations of more than one type (Airberry, 2012). It is also one of the latest WLAN technologies for providing large network coverage with low deployment cost, as well as for increasing network flexibility and robustness (Vanhatupa *et al*., 2008; Huang *et al*. 2008; Hou *et al*. 2008; Baiamonte *et al*. 2008). WMN are anticipated to resolve the limitations and to significantly improve the performance of ad hoc networks, wireless LAN, wireless PAN and wireless MAN (Akyildiz *et al*., 2005). While providing predictable Quality of Service (QoS) for users, consideration should also be given to the deployment cost, service area, number of users, and resource utilization. Similarly, internet providers use mesh networks as backbone connections to offer their customers Internet access (Airberry, 2012; Jun and Sichitiu, 2008; Hossain and Leung, 2008; Conti *et al*. 2008). According to Hossain and Leung (2008), since the concept can be used for different wireless access technologies such as IEEE 802.11, 802.15, 802.16-based wireless LAN, wireless PAN and wireless MAN technologies, the potential application scenarios for wireless mesh networks include backhaul support for cellular networks, home networks, enterprise networks, community networks, and intelligent transport system networks. Hence, Wireless coverage of a large area can be achieved in a lot of ways, but none as efficient as utilizing modern day wireless mesh technology. According to Airberry (2012), originally mobile wireless solution for military applications in the US, have been used since 2000 mainly as civil network solutions for whole streets to connect private households to broadband Internet via WLAN, which gained rapidly in popularity. As a result, mesh networks found its way into industry applications such as network measuring devices and meters, in company and city networks, in mobile applications between vehicles, and based on other technologies, such as Zigbee, used in sensor networks where cabled networks would be too complex, uneconomical or simply impossible. Consequently, Hashemian (2011) noted that wireless sensors are becoming very popular in industrial processes for measurement and control, condition monitoring, predictive maintenance, and management of operational transients and accidents. Accordingly, many sensor manufacturers have teamed up with companies who make wireless transmitters, receivers, and network equipment to provide industrial facilities with integrated networks of wireless sensors that can be used to measure process temperature, pressure, vibration, humidity, and other parameters to improve process safety and efficiency, increase output, and optimize maintenance activities. Therefore, power generation utilities have begun to use wireless technologies in their fossil, co-generation, and nuclear power plants. Hence, in NPP, redundancy is an important aspect of defence against mishaps and wireless sensors provide an easy, cost-effective path to redundancy without compromising safety. However, a process parameter may be measured with both wired and wireless sensors. But the wired sensors can be designated as the primary element and used all the time, while the wireless sensors, as the back-up element and used only when the wired sensor is unavailable (Mok *et al*. 2010). The advantage of this for instance is in the case of a loss-of coolant accident (LOCA), where wires may become wet and provide poor signals while wireless sensors could be made to be more immune to water damage and provide more reliable signals for post-accident monitoring of the plant. This however offers not only redundancy but also diversity. The technology has therefore matured to the point that it can now be safely applied in industrial control, monitor, and asset management applications being cost-effective alternative communication path for many legacy control systems, enabling access to the intelligent information in field devices. Hence, it provides simple and reliable way to deploy new points of measurement and control without the wiring costs and without having to completely change existing systems as it provides an infrastructure for both central as well as mobile users to access their process and process equipments. The comparison between various wireless technologies is as shown below on Table. 6.3 (Korsah *et al.* 2009):

Table 6.3: Comparison of Wireless Technology (Sidhu et al. 2007)

Technology	WiFi – 802.11n	ZigBee	WiMAX
Application	Wireless LAN, Internet	Sensor Networks	Metro Area Broadband Internet connectivity
Typical Range	100m	70-100m	50km
Data Rate	108 – 600Mbps	250Kbps	75Mbps
Modulation	DSSS	DSSS	QAM
Network	IP & P2P	Mesh	IP
IT Network Connectivity	YES	NO	YES
Network Topology	Infrastructure (Ad-hoc also possible)	Ad-hoc	Infrastructure
Access Protocol	CSMA/CA	CSMA/CA	Request /Grant
Key Attributes	Wider Bandwidth, Flexibility	Cost, Power	Throughput, Coverage

There are several on-going research efforts to improve the capacity of WMN by exploiting alternative approaches such as multiple radio interfaces, directional antennas, multiple-input multiple-output (MIMO) techniques and modified medium access control (MAC) protocols (Conti *et al*. 2008). Accordingly, by using directional transmission, the interference between network nodes can be mitigated which will eventually improve the capacity of the network and also improve energy efficiency. However, this brings challenges to the MAC protocol design. The MIMO technique consists of using multiple antennas which potentially increases the system's capacity. MIMO deploys simultaneous transmissions and transmit/receive diversity (receive diversity is when the same information is received by different antennas while transmit diversity is when the same information is sent from multiple transmit antennas). However, an efficient MAC protocol exploiting MIMO characteristics is needed to achieve significant throughput improvement. As far as the MAC protocols are concerned, scalability is still a very challenging issue for designing an efficient MAC protocol for WMN. Most of the existing MAC protocols solve the problem partially, but raise other problems such as throughput, capacity or fairness. Moreover, a MAC protocol for WMN must consider both scalability and heterogeneity between different network nodes (i.e. mesh routers, mesh clients).

6.2.2.5.1 Advantages of WMN

The following are the advantages of WMN (Akyildiz *et al*. 2005; Gungor *et al*. 2008; Huang *et al*. 2008; Hou *et al*. 2008):

- Low up-front cost: Using fewer wires means it costs less to set up a network, particularly for large areas of coverage.
- Reliable service coverage: Wireless mesh nodes are easy to install and uninstall, making the network extremely adaptable and expandable as more or less coverage is needed.
- Easy network maintenance: Mesh networks are "self configuring;" the network automatically incorporates a new node into the existing structure without needing any adjustments by a network administrator.
- Robustness: They are useful for Non-Line-of-Sight (NLoS) network configurations where wireless signals are intermittently blocked. For example, in an amusement park where Ferris wheel occasionally blocks the signal from a wireless access point. If there are dozens or hundreds of other nodes around, the mesh network will adjust to find a clear signal.
- Mesh networks are "self healing," since the network automatically finds the fastest and most reliable paths to send data, even if nodes are blocked or lose their signal.

However, the feature of dynamically self-organized and self-configured of WMN (Gkelias and Leung, 2008; Akyildiz *et al*. 2005; Gungor *et al*. 2008; Huang *et al*. 2008; Hou *et al*. 2008; Zhang *et al*. 2008; Agg'elou, 2009) whereby the nodes in the mesh network automatically establish and maintain network connectivity brings many advantages to the end-users. Accordingly, with the use of advanced radio technologies such as multiple radio interfaces and smart antennas increased the network capacity significantly. Also, the gateway and bridge functionalities in mesh routers enable the integration of wireless mesh networks with various other existing wireless networks such as wireless sensor networks, wireless-fidelity (Wi-Fi), and Wi-Max respectively. Zhang *et al*. (2008) have noted that there are still several challenges and issues preventing WMNs to be widely deployed in large scales. The first major issue is that the performance (throughput, delay, or packet loss rate) of WMNs drops sharply with increasing number of wireless hops the packets traverse through. The multi-radio, multi-channel technique is being researched to overcome this problem. The second major issue is the lack of an integrated cross-layer solution to provide security in WMNs, which has received meagre attention in the literature. Clearly, without a well designed security solution, WMNs are vulnerable to various types of internal and external attacks that may cause significant inconvenience to the users and operators. Hence, to ensure security in any application, the following general goals are desired:

- Confidentiality or Privacy
- Integrity
- Availability
- Authentication
- Authorization
- Accounting

According to Baiamonte *et al*. (2008), MWN have two types of nodes: mesh routers and mesh clients. Both types of nodes operate not only as hosts but also as routers, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations. Also, a mesh router may have gateway/bridge functionalities. The following are the benefits and characteristics of WMN (Gungor *et al*., 2008; Akyildiz *et al*. 2005):

- Increased Reliability
- Low Installation Costs
- Large Coverage Area
- Automatic Network Connectivity

6.2.2.5.2 WMN Core Components

WMN have four core components; Mesh access points, Prime infrastructure, Wireless LAN controller and Mesh software architecture (Cisco, 2012):

- **Mesh access points**

The proposed Cisco Aironet 1550 Series Outdoor Mesh Access Point is a modularized wireless outdoor 802.11n access point design that supports point-to-multipoint mesh wireless connectivity, wireless client access simultaneously and also operate as a relay node for other access points that are not directly connected to a wired network. Through intelligent wireless routing provided by the Adaptive Wireless Path Protocol (AWPP), the access point can identify its neighbours and intelligently choose the optimal path to the wired network by calculating the cost of each path in terms of signal strength and the number of hops required to get to a controller.

- **Prime infrastructure**

The Prime Infrastructure is used to design, control, and monitor WMN from a central location. However, the Prime Infrastructure provides a graphical platform for wireless mesh planning, configuration, and management. The Prime Infrastructure therefore runs on a server platform with an embedded database, which provides scalability that allows hundreds of controllers and thousands of Cisco mesh access points to be managed.

- **Wireless LAN controller (referred to as controller)**

The wireless mesh solution is supported on Cisco 2500, 5500, and 8500 Series Wireless LAN Controllers. According to Cisco (2011), the controller works in conjunction with Cisco lightweight access points and the Cisco Wireless Control System (WCS) to provide system-wide wireless LAN functions. It also provides real-time communication between wireless access points and other devices to deliver centralized security policies, guest access, Wireless Intrusion Prevention System (WIPS), context-aware (location), RF management, quality of services for mobility services such as voice and video, and office extended access point (OEAP) support for the teleworker solution. Figure 6.5 shows a 2504 controller network topology and network connections with the required medium dependent interface (MDI) Ethernet cables.

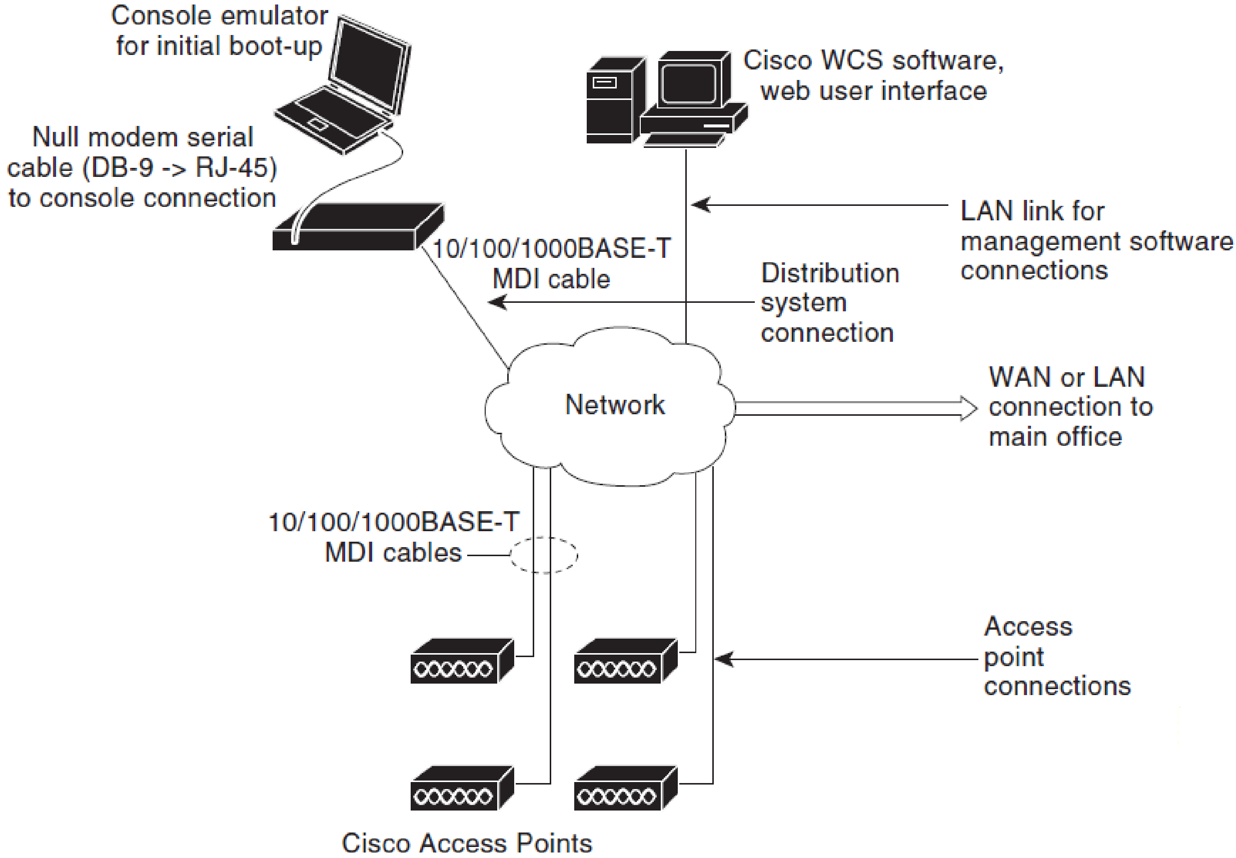


Figure 6.5: Controller Topology and Network Connections (Cisco, 2011)

Mesh Software Architecture

The mesh network architecture such as Cisco Wireless Control System (WCS) is the industry's most comprehensive management platform for lifecycle management of 802.11n and 802.11a/b/g, enterprise-class wireless networks. It delivers cost-effective management solution that enables successful planning, deployment, monitoring, troubleshooting and reporting of indoor and outdoor wireless networks. Though, it runs on a server platform with an embedded database but it provides the scalability necessary to manage hundreds of wireless LAN controllers which in turn can manage thousands of Cisco Aironet lightweight access points. As shown in Figure 6.5 above, Cisco wireless LAN controllers can be located on the same LAN as Cisco WCS, on separate routed subnets, or across a wide-area connection (Cisco, 2007; Cisco, 2012).

6.2.2.6 The IEEE 802.11 Network Standards

The biggest improvements to WLAN technology is the development of the 802.11n standard. The 802.11n wireless network is comparable to wired Ethernet connections. It provides higher performance, availability and predictability of the network than legacy systems (802.11a, 802.11b, and 802.11g) as shown in Fig 6.6. While Fig 6.6 provides the graphical comparison with the legacy systems, Table 6.4 shows the tabular relationship. Accordingly, it supports operation in both the 2.4-GHz and 5-GHz bands, which provides flexibility and backward compatible with 802.11g and 802.11a legacy WLANs. However, full performance potential is achieved by implementing it on 5-GHz band (Geier, 2010).

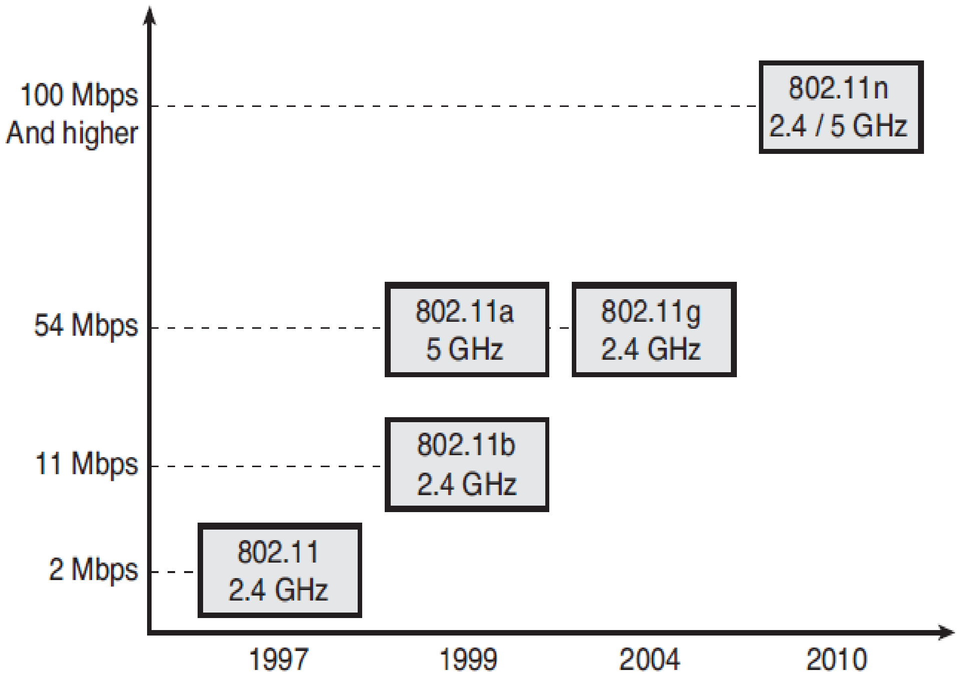


Figure 6.6: IEEE 802.11 Standards (Geier, 2010)

Table 6.4: The 802.11 Standard Comparisons (Geier, 2010)

	RF Spectrum	Max Speed	compatibility	RF Interference Impacts	Date Ratified
802.11a	5 GHZ	54 Mb/s	Does not work with 802.11b or 802.11g	Slight	1999
802.11b	2.4GHZ	11Mb/s	Works with 802.11g	Moderate	1999
802.11g	2.4GHZ	54 Mb/s	Works with 802.11b	Moderate	2004
802.11n	2.4GHZ and 5GHZ	Hundreds of Mb/s depending on the configuration	Works with 802.11g	Slight	2009

6.2.2.7 Routing Mechanism of the Mesh Network

A WMN consists of mesh routers and mesh clients. The mesh node's, mesh technology is a Layer 2 technology in accordance with the ISO/OSI model. Unlike other mesh protocols and dynamic routing protocols, an Ethernet-compatible interface is provided so that the user may consider mesh as a big switch featuring dynamic size and ports which are distributed across a number of different devices. The mesh itself is based on Ethernet-compatible interfaces, allowing WLAN devices to be integrated in the mesh in the infrastructure and ad-hoc modes, Ethernet interfaces and fibre optic interfaces (Airberry, 2012). The mesh routers are generally stationary nodes and form a multi-hop wireless backbone between the mesh clients and the node directly connected to the wired network. However, each mesh router operates not only as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations (Conti *et al*. 2008; Gkelias and Leung, 2008). Most suitable routing methods for WMNs are based on proactive hop-by-hop and multi- hop routing (Akyildiz *et al*. 2005; Conti *et al*. 2008; Glatz, *n.d*.; Hossain and Leung, 2008;Huang *et al*. 2008; Jun and Sichitiu, 2008; Vanhatupa *et al*., 2008). Even though, routing has been based only on hop count, but with an effective routing, it is possible to avoid interference hotspots by using high capacity links. Also, as a network with capability of developing dynamic networks, it participates initially to explore its neighbourhood by transmitting its own identity and features through broadcast message to all users in routing protocols, these data packets are frequently referred to as "\HELLO packets" (Airberry, 2012; Hou *et al*. 2008). Therefore, as each participant performs this process, the participant detects which devices operate within its radio range or neighbourhood packet loss rate, signal-to-noise ratio or selected bit rate of the WLAN's. This signal quality is then incorporated into the metrics used to evaluate and compare routes. Consequently, information about the routes is transmitted from device to device with the mesh nodes, mesh algorithm determining the optimum route through the packets sent, with each participant transmitting route packets featuring the route metrics. However, additional factors, such as signal quality in both directions (different antennae may mean that signal quality is better in one direction than in the other) and the number of hops also have an impact in the path choice that is ultimately made which influences the route selection algorithm. Accordingly, the mesh network properties resulting from these mechanisms make it attractive for a number of different applications: as the routing packets travel across the whole network, there is a wide range of possible routes, ensuring redundancy. Additionally, two WLAN modules may be configured on different channels and operated in the mesh mode, achieving redundancy and expanding the mesh network across several radio channels while maintaining the properties of a large, interconnected mesh network with all its advantages. If two devices have a connection on both radio frequencies, this allows the maintenance of the connection, even if one of the two frequencies is disrupted. According to Glatz, (*n.d*.), wireless mesh routing protocols may be classified into the following categories:

- pro-active (table-driven)
- reactive (on-demand)
- hybrid (pro-active/reactive)
- hierarchical
- geographical
- power aware

According to Baiamonte *et al*. (2008), using the hop count as a metric for route selection in single-rate networks may be appropriate but in a multi-rate environment it tends to select short paths composed of maximum length links. And since long distance links operate at low rates, poor throughput performances are likely to be obtained. Therefore, to select high throughput paths in multihop networks, they have proposed the use of the expected transmission count (ETX) based on the ETX metric, the route featuring the fewest expected number of transmissions (including retransmissions) to deliver a packet is chosen.

6.2.2.8 Implications of WLAN deployment

Despite numerous advantages of using WLAN, there are implications such as Security, interference, Impacts of multipath propagations, Roaming issues, Battery Limitations, interoperability and Installation issues. They have been discussed with their possible remedies as follows (Geier, 2010):

6.2.2.8.1 Security Issues

Network security refers to the protection of information and resources from loss, corruption, and improper use. With WLANs, security vulnerabilities fall within the following: Passive monitoring, unauthorized access and Denial of service (DoS). The method for resolving passive monitoring is to implement encryption between all client devices and the access points. Encryption alters the information bits in each frame based on an encryption key so that the hacker cannot make sense of the data captured through passive monitoring and the encryption. This process is called Wired Equivalent Privacy (WEP), which was part of the original 802.11 standard ratified in 1997. However, it is fairly easy to crack but not recommended for encrypting sensitive information. Therefore, conventional encryption methods, such as Wi-Fi Protected Access (WPA) offer much stronger security. Accordingly, a hacker that can connect to the WLAN have possibility of accessing anything on the network, including client devices, servers and applications by looking for back doors and other security glitches to compromise the security of the network. While some organizations lock down servers and applications, others do not. Therefore, gaining access will be much easier by staging man-in-the middle attack by exploiting the TCP/IP Address Resolution Protocol (ARP) functions. ARP is a crucial function that a source station such as an 802.11 radio uses to discover the physical address of a destination station. This physical address is the MAC address, which is embedded in the client radio by the manufacturer and unique from any other client device or network component. A way to counter unauthorized access is to employ an authentication system that verifies the identity of users, client devices and access points before allowing them to operate on the WLAN. The user provides credentials, such as username and password or digital certificate, and an authentication server determines whether the person (or client device) can access the network. If not, the network does not allow the client device to connect to the access point. The function of an added protection is to keep all the traffic on the WLAN on a virtual LAN (VLAN) different from VLAN supporting sensitive applications and servers. However, attack on DoS, is an assault that can cripple or disable a WLAN. Consequently, it is an attack that can come in one of two forms: either by a huge flood of packets that uses up all the network's resources and forces its shutdown or a very strong radio signal that totally dominates the airwaves and renders access points and radio cards useless. There is not much that can be done to entirely prevent a DoS attack but it can be minimized by making the facility as resistive as possible to incoming radio signals. This includes using directive antennas near the periphery of the building and aiming the directive side of the antenna indoors to reduce the listening capability of the antenna to signals originating outdoors.

6.2.2.8.2 Interference:

Interference of radio signal involves the presence of unwanted signals that disrupt normal WLAN operations. Because of the 802.11 medium access protocol, an interfering radio signal of sufficient amplitude and frequency can appear as a bogus 802.11 station transmitting a packet. This causes legitimate 802.11 stations to wait for indefinite periods of time before attempting to access the medium until the interfering signal goes away. As a result, rather than waiting to investigate radio signal interference problem, it is necessary to investigate the potential for radio signal interference and attempt to reduce the sources of interference by designing the WLAN to accommodate certain types of interference.

6.2.2.8.3 Impacts of Multipath propagations

Multipath propagation is the phenomenon that results in radio signals reaching the receiving antenna by two or more paths as a result of atmospheric ducting, ionospheric reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings (Mitra, 2009). According to Geier (2010), the effects of multipath propagation is compensated by wireless LAN manufacturers using special processing techniques such as equalization and antenna diversity methods for reducing the number of problems arising from it.

6.2.2.8.4 Roaming Issues

Wireless technologies provide access point roaming protocols. For instance, with 802.11 networks, the client radio makes a decision to handoff to the next access point when retransmissions and received signal levels indicate a need to handoff. A decision to handoff too soon generally leads to skipping back and forth between access points. Sometimes, roaming might take much longer than expected. Therefore in deploying WLAN applications, consideration needs to be taken for wireless voice applications, which are not tolerant to roaming delays exceeding 100 milliseconds. The use of wireless middleware can also help accommodate patterns of broken communications between the client and the server caused by roaming delays.

6.2.2.8.5 Battery Limitations

The operating time, due to the extra load on the radio card by operating the computer before needing to recharge the batteries can significantly decrease the amount of time available to less than an hour especially, if the client device accesses the network often or performs other functions, such as printing. To counter this problem, most vendors implement power management techniques in the client devices and radios such as Doze mode and Sleep mode. The doze mode keeps the radio off most of the time and wakes it up periodically to determine if there is any message in a special mailbox. This mode alone generally uses approximately 50 percent less battery power. While the sleep mode causes the radio to remain in a transmit-only – standby mode. The radio wakes up and sends information if necessary, but it is not capable of receiving any information.

6.2.2.8.6 Interoperability Problems

Client cards and access points compliant with the 802.11n standard are backward compatible with the common 802.11 versions, such as 802.11a, 802.11b, and 802.11g. Hardly will there be interoperability issues with the basic 802.11 functions, such as association and data transfer, especially if all the devices on the network have undergone successful Wi-Fi interoperability testing. Therefore, to ensure interoperability with WLANs, it is best to implement client radios and access points from the same vendor if possible. Even though there is successful implementation of multivendor WLANs, that reduces the WLAN features to the lowest common denominator.

6.2.2.8.7 Installation Issues

To avoid installation problems, there is need to perform a thorough wireless site survey to assess the coverage of the network. Propagation tests give the information necessary to plan optimum installation locations for access points, by allowing coverage over required areas. Neglecting this, might leave some users in a coverage hole without reliable connections to the network.

6.2.3 Data Processing Centre

Monitoring data processing centre is responsible for processing data and displaying the result (Huang and Sun, 2011). The readings of Geiger counters at different stations are sent through a wireless mesh link to the data processing centre where the results are collated real-time with the help of data viewer application for analysis.

6.3 Solution Description

The solution aims at monitoring live feed data on the ionizing radiation levels at a nuclear or radiological facility. The proposed system have the capability of being operated with the GM attached to a computer with installed applications (GQ GMC data viewer or GQ Geiger counter data logger pro) for real-time measurement for which the data can be downloaded subsequently for analysis. However, the objective of this thesis is based on the centralized monitoring system with many GM nodes (depending on the size of the facility) for real-time monitoring through WMN to the central server for display and monitoring.

6.3.1 Modular Design

The requirement for this kind of setup is the GMC-320 Plus radiation detector, Universal Serial Bus (USB) cable, the monitoring software (GQ GMC Data Logger PRO or GQ GMC Data Viewer) and a computer. The USB port of the GM communicates with the Soft Geiger Counter Data Viewer software for data monitoring and saving the data on a computer real-time for future references and analysis. The following Figure 6.7 and Figure 6.8 are the graphical measurements from the Data logger Pro and Data Viewer real-time radiation measurement for 35 minutes which resulted to 1.25mSv/year as shown in equation (7.1).

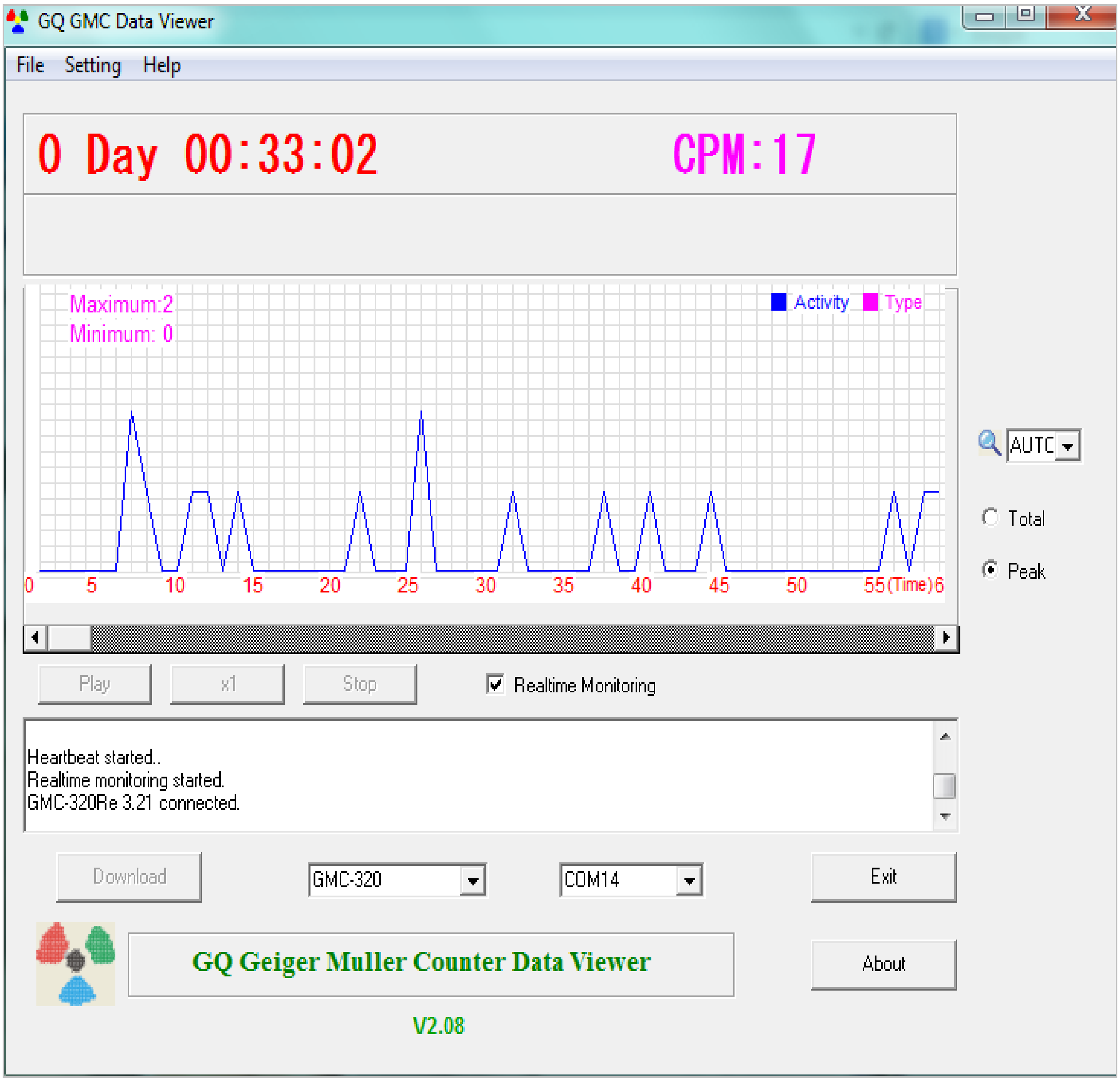


Figure 6.7:Real-Time Data Viewer graphics

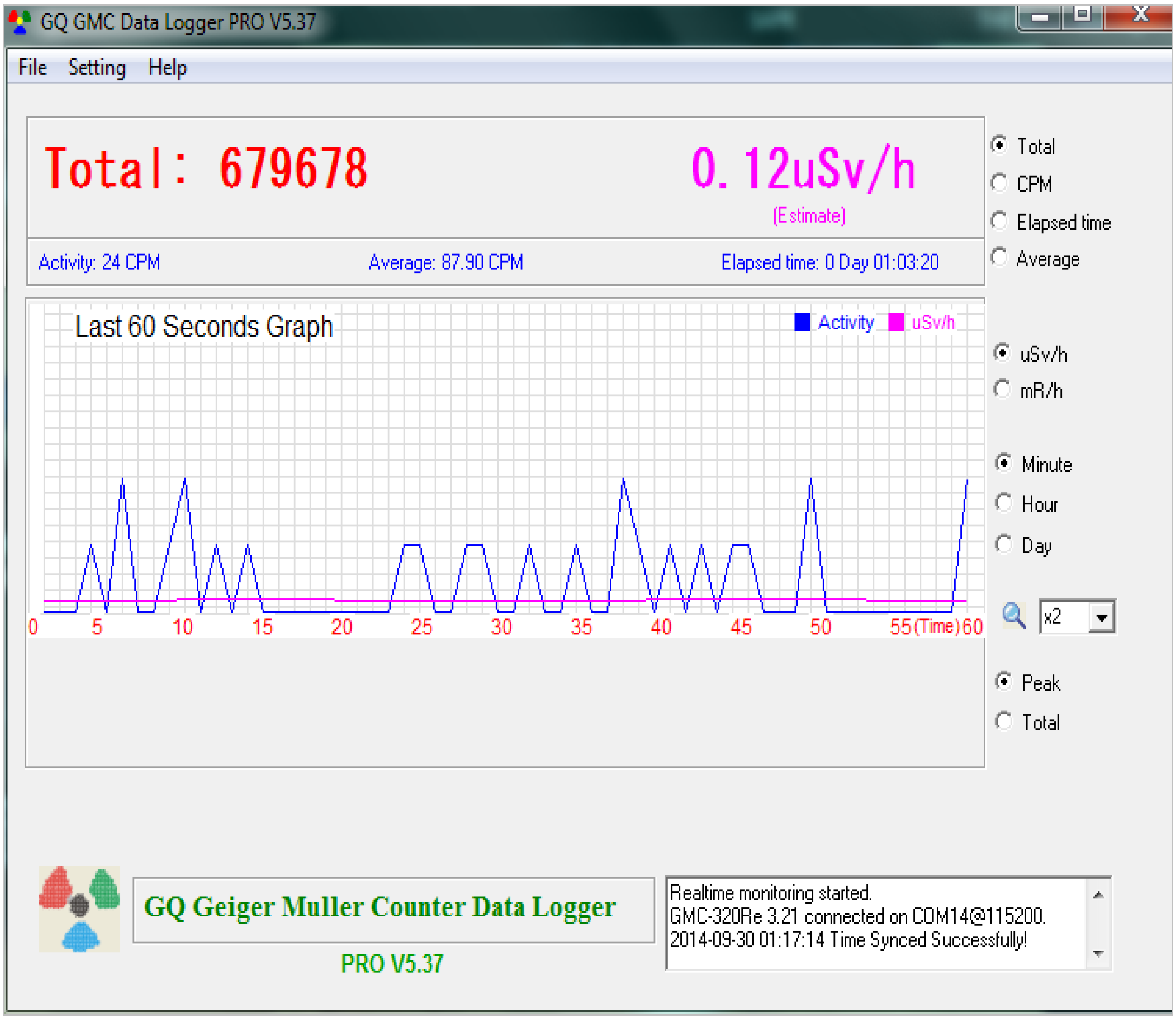


Figure 6.8:Real-Time Data Logger Pro graphics

The data viewer software measurements are in Count Per Minute (CPM) while for data logger which is of more advanced application, it is capable of displaying the readings in micro Sievert per hour (µSv/h), milli rem per hour (mR/h) and CPM respectively. Table 6.5 is the data viewer readings on 29/09/2014 between 19:32 to 20:06 (35 minutes) and Table 6.6 is data Logger Pro reading on 30/09/2014 between 0.15 to 0.49 (35 minutes). The outcome of these readings is 1.25mSv/year as shown in Equation (7.1).

Table 6.5: GQ GM Data Viewer reading in CPM

GQ Electronics LLC	GMC-300 Data Viewer															
Date Time	CPM	1s	2s	3s	4s	5s	6s	7s	8s	9s	10s	11s	12s	13s	14s	15s
29-09-14 19:32	24	0	0	0	0	0	0	1	1	1	3	0	0	1	1	0
29-09-14 19:33	30	0	0	1	1	0	0	0	2	0	2	0	0	0	1	0
29-09-14 19:34	31	1	1	1	0	1	0	0	0	0	0	0	0	0	0	2
29-09-14 19:35	21	1	0	0	0	1	1	0	1	1	2	0	0	0	2	0
29-09-14 19:36	22	0	0	0	0	2	0	0	0	0	1	0	0	0	0	2
29-09-14 19:37	35	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0
29-09-14 19:38	24	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
29-09-14 19:39	21	2	0	0	1	0	0	1	1	0	0	0	1	0	0	0
29-09-14 19:40	26	0	1	0	1	3	0	1	0	0	0	0	1	0	0	0
29-09-14 19:41	24	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0
29-09-14 19:42	27	0	0	1	0	0	0	0	1	0	2	0	0	1	0	0
29-09-14 19:43	27	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0
29-09-14 19:44	23	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1
29-09-14 19:45	17	0	1	0	0	1	0	0	1	0	1	0	2	0	0	1
29-09-14 19:46	30	0	0	0	0	1	0	1	0	1	1	0	1	0	0	1
29-09-14 19:47	23	0	0	0	2	0	1	0	0	0	0	0	0	0	0	2
29-09-14 19:48	24	0	0	2	0	0	1	0	0	0	1	0	0	0	0	0
29-09-14 19:49	21	0	0	0	1	0	0	0	0	1	0	1	0	1	1	2
29-09-14 19:50	22	1	0	0	0	0	0	0	0	1	0	0	0	2	1	0
29-09-14 19:51	22	0	0	0	0	1	0	0	2	0	0	0	0	2	0	0
29-09-14 19:52	17	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
29-09-14 19:53	25	1	0	0	0	1	0	0	0	2	0	0	0	1	0	0
29-09-14 19:54	27	1	0	0	3	0	0	2	0	0	1	0	0	1	1	0
29-09-14 19:55	25	0	2	1	0	0	1	0	0	0	0	0	1	1	0	0
29-09-14 19:56	18	0	0	0	0	0	1	1	0	0	0	1	0	4	0	0
29-09-14 19:57	19	1	0	1	0	0	0	1	0	1	0	1	0	0	1	0
29-09-14 19:58	27	0	1	1	1	0	0	1	0	1	0	0	0	1	0	0
29-09-14 19:59	19	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
29-09-14 20:00	21	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0
29-09-14 20:01	15	0	1	1	0	0	0	1	0	0	1	2	0	0	0	0
29-09-14 20:02	29	0	0	2	2	0	0	1	0	1	1	0	0	0	0	0
29-09-14 20:03	21	1	1	0	0	0	2	1	0	0	0	0	1	0	0	1
29-09-14 20:04	21	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
29-09-14 20:05	24	1	0	1	0	0	0	0	0	0	1	0	1	0	1	1
29-09-14 20:06	23	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0

Table 6.6: GQ GM Data Logger Pro reading in CPM and uSv/h

Date Time	uSv/h	CPM	1s	2s	3s	4s	5s	6s	7s	8s	9s	10s	11s	12s	13s	14s	15s
30-09-14 0:15	0.06	12	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
30-09-14 0:16	0.125	25	0	1	0	1	1	0	1	1	0	0	1	0	0	1	1
30-09-14 0:17	0.135	27	1	0	0	0	0	2	1	0	0	2	1	0	1	0	0
30-09-14 0:18	0.11	22	1	0	2	1	0	1	0	0	0	0	0	0	1	0	1
30-09-14 0:19	0.145	29	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:20	0.125	25	0	1	1	0	1	0	1	0	2	0	1	0	0	0	0
30-09-14 0:21	0.12	24	1	0	1	1	0	0	0	0	2	0	0	0	0	1	0
30-09-14 0:22	0.135	27	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1
30-09-14 0:23	0.12	24	0	0	0	2	0	0	1	1	1	0	0	0	1	0	0
30-09-14 0:24	0.14	28	0	1	2	1	0	1	1	0	0	0	0	0	0	1	1
30-09-14 0:25	0.055	11	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0
30-09-14 0:26	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:27	0.01	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:31	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:32	0.01	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:33	0.01	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:36	0.025	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:37	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:38	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:39	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:40	0.05	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:41	0.005	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
30-09-14 0:42	0.05	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:44	0.05	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:45	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:46	0.015	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-09-14 0:48	0.66	132	0	0	0	0	0	0	0	127	0	0	0	0	0	3	1
30-09-14 0:49	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2.19																
Average	0.063																

6.3.2 Network Design

The centralized network monitoring system comprises of various test areas with many radiation detection nodes of digital Geiger counters at various remote stations depending on the size of the facility. These Geiger counters will be integrated with collating units – a micro controller, Arm Cortex – A9 processor from National Instrument (NI myRio) – a wireless micro-controller with primary function to aggregate the data packets coming from the Geiger counters and sending to the nearest IP gateway through the wireless mesh link. The detailed design requirements are as shown on Table 6.7 below:

6.4 Design Requirements

Table 6.7: Design requirements and Specifications

s/n	Devices	Specifications	Qty
1	Geiger Muller Counter (GMC) Radiation detector	GQ GMC-320-Plus 	6
2	NI my RIO Micro Controller	National Instruments Micro Controller wireless Interface Card 	6
3	Switches	WS-C2960-24PC-L Catalyst 2960 24 10/100 PoE + 2 T/SFP LAN Base Image, CAB-ACE AC Power Cord (Europe) C13 CEE 7 1.5M 	3
4	Wireless controller	AIR-CT2504-15-K9 2504 Wireless Controller with 15 AP Licenses 	1
5	Layer 3 core switch - CORE SWITCHING	WS-C3560X-24P-E Catalyst 3560X 24 Port PoE IP Services, C3KX-PWR-715WAC/2 Catalyst 3K-X 715W AC Secondary Power Supply, C3KX-NM-1G Catalyst 3K-X 1G Network Module option PID, CAB-3KX-AC-EU AC Power Cord for Catalyst 3K-X (Europe) 	1
6	Mesh access point- OUTDOOR MESH ACCESS POINTS	AIR-CAP1552E-E-K9 802.11N Outdoor Mesh Access Point, Ext. Ant., E Reg. Domain, AIR-1520-BATT-6AH 1520 Series Battery Backup System, AIR-ANT2547V-N 2.4 GHz 4dBi/5 GHz 7dBi Dual Band Omni Antenna, N connector, AIR-CORD-R3P-40UE= 1520 Series AC Power Cord, 40 ft. 	6
7	HP Server	G8 Intel Xeon E5-2609 (Quad-core, 2.40 GHz, 10MB, 80W) 1 processor, 8GB RAM, 4 x 300GB 2.5"" SAS HDD SFF. 1Gb 331FLR Ethernet Adapter 4 Ports, 1 x 460w CS Gld Power Supply. Smart Array P420i 512MB FBWC, 2U Form Factor + DVD-RW Optical Drive 	1
8	Wireless Control System (WCS)	Cisco Wireless Control System (WCS)	1

6.4.1 Geiger Mueller Counter (GMC) Radiation detector

The proposed radiation detector is the GQ GMC-320-Plus as shown earlier in Figure 6.3 because of its features as highlighted in subsection (6.2.1.3) as compared to the earlier versions.

6.4.2 NI my RIO Micro Controller

This serves as the processor board often referred to as the most important module which contains components for data acquisition, processing, and communication (Liu *et al*. 2005). However, it is the proposed micro controller (See Figure 6.9) for this design. According to NI (2014), the following are its specifications:

- Affordable tool to teach and implement multiple design concepts with one device
- 10 analog inputs, 6 analog outputs, 40 digital I/O lines
- Wireless, LEDs, push button, accelerometer onboard
- Xilinx FPGA and dual-core ARM Cortex-A9 processor
- Programmable with NI Lab VIEW or C; adaptable for different programming levels

.

Figure 6.9: NI my RIO Micro Controller

6.4.3 Cortex-A9 Processor

The ARM Cortex-A9 processor is a power-efficient and popular high performance in low power or thermally constrained cost-sensitive devices (ARM, 2014). It is available as a single processor solution offering an overall performance enhancement of well above 50% compared to ARM Cortex-A8 solutions. However, Cortex-A9 MPCore offers up to 4 processors delivering when needed, on lightweight workload as well as peak performance. Therefore, both the Cortex-A9MPCore and the Cortex-A9 application-class processors are supported by a rich set of features and ARMv7 architectural functionality so as to deliver a high-performance and low-power solution across both application specific and general purpose designs as shown on Table 6.8 (Embest, 2011; ARM, 2014):

Table 6.8: Features and Benefits of ARM Cortex-A9 processor (ARM, 2014)

Feature	Benefit
High-Efficiency Superscalar Pipeline	Industry leading performance with over 2.0 DMIPS/MHz for unprecedented peak performance while also maintaining low power for extended battery life and lower cost packaging and operation.
NEON Media Processing Engine	Accelerating media and signal processing functions for increased application specific performance with the convenience of consolidated application software development and support.
Floating-Point Unit	Provides significant acceleration for both single and double precision scalar Floating-Point operations. Double the performance of previous ARM FPU, this unit provides industry leading image processing, graphics and scientific computation capabilities.
Optimized Level 1 Caches	Performance and power optimized L1 caches combine minimal access latency techniques to maximize performance and minimize power consumption. Also providing the option for cache coherence for enhanced inter-processor communication or support of rich SMP capable OS for simplified multi-core software development.
Thumb -2 Technology	Delivers the peak performance of traditional ARM code while also providing up to a 30% reduction in memory required to store instructions.
Trust Zone Technology	Ensures reliable implementation of security applications ranging from digital rights management to electronic payment. Broad support from technology and industry Partners.
RCT and DBX Technology	Provides up to 3x reduction on code size for Just-in-time (JIT) and ahead-of-time compilation of byte code languages while also supporting direct byte code execution of Java instructions for acceleration in traditional virtual machines.
L2 Cache Controller	Providing low latency and high bandwidth access to up to 2 MB of cached memory in high frequency designs, or design needing to reduce the power consumption associated with off chip memory access.
Program Trace Macro cell and Core Sight Design Kit	Together these components provide the software developer with the ability to non-obtrusively trace the execution history of multiple processors and either store this, along with time stamped correlation, into an on-chip buffer, or off chip through a standard trace interface so as to have improved visibility during development and debug.

6.4.4 Switches

The proposed switch is Cisco Catalyst 2960 as shown in Figure 6.10 below. It is an intelligent Ethernet Switches that provides 10/100 fast Ethernet and 10/100/1000 Gigabit Ethernet connectivity. With Power over Ethernet (PoE), it is new of the Cisco Catalyst 2960 Series of fixed-configuration standalone switches for entry-level enterprise, midmarket, and small branch office networks. It supports 24 simultaneous full-powered PoE ports at 15.4W. Table 6.9 shows detailed specification of the switch.

Figure 6.10: Cisco Catalyst 2960 24 10/100 PoE + 2 T/SFP LAN (Provantage, 2014a)

Table 6.9: Specifications of Cisco Catalyst 2960 24 10/100 PoE + 2 T/SFP LAN (Provantage, 2014a)

Product Name	Catalyst 2960 24 10/100 PoE + 2 T/SFP LAN
Product Type	Ethernet Switch
Manageable	Yes
Ethernet Technology	Fast Ethernet
Product Family	Catalyst 2960
Media Type Supported	Twisted Pair
Total Number of Network Ports	24
PoE (RJ-45) Port	Yes
Form Factor	Rack-mountable
Network Technology	10Base-T & 10/100Base-TX
Green Compliant	Yes
Green Compliance Certificate/Authority	RoHS
Number of Total Expansion Slots	2
Port/Expansion Slot Details	2 x Gigabit Ethernet Expansion Slot
Height	1.7"
Width	17.5"
Depth	13"
Expansion Slot Type	SFP
Product Series	2960
Product Model	2960-24PC-L
Product Line	Catalyst
Input Voltage	110 V AC & 220 V AC
Layer Supported	2
Twisted Pair Cable Standard	Category 5
Number of SFP Slots	2
Shared SFP Slot	Yes
Memory Technology	DRAM
Management	CLI, Telnet, HTTP, Syslog, DHCP, RMON, IEEE 802.1p QoS, IEEE 802.1Q VLAN, SNMP v1, v2, v2c, v3 & Cisco Works LAN Management Solution
Flash Memory	32 MB
Power Source	Power Supply
Standard Memory	64 MB
Limited Warranty	Lifetime

6.4.5 Wireless Controller

The proposed wireless controller is Cisco 2504 (See Figure 6.11) designed for 802.11n performance which provides real-time communication between Cisco Aironet access points to simplify the deployment and operation of wireless networks (Provantage, 2014b). However, as a component of the Cisco Unified Wireless Network, it delivers centralized security policies, wireless intrusion prevention system (WIPS) capabilities, scalability and performance for 802.11n networks.

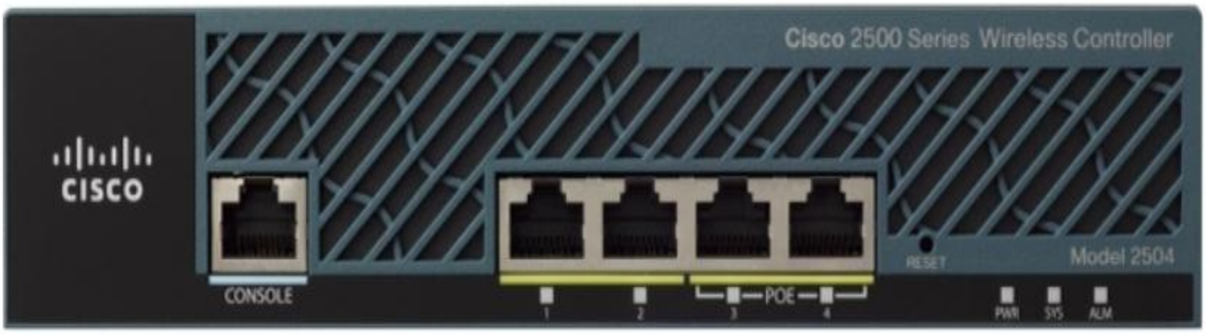


Figure 6.11: Cisco 2504 Wireless Controller with 15 AP Licenses (Provantage, 2014b)

6.4.6 Core Switching

The proposed core switching is the Cisco Catalyst 3560-X enterprise as shown below in Figure 6.12, stackable and standalone switch with the following features: high availability, scalability, security, energy efficiency, and ease of operation with innovative features such as Cisco Stack Power, IEEE 802.3 at Power over Ethernet Plus (PoE+) configurations, optional network modules, redundant power supplies, and Media Access Control. Hence, it also provides ease of management, enhances productivity by enabling applications such as IP telephony, wireless, and video for borderless network experience (Provantage, 2014c).

Figure 6.12: Cisco WS-C3560X-24P-E Catalyst 3560-x 24 Port Gbe PoE Ip Services (Provantage, 2014c)

6.4.7 Mesh Access Point

A wireless Access point (AP) is a computer hardware that allows wireless communication to connect to a wireless network by providing a bridge for data communication between wireless and wired devices such as personal digital assistants (PDA) and mobile computers

(GHKSAR, 2010). It is the core of the network (GHKSAR, 2010; Akyildiz *et al*. 2005; Badia *et al*. 2008). Therefore, the proposed AP for this design is Cisco Aironet 1552E (See Figure 6.13) known for creating self-healing, and self-optimizing in wireless network. It also offers a flexible, secure, and scalable mesh network for high-performance mobility across large metropolitan-sized areas, enterprise campuses, manufacturing yards, and mining pits. Hence supports multiple-device and multiple-network application delivery such as real-time seamless mobility, video surveillance, 3rd Generation (3G) and 4G data offload, and public and private Wi-Fi access (FrontierPC, 2013). Hence, its security clearly has an overall effect on the security of the wireless network and securing it is mandatory in protecting the entire network. As the backbone of the WMN, Mesh Access Point (MAP) known as Mesh Relay (MR) physically covers a large region wirelessly. It can also be provided with a wired connection, and acts as a gateway to the Internet. However, the Mesh Client (MC) interacts only with the MR connected to (Badia *et al*. 2008). Access points have multiple radios. For instance, an 802.11n access point has a 2.4-GHz and 5-GHz radio. This makes it possible to maintain some clients operating on 2.4-GHz channels and some clients operating on 5-GHz channels, which could support both 802.11g and 802.11n client radios on the same network (Geier, 2010). Similarly, Cisco (2012) noted that it is a modularized wireless outdoor 802.11n AP designed for use in a mesh network which supports point-to-multipoint mesh wireless connectivity and wireless client access simultaneously. However, the AP can also operate as a relay node for other APs that are not directly connected to a wired network. Intelligent wireless routing is provided by the Adaptive Wireless Path Protocol (AWPP). Besides its supports for two radios (2.4-GHz and 5-GHz), it also provides client access without the need for a license (Cisco, 2013; Cisco, 2012). The 5-GHz radios are primarily used for backhaul operations to reach a wired network and the 2.4-GHz radio is used for wireless clients. According to Gkelias and Leung (2008), for wide area access, the access points are typically located at high towers or at the rooftop of buildings. As the capacity demand increases, the AP is moving closer to the user and it could be placed at below-the rooftop heights. In this way it can provide better signal reception and higher spatial frequency reuse factor. However, in order to reduce the deployment cost and being closer to the users, the APs and relay nodes of WMN are mostly mounted at low to moderate heights of 3- 10m on electrical and telephone poles, traffic lights, building sidewalls and rooftops where direct Line of Sight (LOS) is difficult to be guaranteed. Depending on the relative position of the AP we can have different communication scenarios that highly affect the channel propagation statistics of Rooftop to Rooftop, Below-rooftop to Below-rooftop and Rooftop to Below-rooftop respectively. According to Geier (2010), a mesh node is the primary component of a mesh network. The Cisco Aironet 1552 series mesh access point is an example of a mesh node. Each mesh node includes an access point, which implements 802.11, and inter-node wireless connectivity to enable communications between mesh nodes. Therefore, client devices equipped with an 802.11 radio device connects to access point function of the mesh node. A single radio can implement both the access point and the inter-node wireless connectivity. In multi-radio mode, the access point can operate independently on a dedicated RF channel while the internodes communications take place on a different RF channel. In this case, communications between the client devices and the mesh node can occur simultaneously with the internodes communications. As a result, multi-radio mesh nodes provide better performance than single-radio solutions. These lightweight access points connect to a WLAN controller, which provides centralized enhancements for management, security, and performance. Accordingly, the optimum solution for providing electrical power to access points when installing a new, large-scale network is the integrated Power over Ethernet (PoE).

Figure 6.13: Cisco Aironet 1552E IEEE 802.11n 300 Mbps Wireless Access Point (FrontierPC, 2013; Das, n.d.)

6.4.8 Server

Server is the process that provides requested services for the Client (Yadav and Singh, 2009). The responsibility of Server may be distributed among different types of servers such as File Server, Print Server, Application Server, Mail Server, Fax Server, Directory Services Server, Web Server, Database Server, Transactions Server and others. With this design therefore, the server will be responsible for storing the data packets as well as running the GQ Geiger Counter Viewer and GQ Geiger Counter logger professional applications for the real-time monitoring. Therefore, the proposed server for this architecture is HP ProLiant ML350p Gen8 E5-2609 Tower Server (See Figure 6.14) and specification as shown on Table 6.10. Hence, Wireless Control System (WCS) application runs on a server platform with an embedded database which provides the scalability necessary to manage hundreds of Cisco wireless LAN controllers and Cisco Aironet lightweight access points (Cisco, 2007; Cisco, 2012).

Figure 6.14: HP ProLiant ML350p Gen8 E5-2609 (470065-762) Tower Server (dtcae, 2014)

Table 6.10: Specifications of HP ProLiant ML350p (dtcae, 2014)

Product Title	**HP ProLiant ML350p Gen8 E5-2609 (470065-762) TOWER SERVER**
Brand	HP
Model Number	470065-762
Warranty	1 Year
Standard Memory	8GB (1x8GB) RDIMM
Memory Slots	24 DIMM slots; Maximum, depending on model
Memory Type	2R x4 PC3L-10600R-9
Expansion Slots	(9) Maximum
Network Controller	1 GB 331i Ethernet Adapter 4 Ports per controller
Hard Drive Installed	4 x 300GB 2.5” SAS HDD SFF hard drive
Storage Controller	(1) Smart Array P420i/512MB FBWC
Optical Drive	DVD-RW
Form Factor	5U Tower
Infrastructure Management	iLO Management Engine, Insight Control (optional)
Power Supply	460Watt
Network Operating System	Microsoft Windows Server 2012
Antivirus Software	ESET NOD32 Antivirus for Business Edition

6.4.9 Wireless Control System (WCS)

The Cisco WCS is the proposed wireless application for this design because it is the ideal management platform for comprehensive lifecycle management of 802.11n and 802.11a/b/g enterprise-class indoor and outdoor wireless networks. It makes wireless LAN configuration, monitoring, and management as simple and as effective as wired systems management

(Cisco, 2012). The requirements and specifications for proper deployment are as shown in Table 6.11. However, the following are the features of Cisco WCS:

- It delivers a wide array of tools and resources with its extremely flexible platform, for effective planning, deployment, monitoring, troubleshooting, and reporting of WLANs that span campus, remote, national, and international locations.
- It provides clear visibility and control of the wireless LAN and RF environment from an easy-to-use, centralized interface.
- It simplifies all WLAN operations, helping to ensure smooth Wi-Fi performance, RF interference mitigation.
- It enhanced network security with Cisco Clean-Air and an optimal wireless experience for all mobile end users.
- It requires minimal support staffing to meet the most demanding operational requirements.

Table 6.11: Product Specification for Cisco WCS (Cisco, 2007; Cisco 2012)

Item	Specification
Operating Systems (Customer Supplied Server)	Cisco WCS can be deployed on a customer supplied server running one of the following operating systems: • Windows 2003 SP1 or greater • Redhat Linux AS/ES v4.0 • VMware ESX Server 3.0.1 or later. (Minimum hardware requirements for a dedicated and guaranteed VMware server. Intel Xeon Quad CPU; 3.15GHz, 8GB RAM, 200GB HDD)
Minimum Server requirements	Cisco WCS High-End Server • 3000 lightweight access points, 1250 standalone access points, 750 wireless LAN controllers • Two Intel Xeon Dual core CPU’s, 3.0 GHz, 8GB RAM, 200GB HDD
	Cisco WCS standard Server • 2000 lightweight access points, 1000 standalone access points, 150 wireless LAN controllers • Intel Dual core CPU’s, 3.2 GHz, 4GB RAM, 80GB HDD
	Cisco WCS Low-End Server • 500 lightweight access points, 200 standalone access points, 50 wireless LAN controllers • Intel CPU’s, 3.06GHz, 2GB RAM, 30GB HDD
	CiscoWorks WLSE Models 1130-19 or 1133 running Cisco WCS • 1500 lightweight access points, 100 wireless LAN controllers • Intel Pentium 4 CPU, 3 GHz, 3GB RAM, 38GB HDD
Minimum client requirements	Internet Explorer 6.0/SP1 or later
Management and security	SNMP v1, v2c, v3 and TACACS+
Managed devices	Cisco 2000, 2100, 4100 and 4400 Series Wireless LAN Controllers; Cisco Catalyst 6500 Series Wireless Services Module (WISM), Cisco Catalyst 3750G integrated Wireless LAN Controller, Cisco wireless Lan Controller Module (WLCM and WLCM-E) for integrated Services Routers, Cisco Aironet lightweight access points, Cisco Aironet lightweight outdoor mesh access points, Cisco Wireless Location Appliance and Cisco Spectrum Expert
Database	Integrated Solid Flow Engine SQL

6.5 Radiation Monitoring System Design

Figure 6.15 is the proposed radiation monitoring system design while Fig 6.16 is the block diagram representation. The architectural blueprint was made based on one Geiger counter (Radiation detector) with an Arm - Cortex, A9 Processor as a micro controller. On implementation, there will be as many Geiger and controllers at various locations of the facility to serve as nodes. As the Geiger increases, the Mesh Access point (MAP) also increases to improve the wireless coverage. The controller is wireless enabled with the primary function of aggregating the data packets coming from the Geiger and sending to the nearest MAP as a gateway through the wireless mesh link.

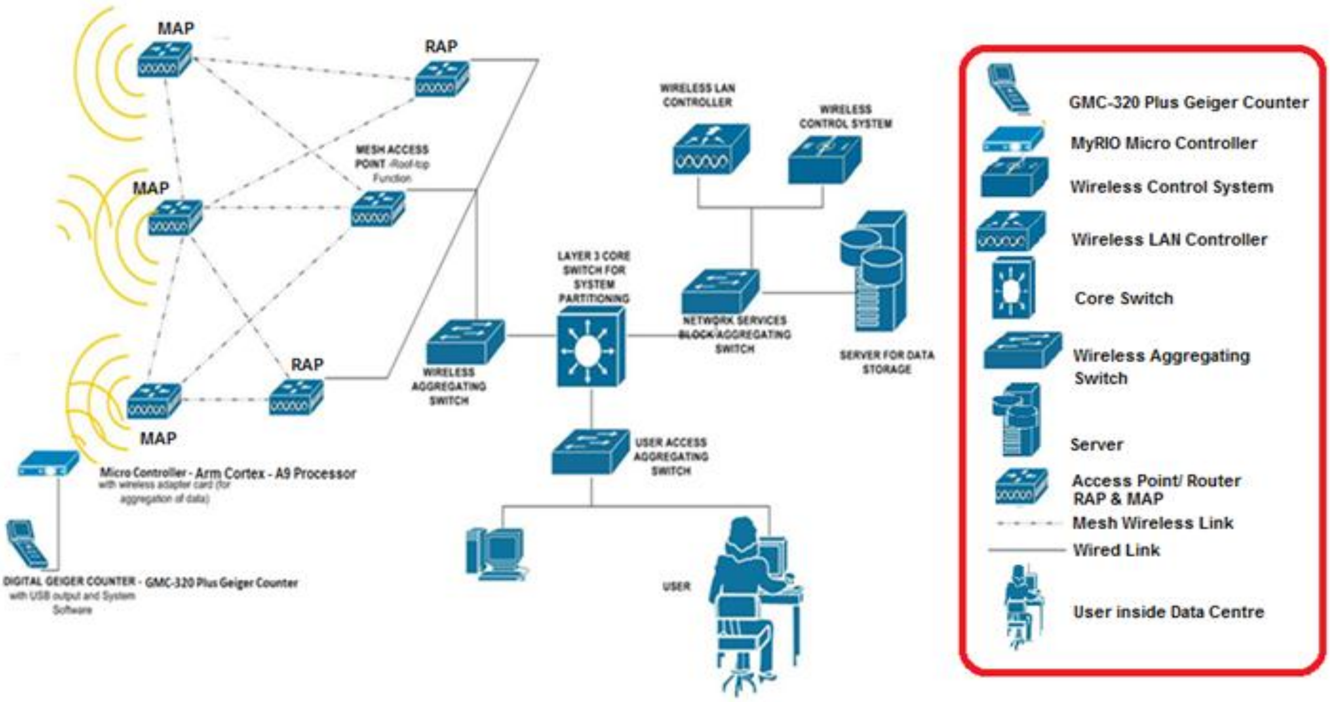


Figure 6.15: Radiation Monitoring System

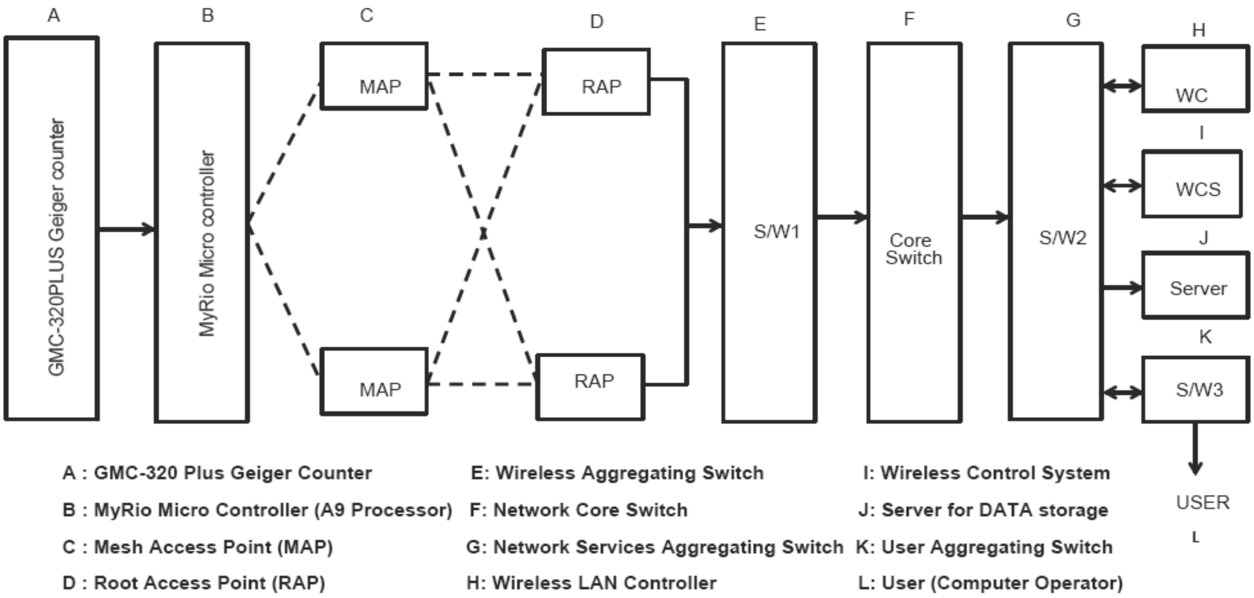


Figure 6.16: Block Diagram of Radiation Monitoring System

6.5.1 Data Packets Transmission

As shown in Figure 6.17 below, a packet radio station wishing to send a data packet must first listen to determine if another station is transmitting. If no other transmission is heard, then the sending station will transmit the packet in a broadcast mode using its omnidirectional antenna. Consequently, with most packet radio networks, the first station to receive the packet will be the neighbouring relay node. This relay will look in its routing table to determine which node to send the packet based on the final destination address. If the destination is located within range, the relay node will broadcast the packet again and the destination will receive it. If the final destination is not close by, the relay node will obtain the address and broadcast the packet to the next relay node closer to the destination. This process will continue until the packet reaches the destination (Server).

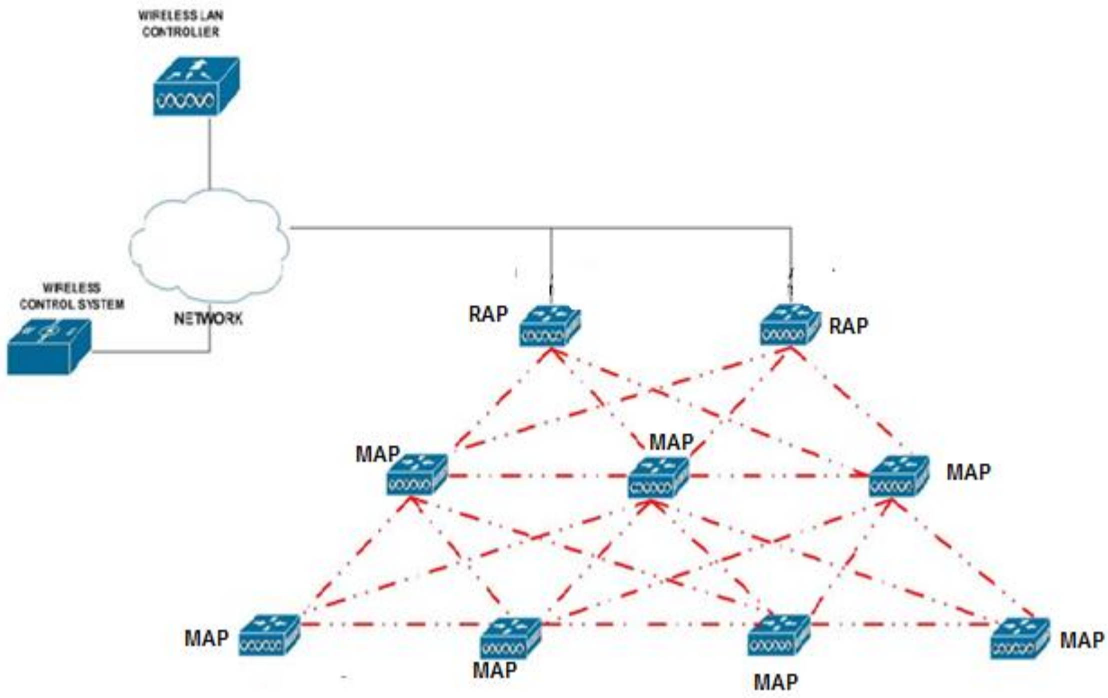


Figure 6.17: The Mesh Network Topology

However, the WLAN controller manages and monitors the mesh nodes, similar to AP. Each AP forms a radio cell, also called a basic service set (BSS), which enables wireless users located within the cell to have connectivity to it. The mesh nodes are actually Wi-Fi access points adapted to communicate wirelessly with each other using proprietary mesh protocols. Accordingly, each mesh node implements a routing protocol that routes packets between client devices and wired connections to the servers. Therefore, mesh nodes use proprietary routing protocols such as Cisco that uses Adaptive Wireless Path Protocol (AWPP). In this network design, it offers multiple paths from source to destination, and intelligent routing algorithms allow each node to make a decision on which path to forward packets through the network to improve performance. If the link between any pair of nodes is clogged, then the algorithms establish another path that avoids the congested link. Similarly, if a node goes down, an alternate route is chosen based on the routing algorithms.

6.6 WLAN Configuration

To implement an AP it is either controller-based solution or without. When it is without a controller, the AP is configured separately, but with a controller-based architecture, the controller will automatically configure each access point based on global settings by logging in to the management console on the wireless controller (Geier, 2010). Based on this design as shown in Figure 6.15 and “H” of the block diagram, it is a controller based architecture. Therefore, all the configuration and management is achieved with the wireless controller (WC). The following are the configuration details:

6.6.1 Enabling the 802.11n mode:

This will enable IEEE 802.11n standard of WLAN

6.6.2 Selecting Frequency band:

The Cisco Aironet 1552E AP is equipped with both 2.4-GHz and 5-GHz radios, either can be selected or both. In most cases, it is advantageous to operate using both bands.

6.6.3 Defining the SSID:

The SSID (Service Set Identification) is the name given to the WLAN that the client radios must have to associate with the network. It is generally best to use a common SSID for all APs to improve roaming for client devices.

6.6.4 Setting of Beacon:

Beacon contains all the information about the network. Beacon frames are transmitted periodically to announce the presence of a wireless LAN. The default interval is 100 milliseconds, but it may be beneficial to increase the beacon interval to allow power-save modes to operate in a manner that is more effective at conserving battery power.

6.6.5 Transmit Power:

The transmit power setting has significant impact on the range and performance of the WLAN. It may be beneficial, however, to operate AP at relatively low transmit power to facilitate a microcell wireless architecture, which can dramatically improve the capacity of the WLAN. Similarly, instead of operating at fixed power levels, automatic assignment method can be selected and the controller automatically adjusts the transmit power levels of the APs as environmental conditions change.

6.6.6 Transmission Channel:

Transmission channels should be set to specific non overlapping channels to avoid inter- AP interference and avoid other interference sources, such as microwave ovens and neighbouring WLAN. Apart from fixed RF channel assignment for each AP, Cisco also implements dynamic channel assignment configuration that automatically sets the RF channels of the 2.4 - GHz access points associated with the controller to channels 1, 6, or 11 as environmental conditions change.

6.6.7 Data Rate:

By default, all data rates generally apply. Data rate settings can impact the range of a WLAN.

6.6.8 Antenna Diversity:

Most APs have diversity antennas, but it is necessary to ensure that the diversity setting in the AP is configured correctly so that diversity is actually implemented. It is not set by default in all cases, so it is best to check and enable diversity to maximize range and performance.

6.6.9 Channel Width:

The 802.11n allows configuration of 20-MHz or 40-MHz channels. 40-MHz channels offer the greatest performance, but it is wise to only use 40-MHz channels in the 5-GHz band. Most APs do not allow configuration of 40-MHz channels in the 2.4-GHz band

6.6.10 Fragmentation Threshold:

It may be beneficial to set the fragmentation threshold to a lower value if RF interference is present. However, lower fragmentation thresholds generate greater overhead. Therefore, setting a lower threshold may reduce overall throughput instead of make it better.

6.6.11 RTS/CTS Threshold:

Request-to-send / clear-to-send (RTS/CTS) can improve throughout when hidden nodes are present. RTS/CTS can be activated for different frame sizes by setting the threshold to a value lower than the default setting.

6.7 Conclusion

We designed the environmental radiation monitoring system of a nuclear facility which is an important component of nuclear accident emergency system. This chapter proposed radiation monitoring system based on IEEE 802.11n wireless mesh network solution which includes nuclear radiation dose collection terminal, wireless transmission system solutions and data processing centre. However, in the nuclear industry, even though, the controlled release of radionuclide’s to the atmospheric and aquatic environment is a legitimate waste management practice, its uncontrolled releases may occur as a result of nuclear or radiological accidents. Therefore, an important and essential element in the control of the discharges is regular monitoring at the source of the discharge as well as the receiving environment thereby ensuring the protection of the public and the environment against the harmful effect of ionizing radiation.

CHAPTER SEVEN

MODELLING AND SIMULATION

7.1 Introduction

Following the design of radiation monitoring system in the previous, this chapter focuses on the modelling and simulation of the radiation monitoring system models (Appendices A, B, C and D). Based on this, we established the minimum radiation level for these models by using the average background radiation level as shown in Table 6.6. However, in a nuclear environment, the radiation level will be a bit higher than the background radiation level due to the presence of nuclear activities. But according to Hall (2012), the design target for maximum radiation at the perimeter fence of a nuclear electricity generating station is 0.05 mSv/yr.

Thus, from Table 6.6, the maximum radiation reading per hour was 0.145µSv/hr

Converting it to per year = 0.145 x (Hours x Days x Months) (7.1)

= 0.145 x = (24x30x12)

= 0.145 x 8640

= 1252.8µSv/hr

Converting to mSv $= \frac{1252.8}{1000}$

= 1.25mSv/year

With the reading of 1.25mSv/year (0.145µSv/hr) indicated that the background radiation reading is higher than the recommended limit for the public by ICRP. Therefore, in proposing any limit for the design, it must not exceed the recommended dose limit by ICRP of 1mSv for public in mSv/year.

But with an average reading of 0.063µSv/hr as in Table 6.6, the converted value of 0.54mSv/year as shown below is hereby recommended as it is below ICRP dose limit.

Converting it to per year = 0.063 x 8640 (7.2)

= 544.32µSv/hr

= 0.54mSv/year

Therefore, the minimum radiation level of 0.05 mSv/yr and maximum radiation level of 0.87mSv/year is hereby proposed for this system, with consideration to ALARA concept and ICRP recommendation of 1mSv/year allowable radiation exposure to the public.

Accordingly, based on the above factor and the significance of the research, it is necessary to investigate first the precautionary measures against external radiation sources which are time, distance and shielding that formed part of the design concepts and how they relate with the radiation monitoring system. Therefore, the following radiation intensities of 0.05 mSv, 2.5 mSv, 20 mSv, 250 mSv, 1000 mSv and 10000 mSv were subjected to various scenarios as shown below:

7.2 Effect of Time on Radiation exposure:

As explained earlier in the literature review, the longer time exposed to a radioactive source, the greater the dose that will be received.

7.2.1 CASE 1:

A. Therefore; with total exposure time to radiation of 30 minutes, Average dosage rate of 0.05mSv/min and with acceptable limit of radiation of 0.05mSv/min, we have Figure 7.1 below:

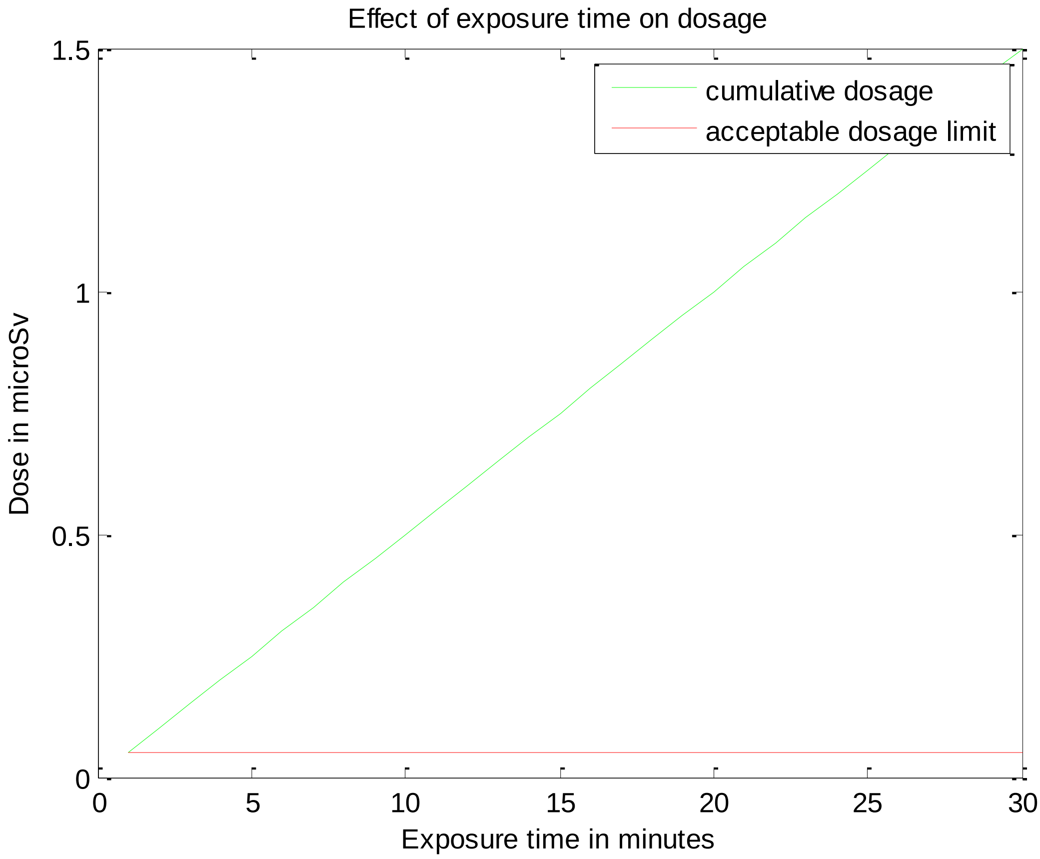


Figure 7.1: Effect of Time = 30 minutes on radiation exposure of 0.05mSv/min

This shows that the dose rate is directly proportional to the radiation dose received. The average dosage rate of 0.05mSv/min used in the above graph is the design target for maximum radiation at the perimeter fence of any nuclear power generating station. Even though in practice the actual dose may be less.

B. At 60 minutes period, we have as shown in Figure 7.2

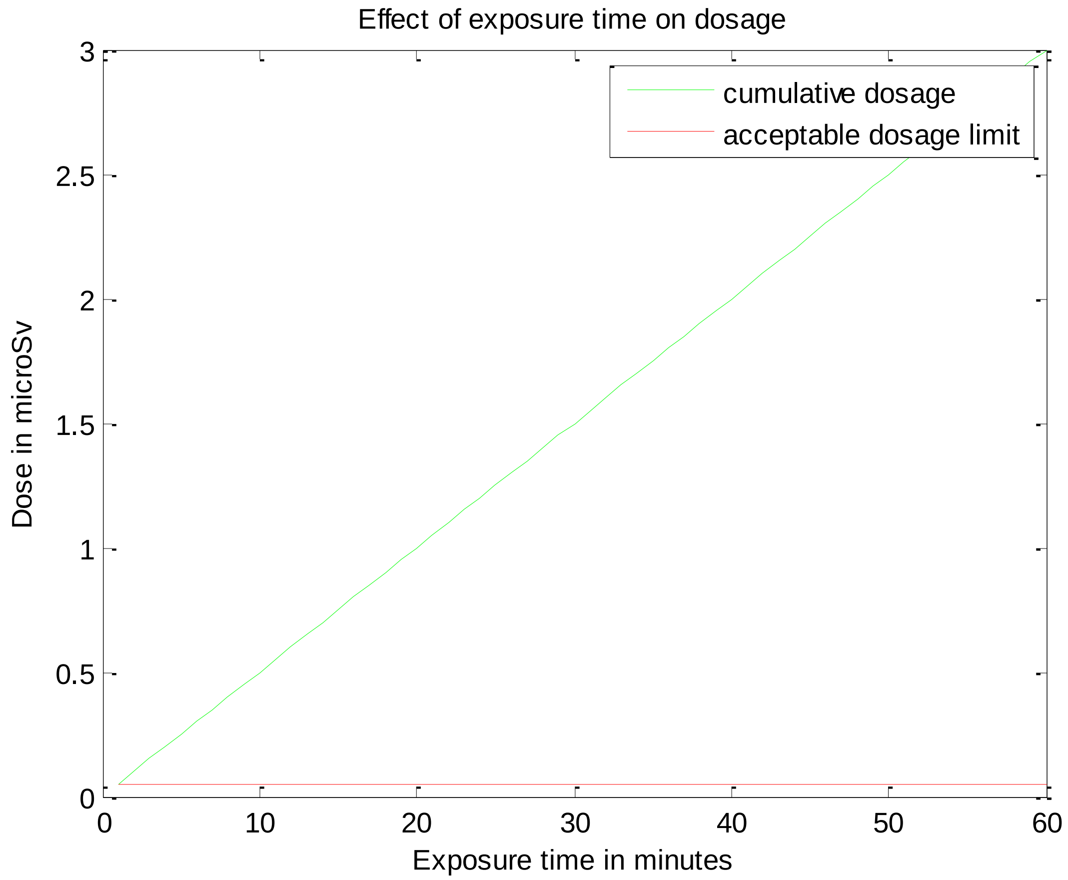


Figure 7.2: Effect of Time = 60 minutes on radiation exposure of 0.05mSv/min

7.2.2 CASE 2:

A. Figure 7.3 is the typical background radiation from natural sources of 2.5mSv /yr, including an average of 0.7 mSv/yr from Radon in air and the minimum dose received by all humans anywhere on Earth which amounts to 1.5 mSv/yr:

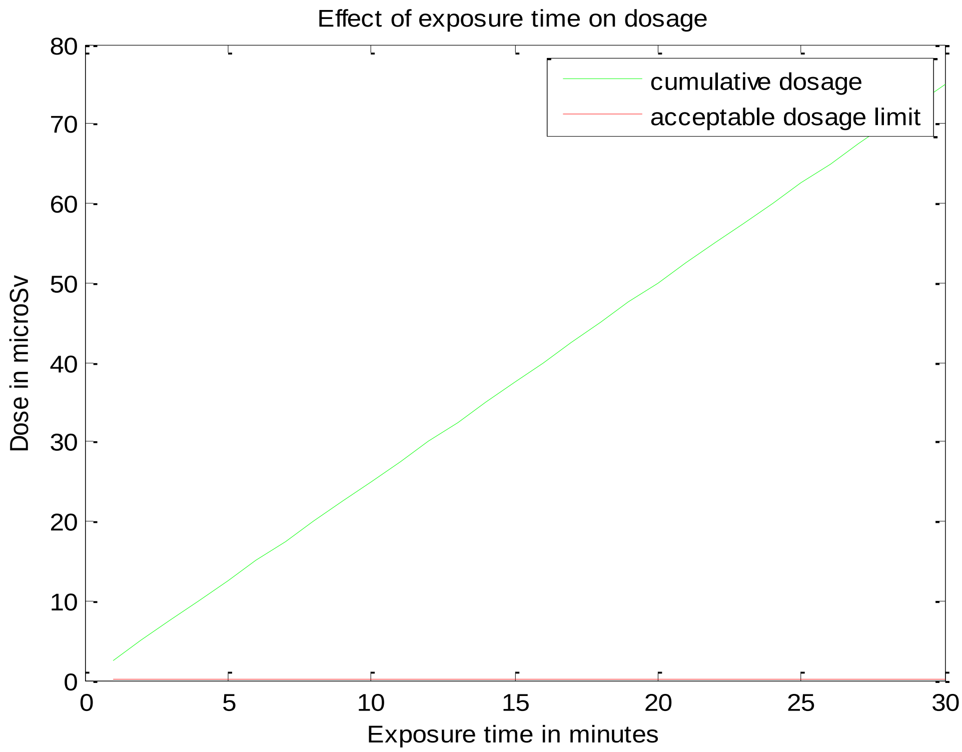


Figure 7.3: Effect of Time = 30 minutes on radiation exposure of 2.5mSv/min

B. At 60 minutes time, we have as seen in Figure 7.4 below:

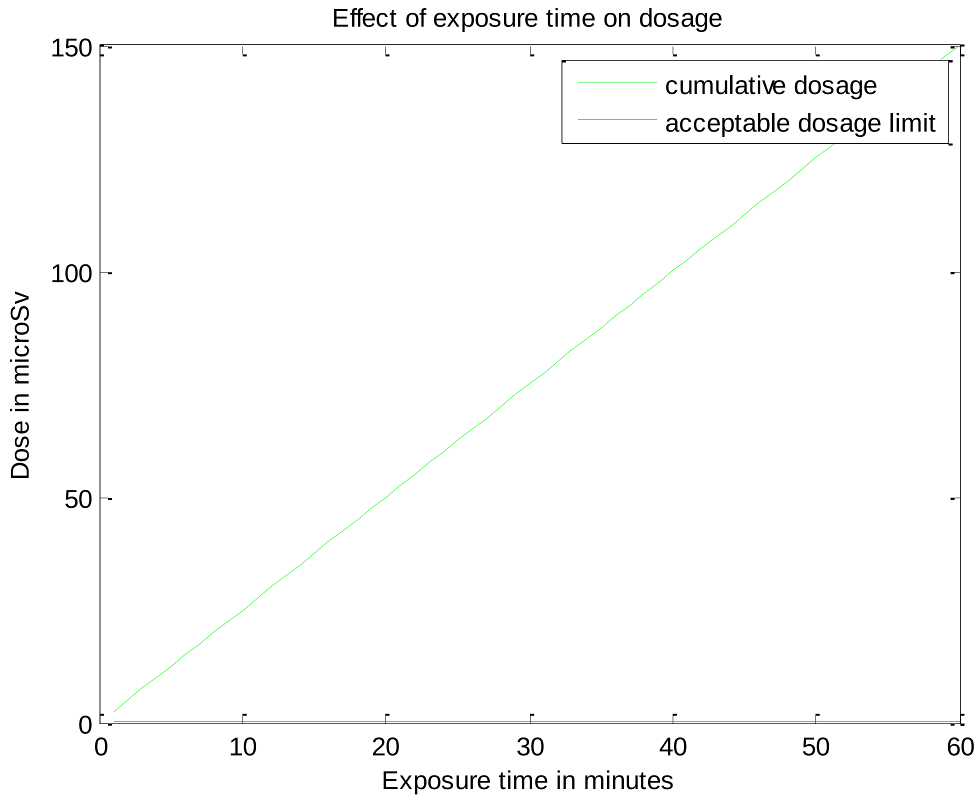


Figure 7.4: Effect of Time = 60 minutes on radiation exposure of 2.5mSv/min

7.2.3 CASE 3:

A. Figure 7.5 is an average radiation dose of 20mSv/yr limit for radiological personnel such as employees in the nuclear industry, uranium or mineral sand miners and hospital workers (who are all closely monitored) will give:

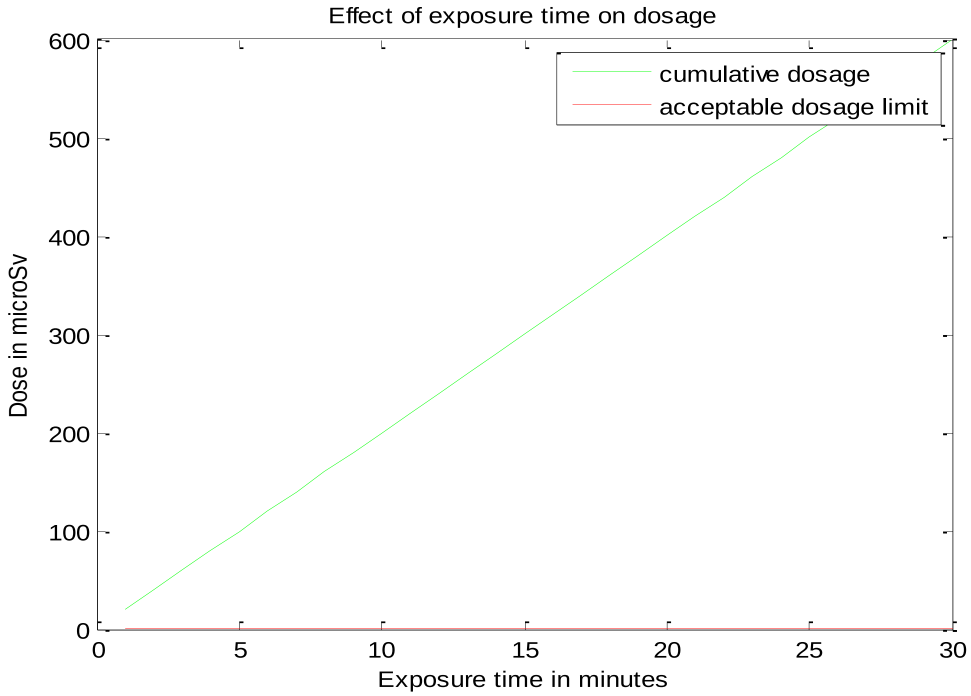


Figure 7.5: Effect of Time = 30 minutes on radiation exposure of 20mSv/min

B. At 60 minutes radiation Time we have Figure 7.6 below:

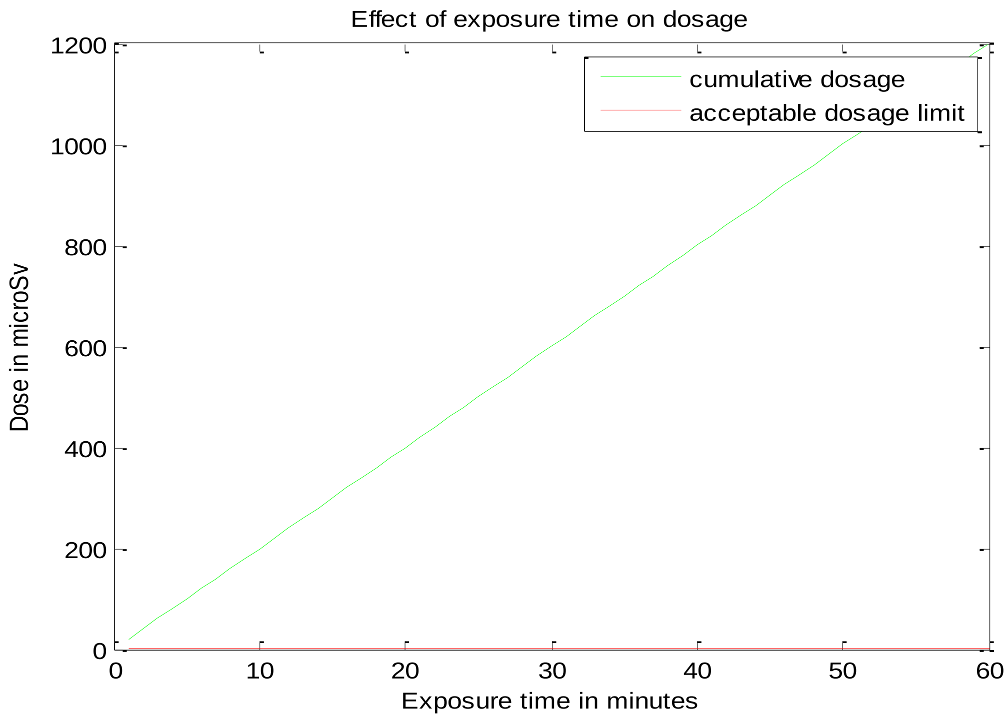


Figure 7.6: Effect of Time = 60 minutes on radiation exposure of 20mSv/min

7.2.4 CASE 4:

A. The maximum short-term dose allowable for workers controlling the Fukushima accident is 250mSv as shown in Figure 7.7:

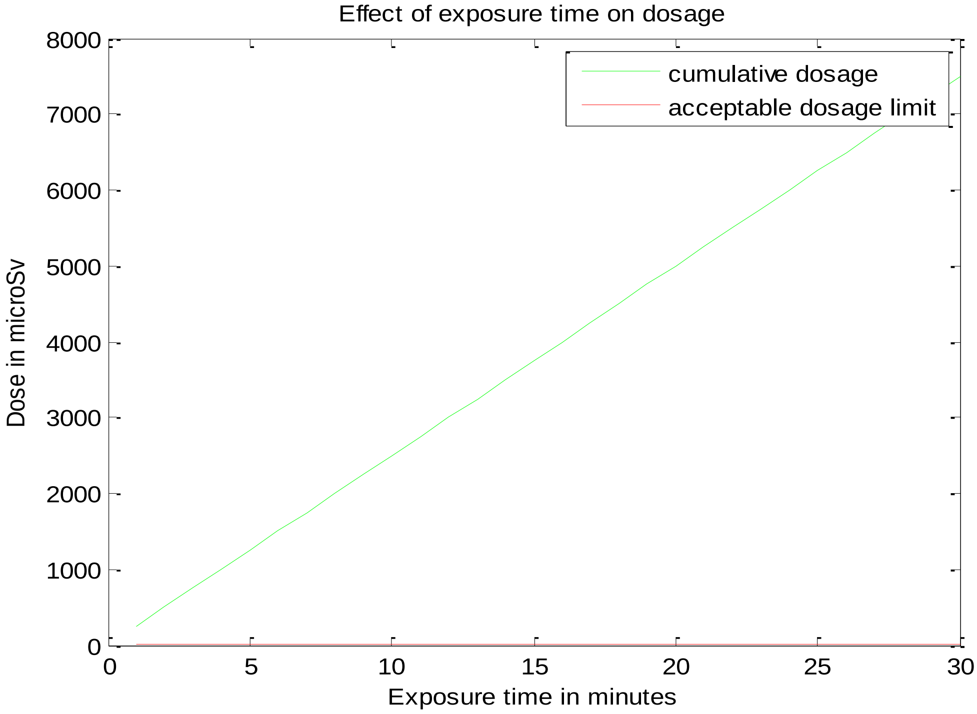


Figure 7.7: Effect of Time = 30 minutes on radiation exposure of 250mSv/min

B. At 60 minutes radiation Time, see Figure 7.8 below:

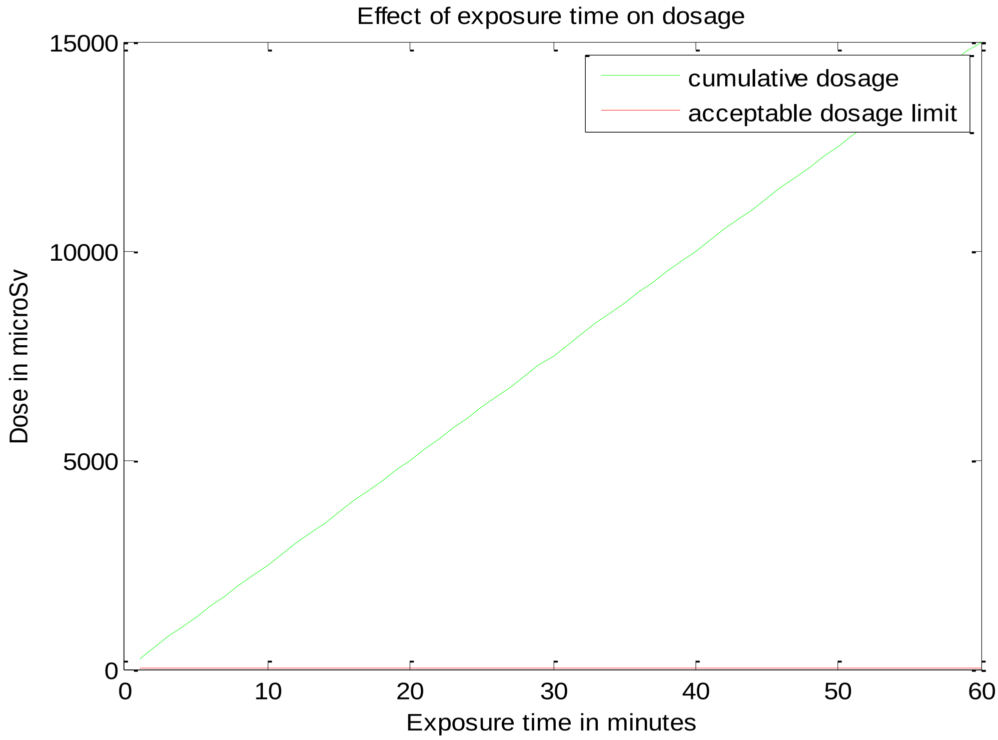


Figure 7.8: Effect of Time = 60 minutes on radiation exposure of 250mSv/min

7.2.5 CASE 5:

A. This is a short-term dose of 1,000mSv in the threshold that can cause immediate radiation sickness in a person of average physical attributes, but would unlikely cause death. However, severity of illness increases with dose and if it is for a long period may develop cancer many years in the future. This is as illustrated in Figure 7.9:

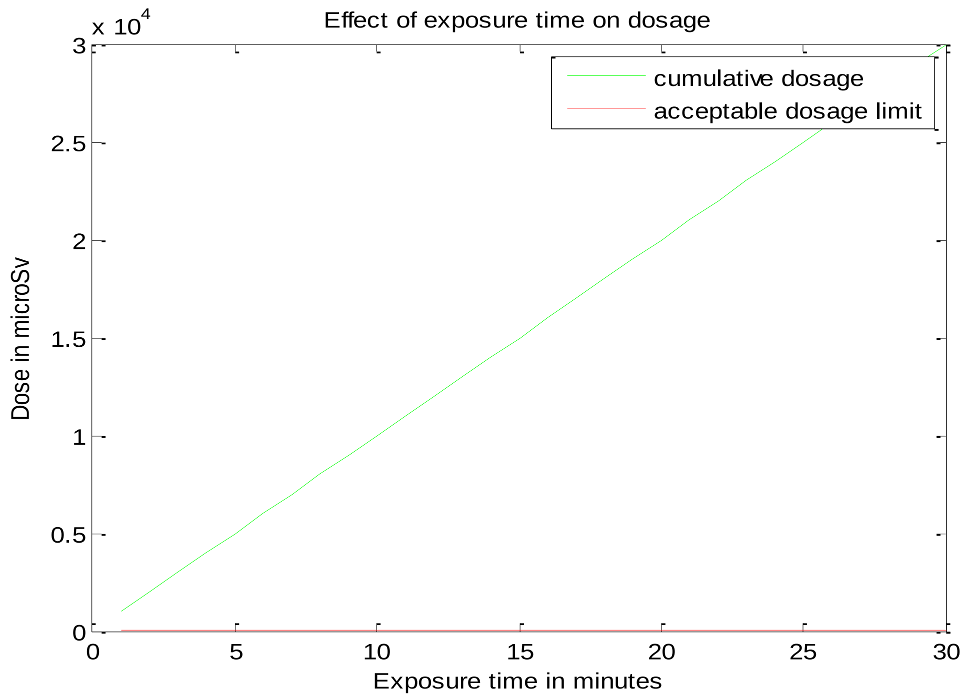


Figure 7.9: Effect of Time = 30 minutes on radiation exposure of 1000mSv/min

B. At 60 minutes radiation Time, we have Figure 7.10 below:

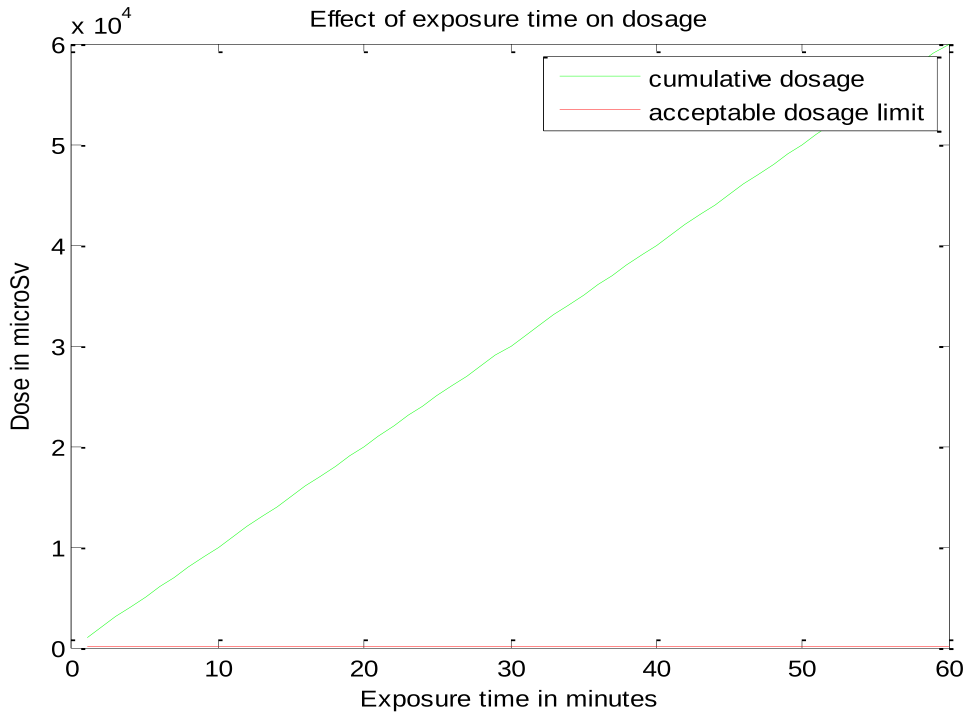


Figure 7.10: Effect of Time = 60 minutes on radiation exposure of 1000mSv/min

7.2.6 CASE 6:

A. Similarly, a dose of 10,000mSv which is referred to as a short-term and whole-body dose which would cause immediate illness, such as nausea and decreased white blood cell count, and subsequent death within few weeks is as shown in Figure 7.11:

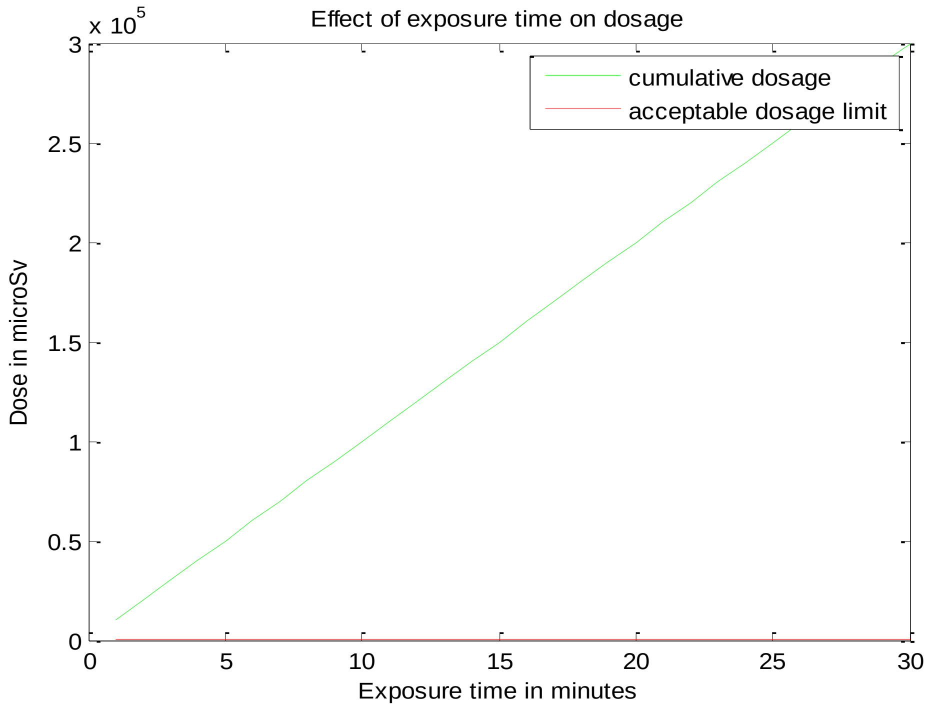


Figure 7.11: Effect of Time = 30 minutes on radiation exposure of 10000mSv/min

B. At 60 minutes radiation Time, we have Figure 7.12 below:

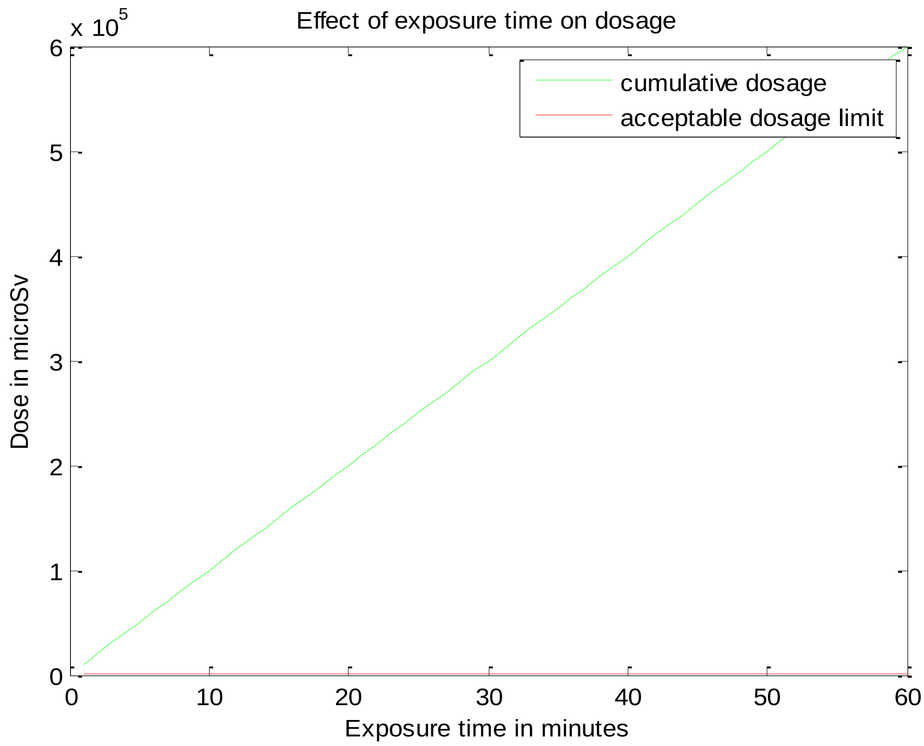


Figure 7.12: Effect of Time = 60 minutes on radiation exposure of 10000mSv/min

7.3 Effect of Distance on Radiation exposure:

According to the inverse square law which states that radiation intensity decreases sharply with distance and this is as illustrated further from the following graphical results:

7.3.1 CASE 1

A. The result of a distance of 10 meters from the initial point of radiation source and radiation intensity of 0.05 mSv with an acceptable dosage limit of 0.05 is as shown in Figure 7.13:

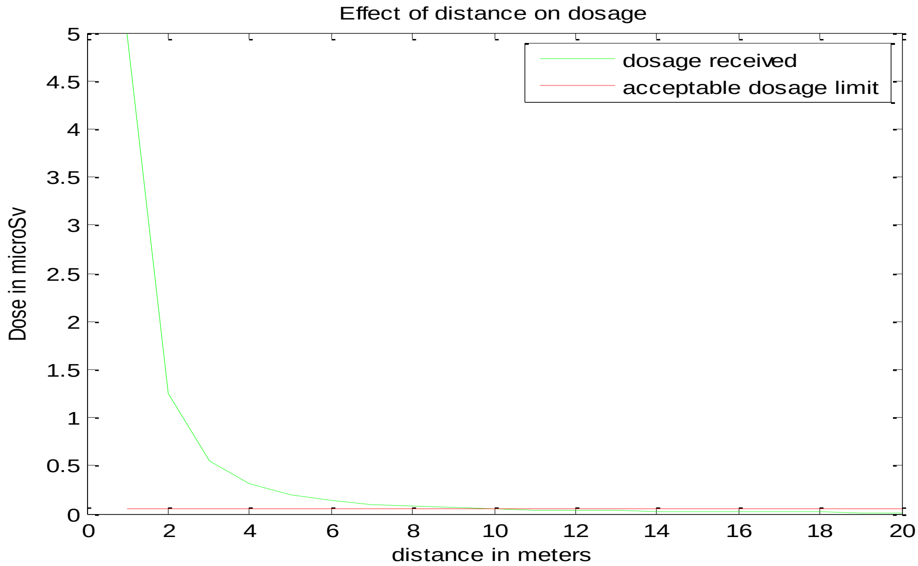


Figure 7.13: Effect of Distance = 10 meters on radiation exposure of 0.05 mSv

:

Therefore, the farther away from a radiation source, the less will be the received exposure.

B. With the same radiation intensity of 0.05 mSv, and the distance increased to 20 meters, we have Figure 7.14:

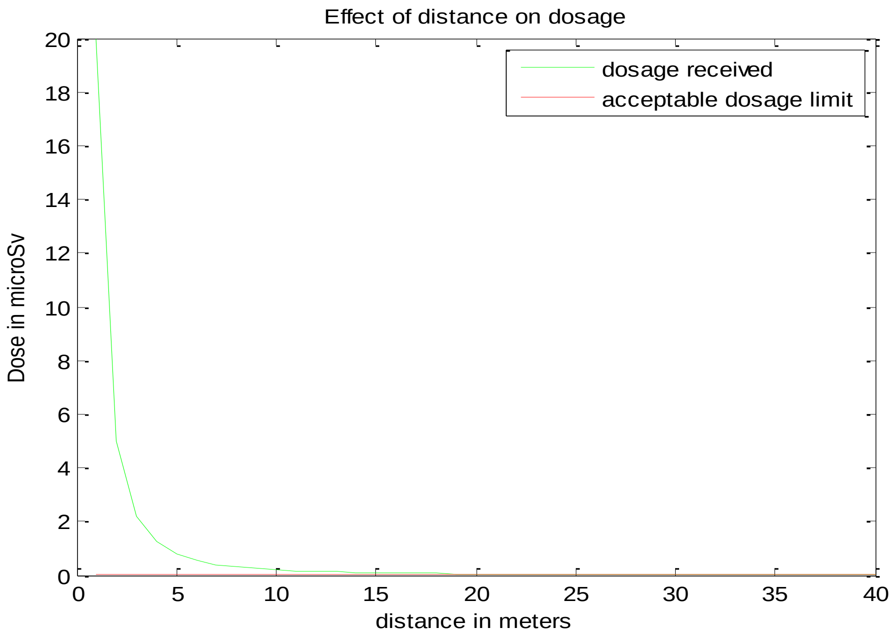


Figure 7.14: Effect of Distance = 20 meters on radiation exposure of 0.05 mSv

7.3.2 CASE 2:

A. Using a distance of 10 meters from the initial point of a radiation source, the radiation intensity of 2.5 mSv and an acceptable dosage limit of 0.05, we have Figure 7.15:

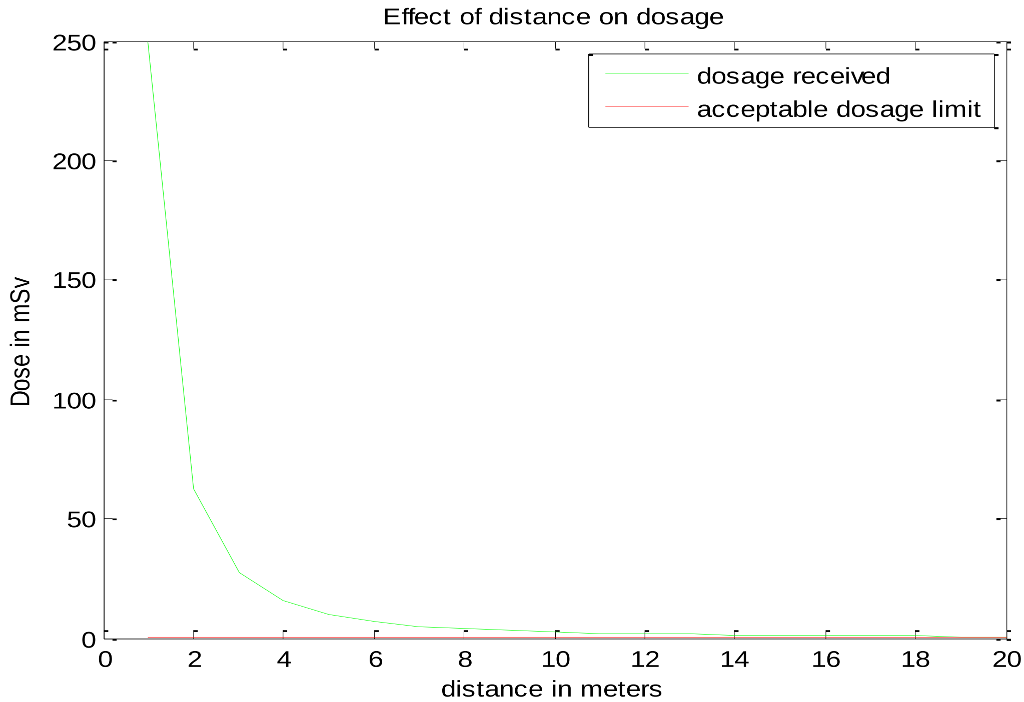


Figure 7.15: Effect of Distance = 10 meters on radiation exposure of 2.5 mSv

B. With the same radiation intensity of 2.5 mSv, and the distance increased to 20 meters, we have Figure 7.16 below:

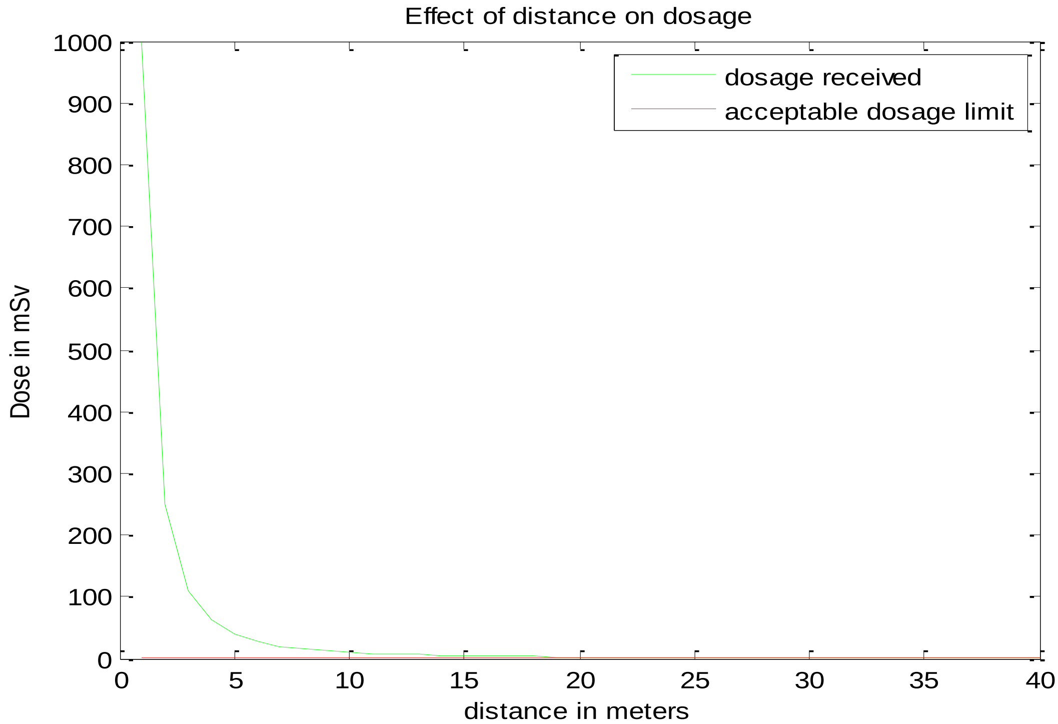


Figure 7.16: Effect of Distance = 20 meters on radiation exposure of 2.5 mSv

7.3.3 CASE 3:

A. Using a distance of 10 meters from the initial point of radiation source, the radiation intensity of 20 mSv and an acceptable dosage limit of 0.05, we have Figure 7.17:

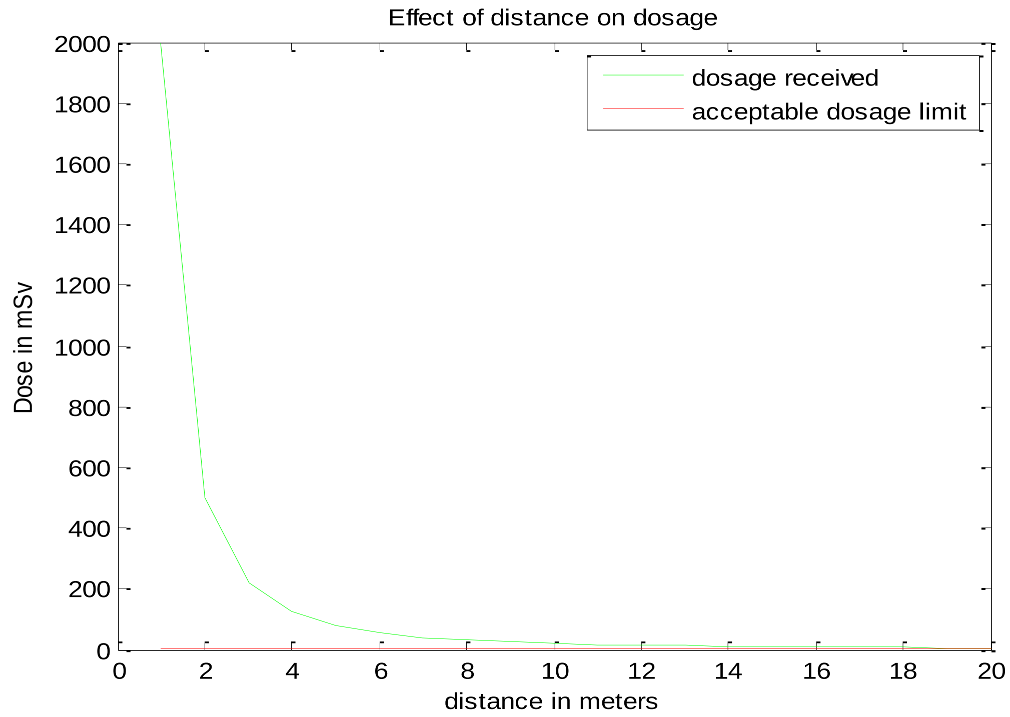


Figure 7.17: Effect of Distance = 10 meters on radiation exposure of 20 mSv

B. With the same radiation intensity of 20 mSv, and the distance increased to 20 meters, we have as shown in Figure 7.18:

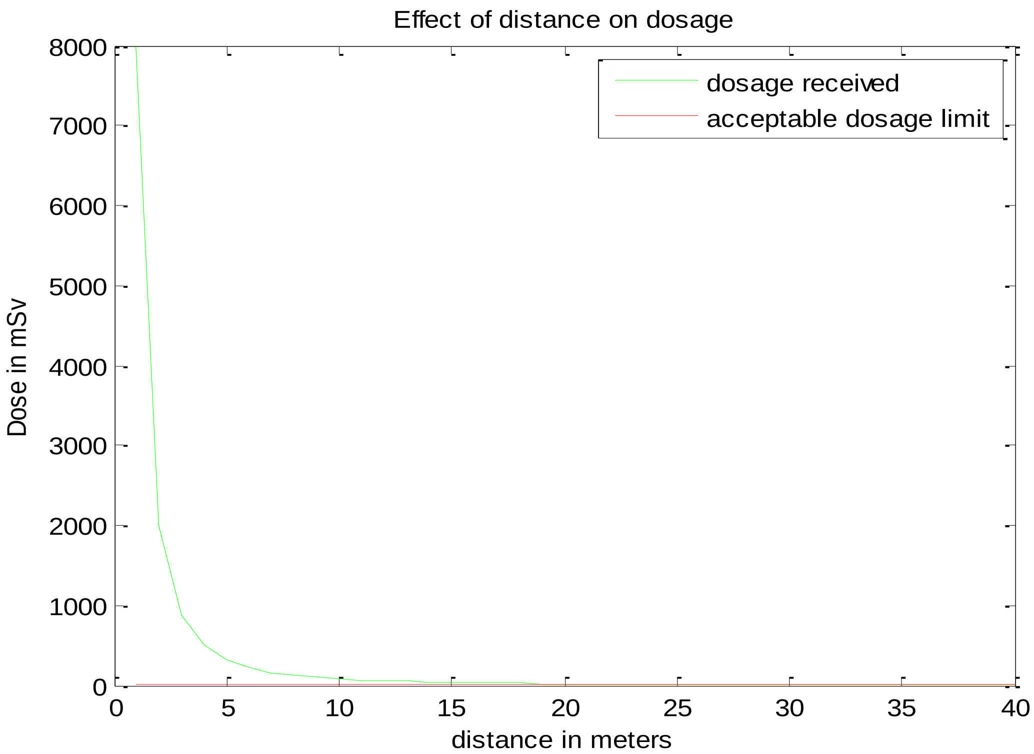


Figure 7.18: Effect of Distance = 20 meters on radiation exposure of 20 mSv

7.3.4 CASE 4:

A. Using a distance of 10 meters from the initial point of radiation source, with the radiation intensity of 250 mSv and an acceptable dosage limit of 0.05, we have Figure 7.19:

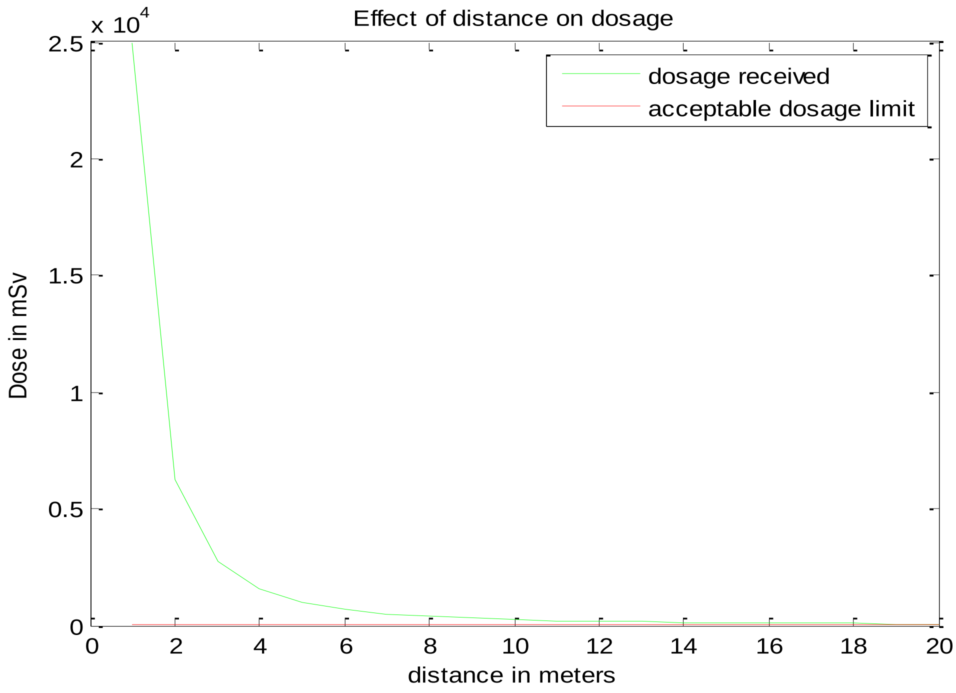


Figure 7.19: Effect of Distance = 10 meters on radiation exposure of 250 mSv

B. Increased distance to 20 meters with the same parameters will give Figure 7.20:

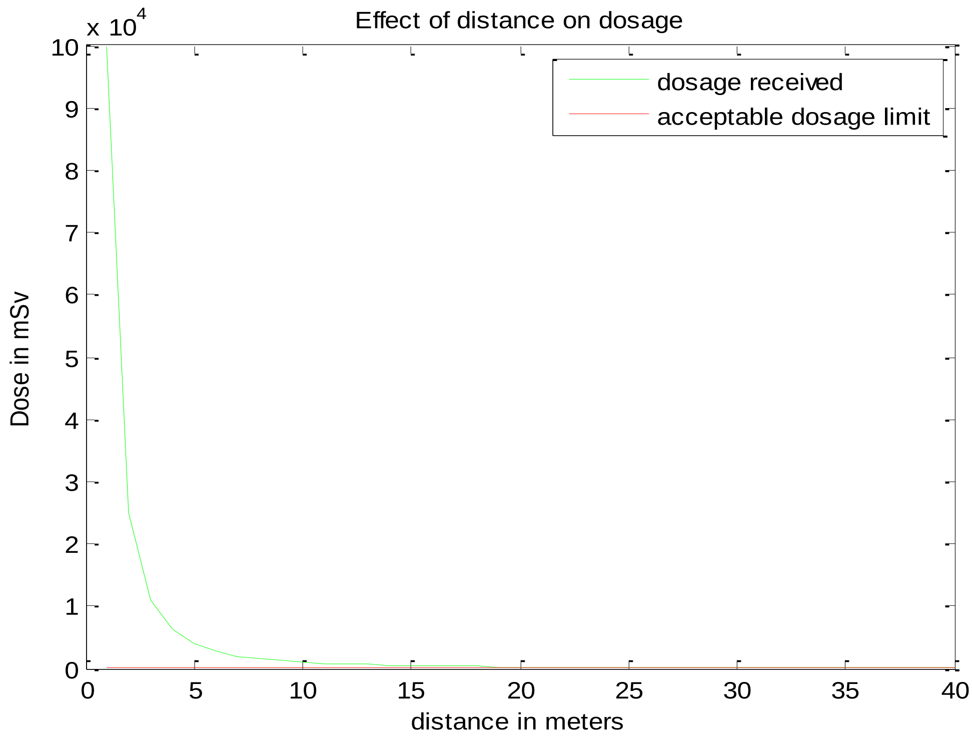


Figure 7.20: Effect of Distance = 20 meters on radiation exposure of 250 mSv

7.3.5 CASE 5:

A. Using a distance of 10 meters from the initial point of radiation source, with the radiation intensity of 1000 mSv and an acceptable dosage limit of 0.05, the result is as shown in Figure 7.21:

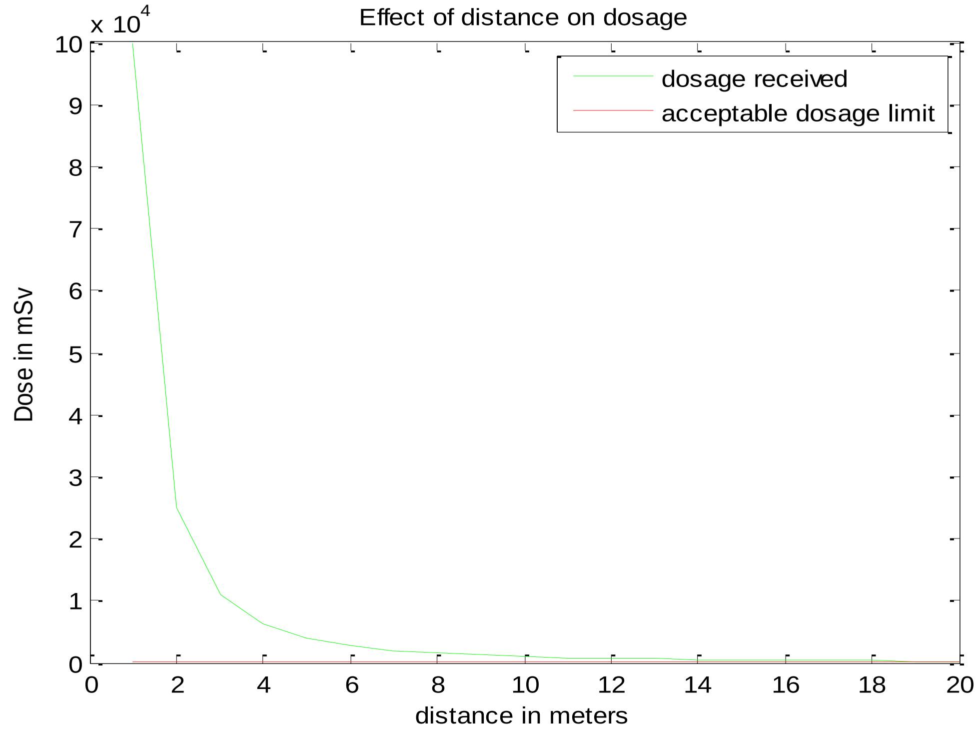


Figure 7.21: Effect of Distance = 10 meters on radiation exposure of 1000 mSv

B. With the distance increased to 20 meters and using the same parameters, gives Figure 7.22:

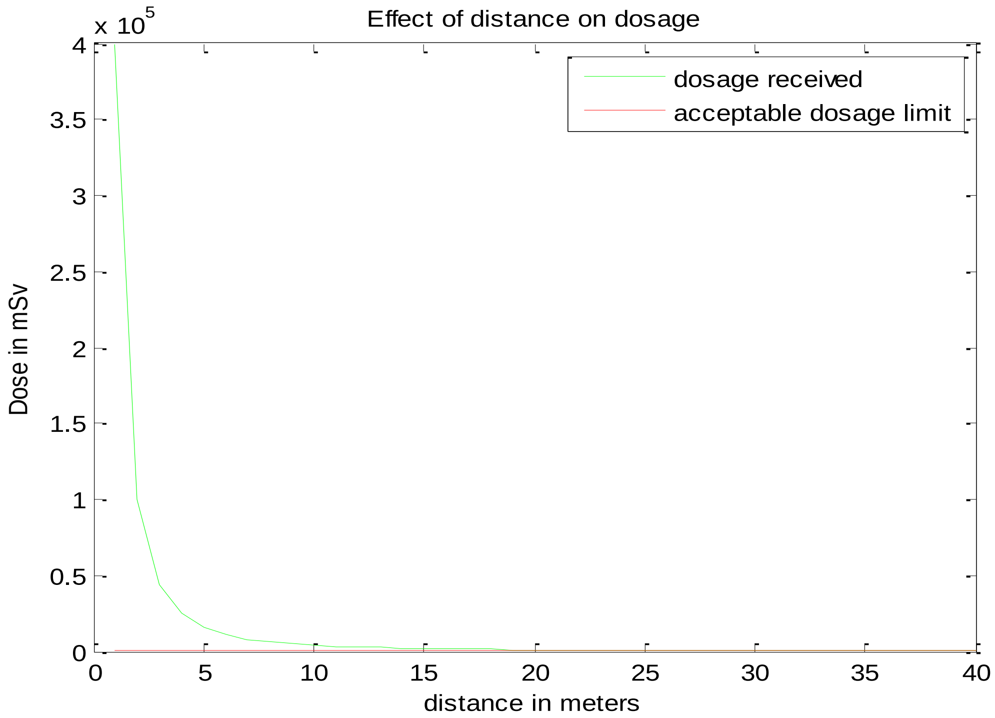


Figure 7.22: Effect of Distance = 20 meters on radiation exposure of 1000 mSv

7.3.6 CASE 6:

A. Using a distance of 10 meters from the initial point of radiation source, with the radiation intensity of 10000 mSv and an acceptable dosage limit of 0.05, gives Figure 7.23

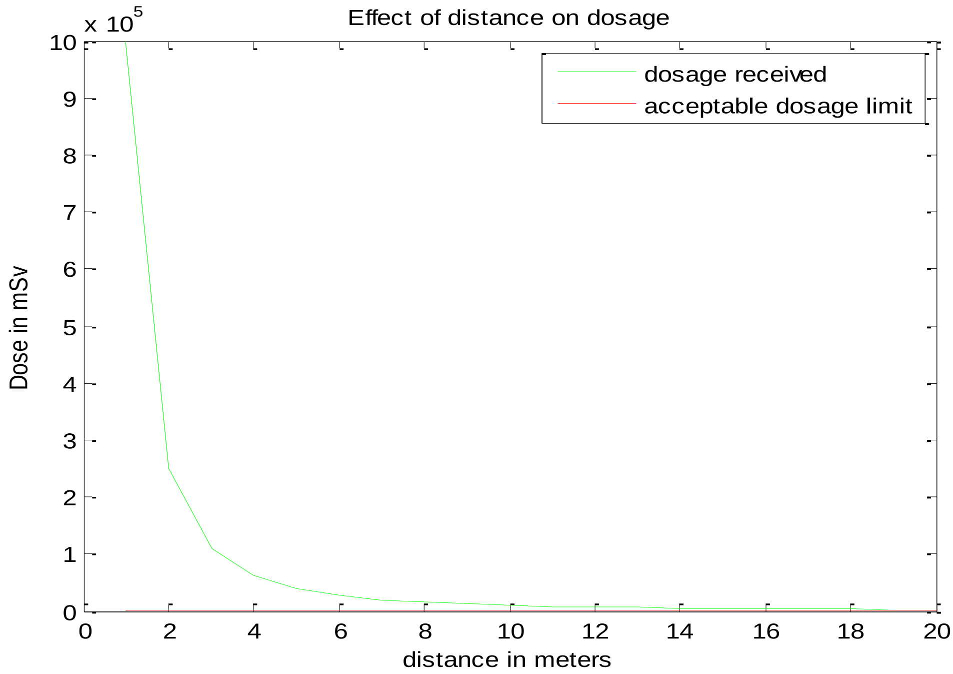


Figure 7.23: Effect of Distance = 10 meters on radiation exposure of 10000 mSv

B. But if the distance increased to 20 meters and using the same parameters, gives Figure 7.24 :

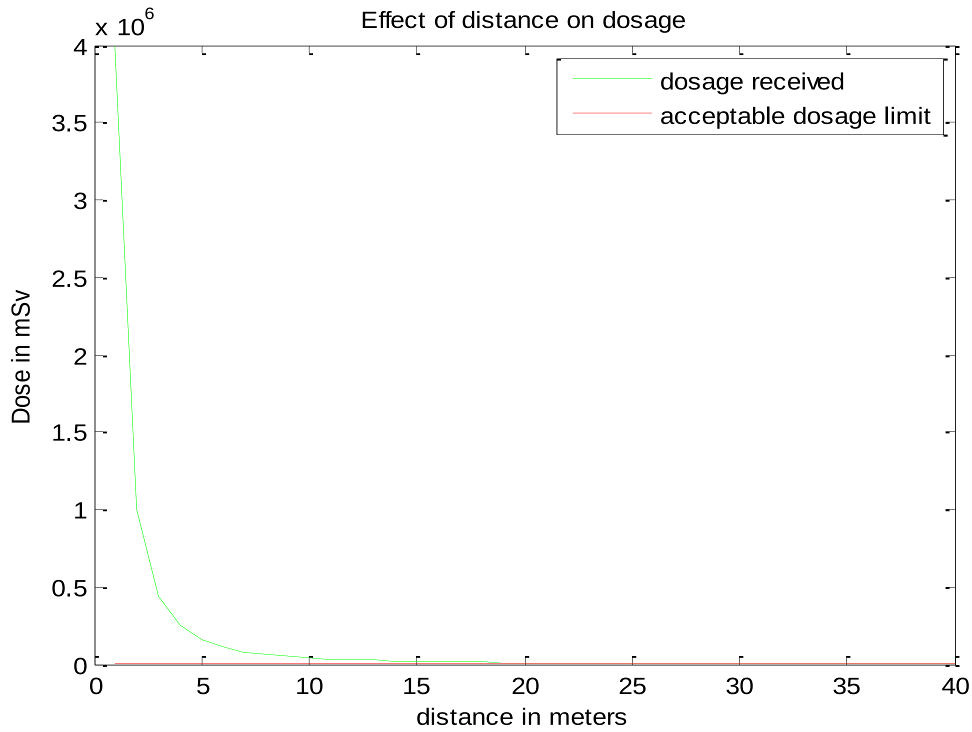


Figure 7.24: Effect of Distance = 20 meters on radiation exposure of 10000 mSv

7.4 Effect of Shielding on Radiation exposure:

The concept of the half value layer (HVL) can be used to understand shielding especially with the radiation from Gamma source. The more materials are made of subatomic particles, the greater the possibility of interactions which will make radiation to lose its energy. Therefore, the denser a material is, the smaller the depth of radiation penetration. The two major sources of Gamma propagation are Irridium-192 and Cobalt-60.

7.4.1 Irridium-192 with Radiation Intensity of 0.05 mSv

Using Concrete with HVL of 44.5 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv will give Figure 7.25 below:

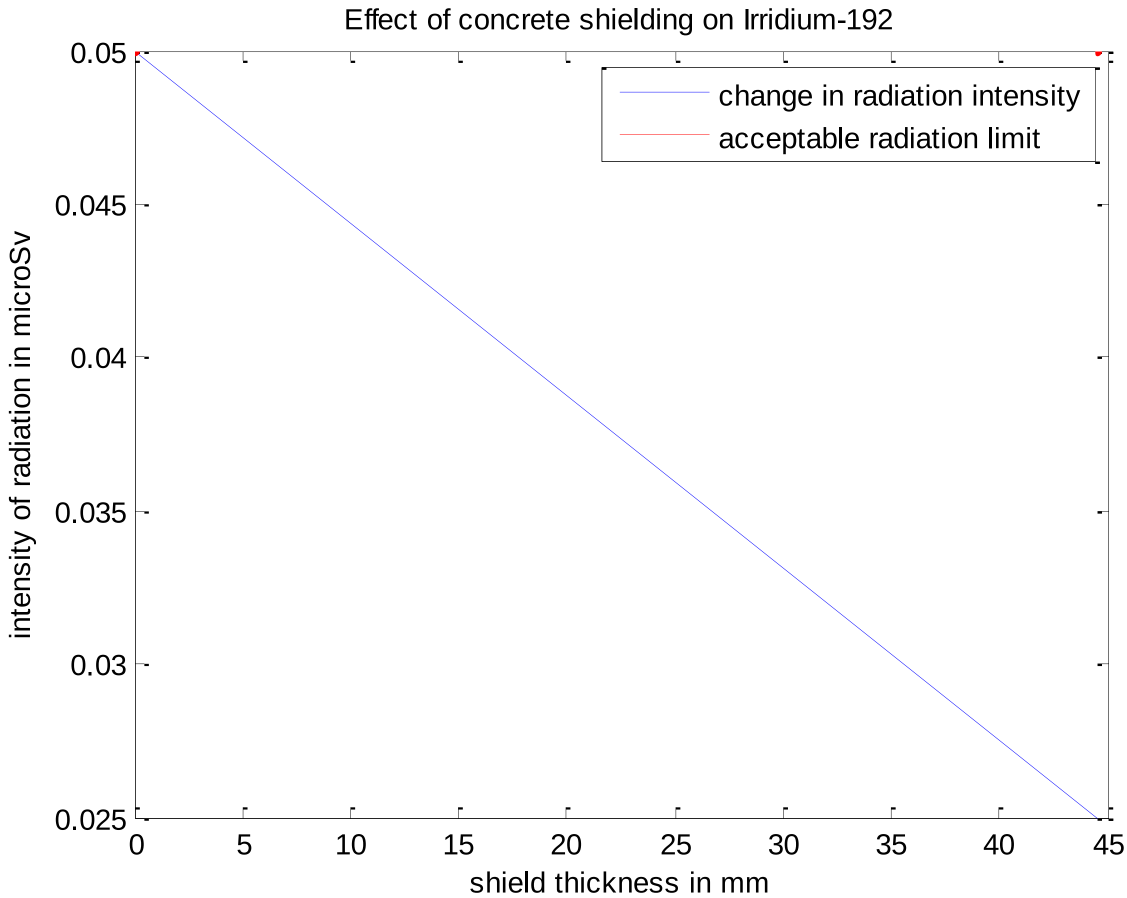


Figure 7.25: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv

Using Steel with HVL of 12.7 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv gives Figure 7.26 below:

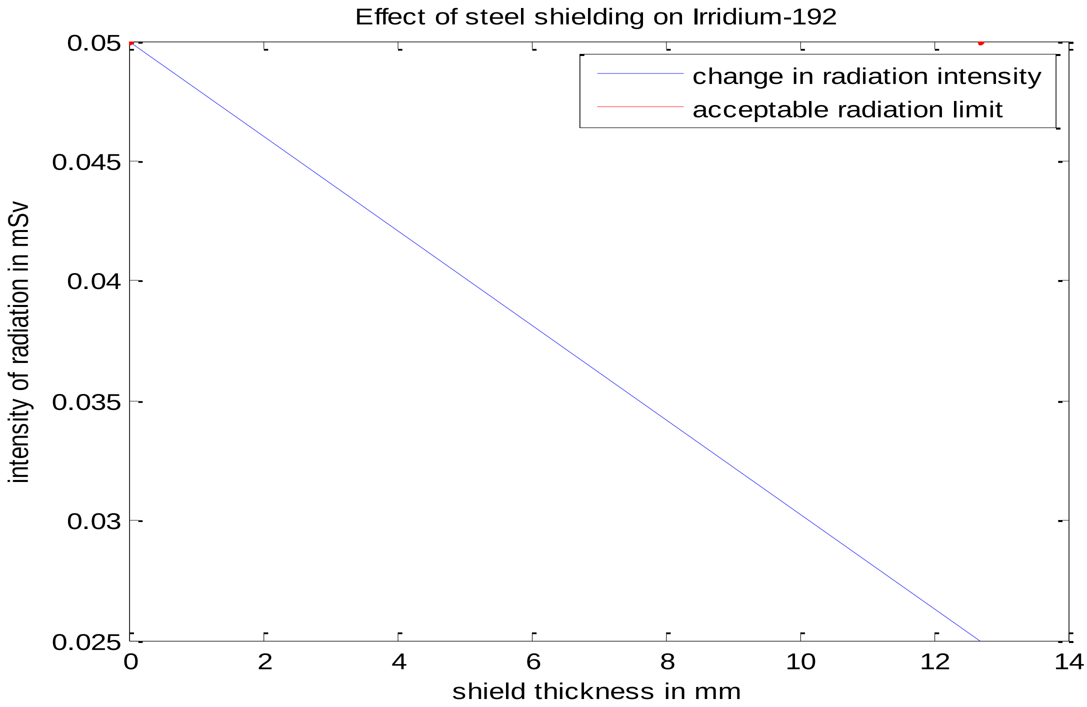


Figure 7.26: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv

Using Lead with HVL of 4.8 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv gives Figure 7.27 as shown:

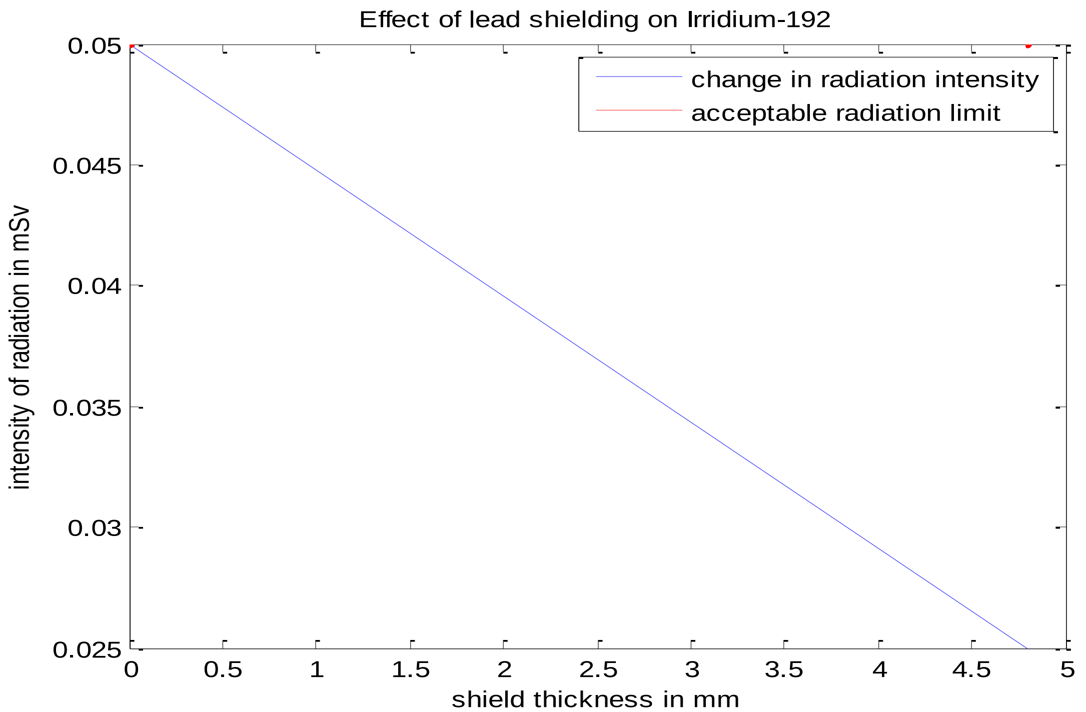


Figure 7.27: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv

Using Tungsten with HVL of 3.3 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv. See Figure 7.28:

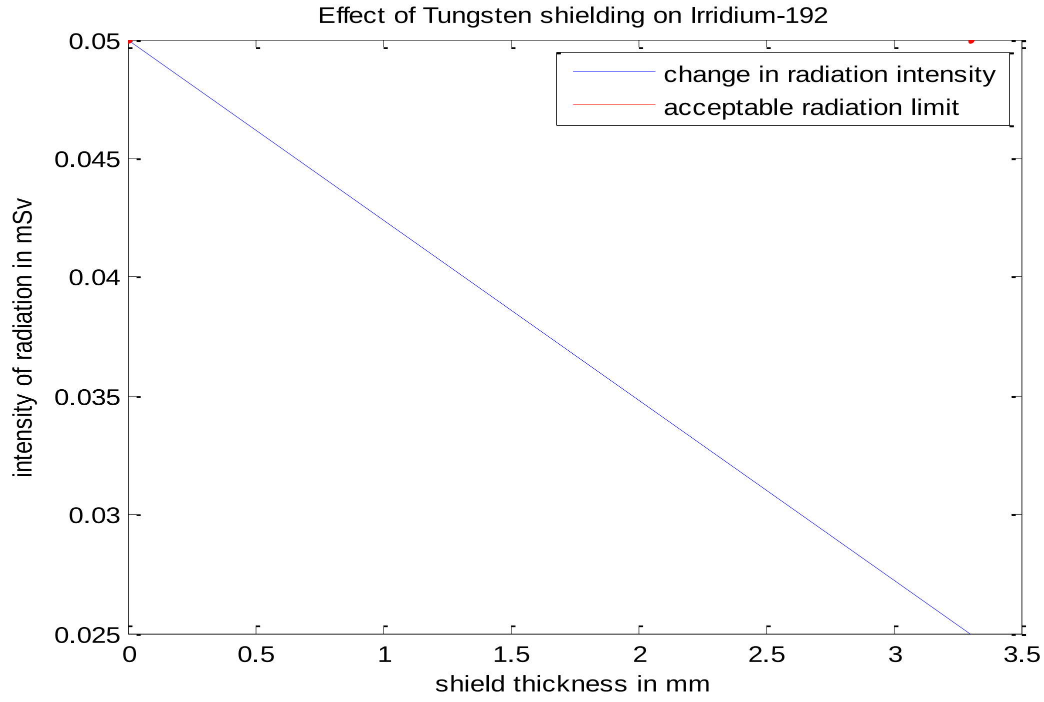


Figure 7.28: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv

The result of using Uranium with HVL of 2.8 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv is as shown below in Figure 7.29:

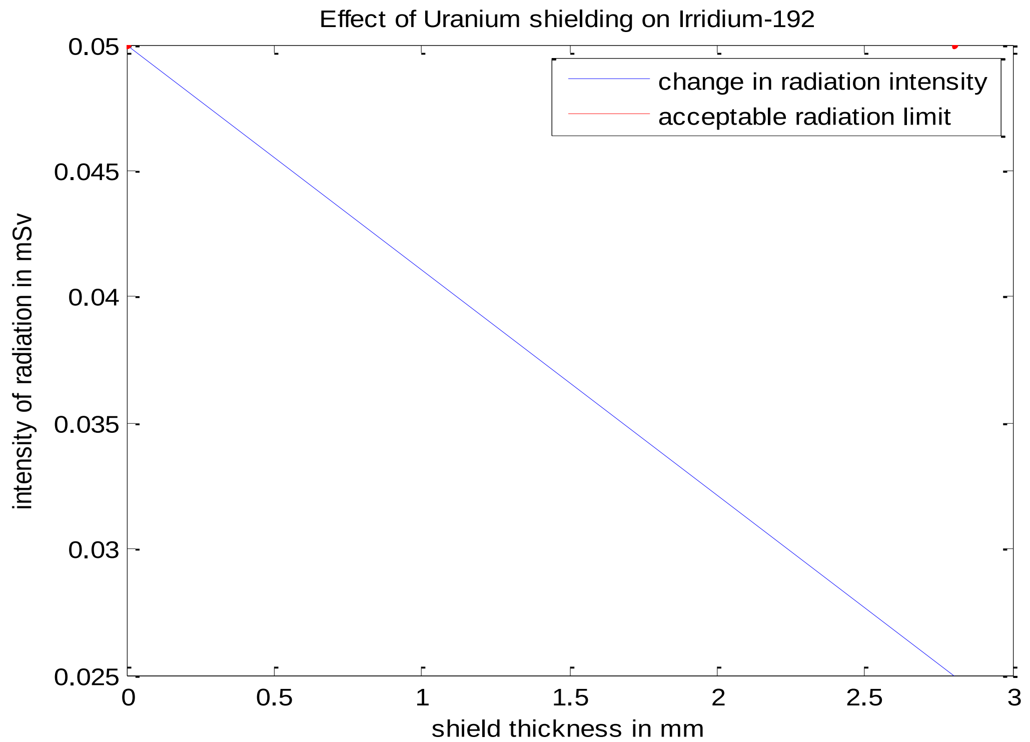


Figure 7.29: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 0.05 mSv

7.4.2 Cobalt-60 with Radiation Intensity of 0.05 mSv:

Figure 7.30 shows Concrete with HVL of 60.5 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv respectively on Cobalt-60.

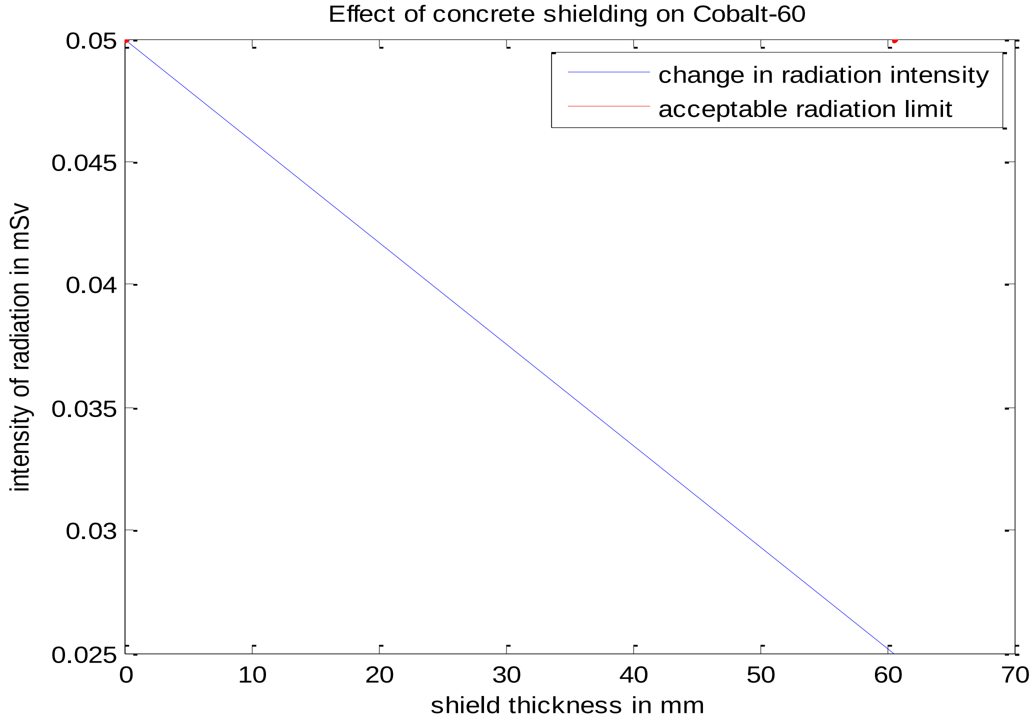


Figure 7.30: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv

Figure 7.31 shows Steel with HVL of 21.6 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv:

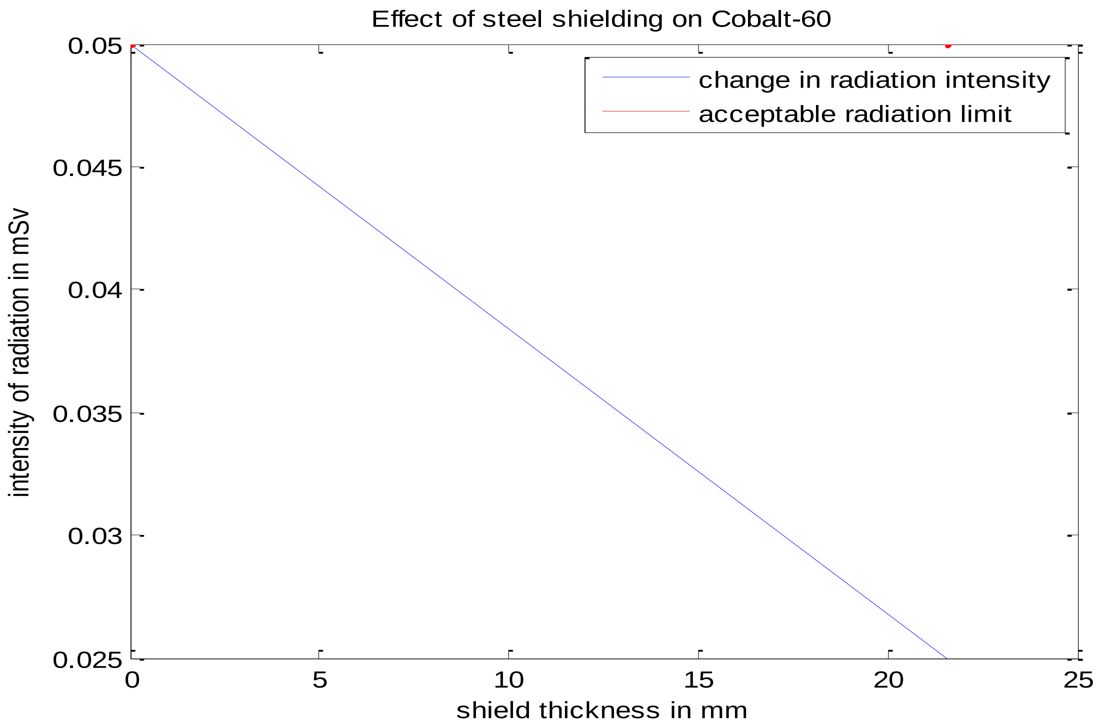


Figure 7.31: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv

Figure 7.32 shows Lead with HVL of 12.5 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv:

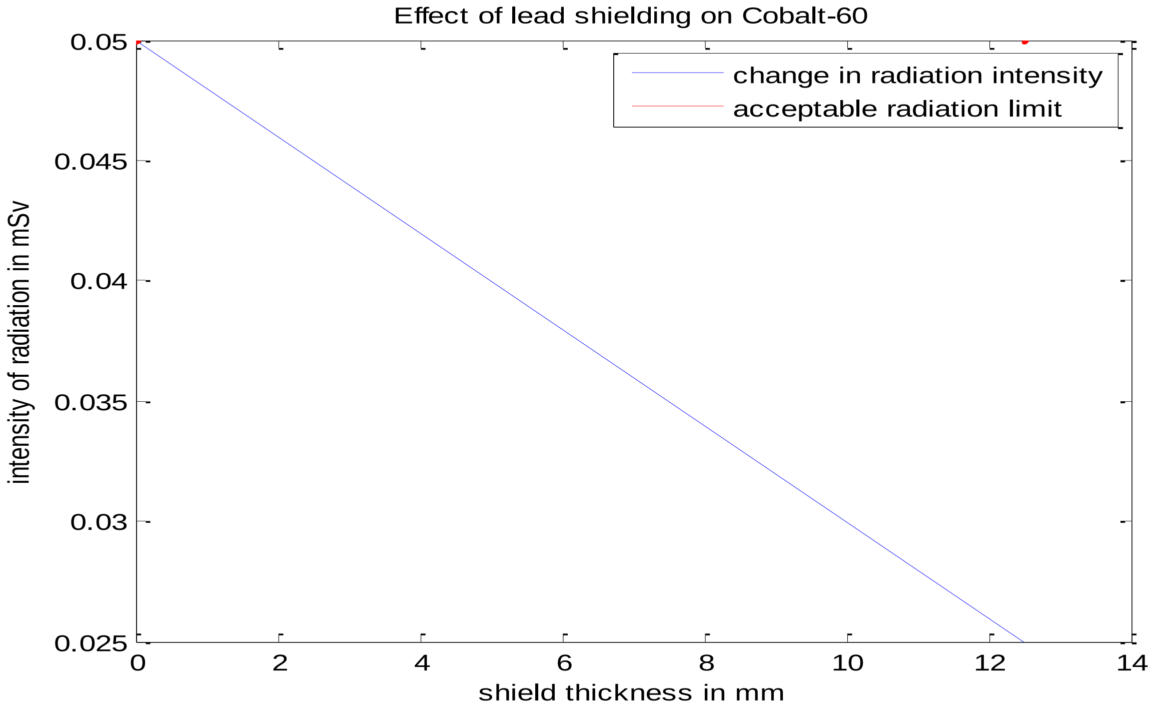


Figure 7.32: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv

Figure 7.33 shows Tungsten with HVL of 7.9 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv:

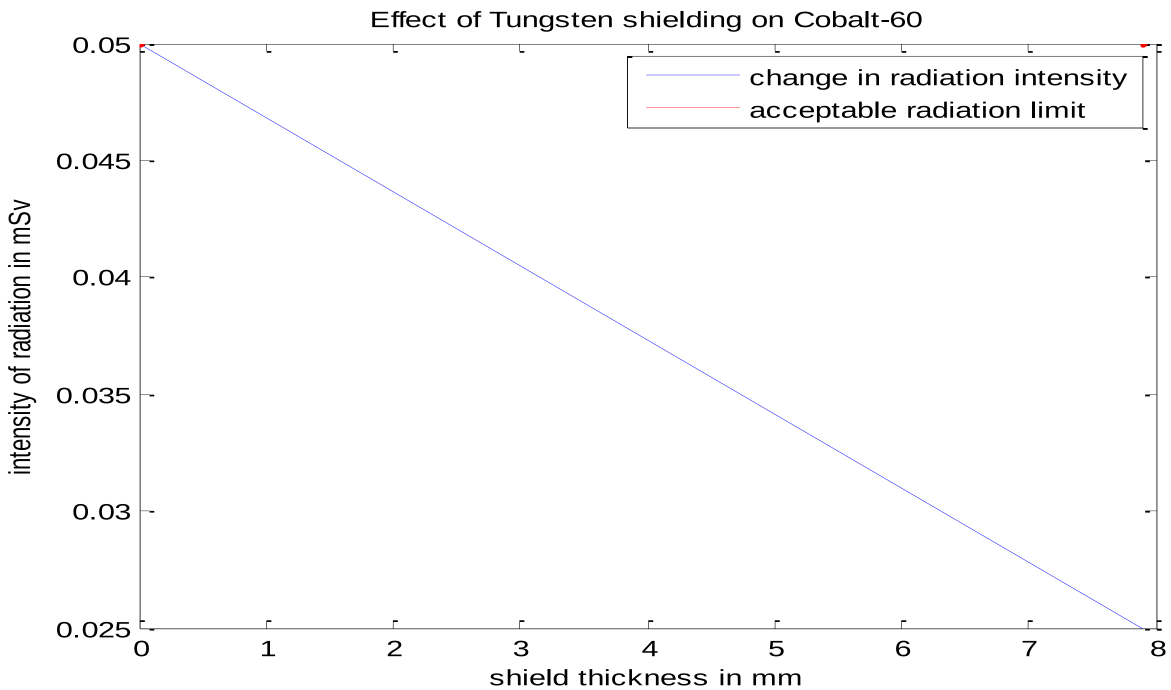


Figure 7.33: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv

Figure 7.34 shows Uranium with HVL of 6.9 mm for shielding, with radiation intensity of 0.05 mSv and radiation limit of 0.05 mSv:

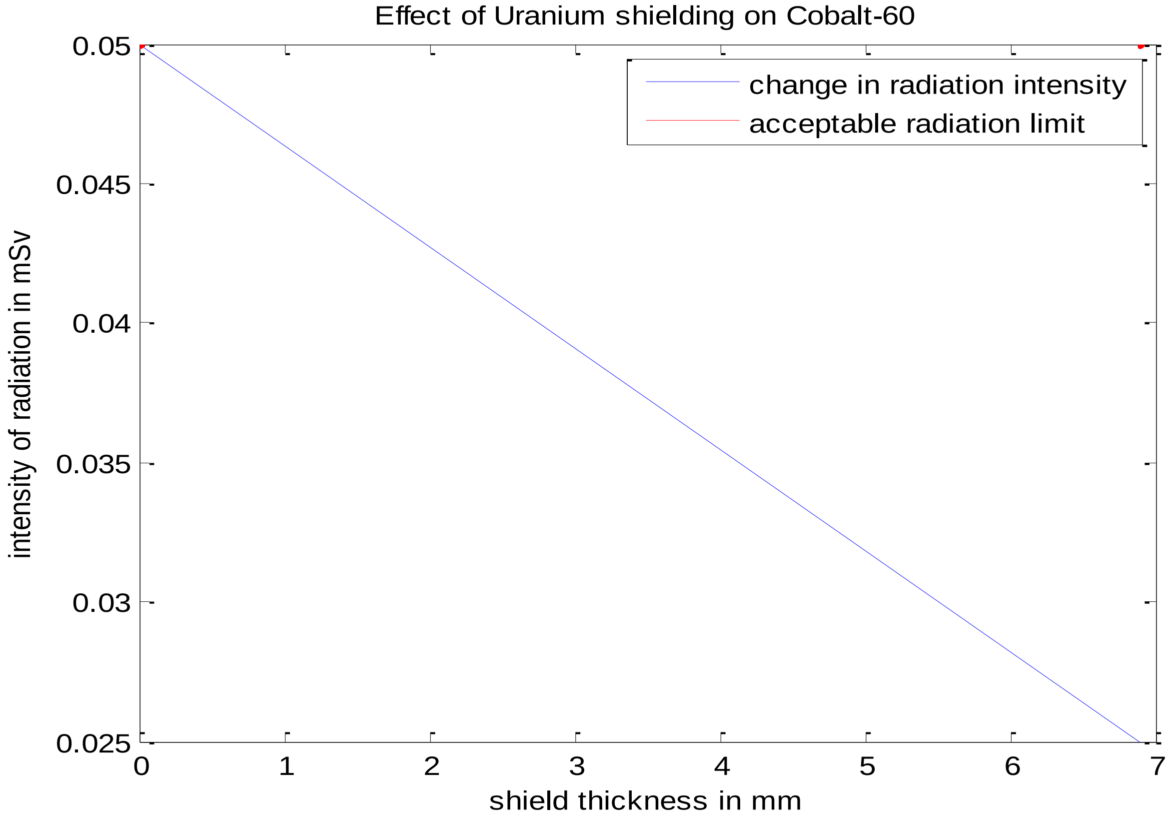


Figure 7.34: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 0.05 mSv

7.4.3 Summary at 0.05 mSv:

With Irridium-192 and Cobalt-60, Concrete, Steel, Lead, Tungsten and depleted Uranium were subjected to shielding with radiation intensity of 0.05 mSv, Concrete and Steel as shown in Figures 7.25, 7.26, 7.30 and 7.31 seemed **NOT** to be very effective in shielding radiation as compared to Lead, Tungsten and depleted Uranium as shown in Figures 7.27, 7.28, 7.29, 7.32, 7.33 and 7.34 above.

7.4.4 Irridium-192 with Radiation Intensity of 2.5 mSv

Figure 7.35 shows Concrete with HVL of 44.5 mm for shielding, with increased radiation intensity of 2.5 mSv and radiation limit of 0.05 mSv respectively:

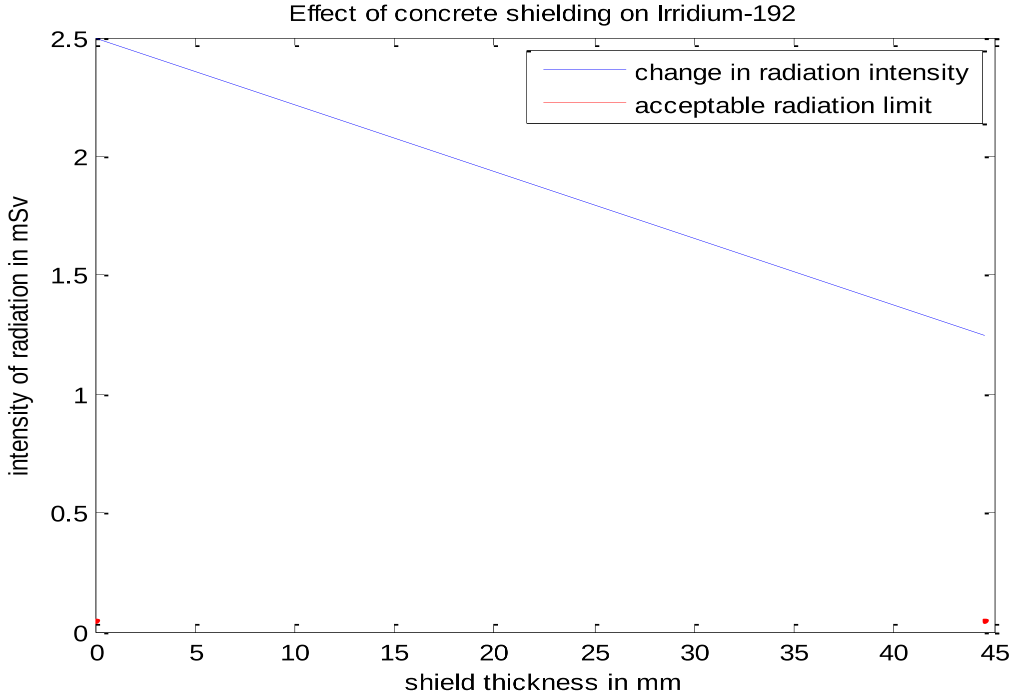


Figure 7.35: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv

The effect of increased radiation intensity to 2.5 mSv for steel shielding is as shown in Figure 7.36 below:

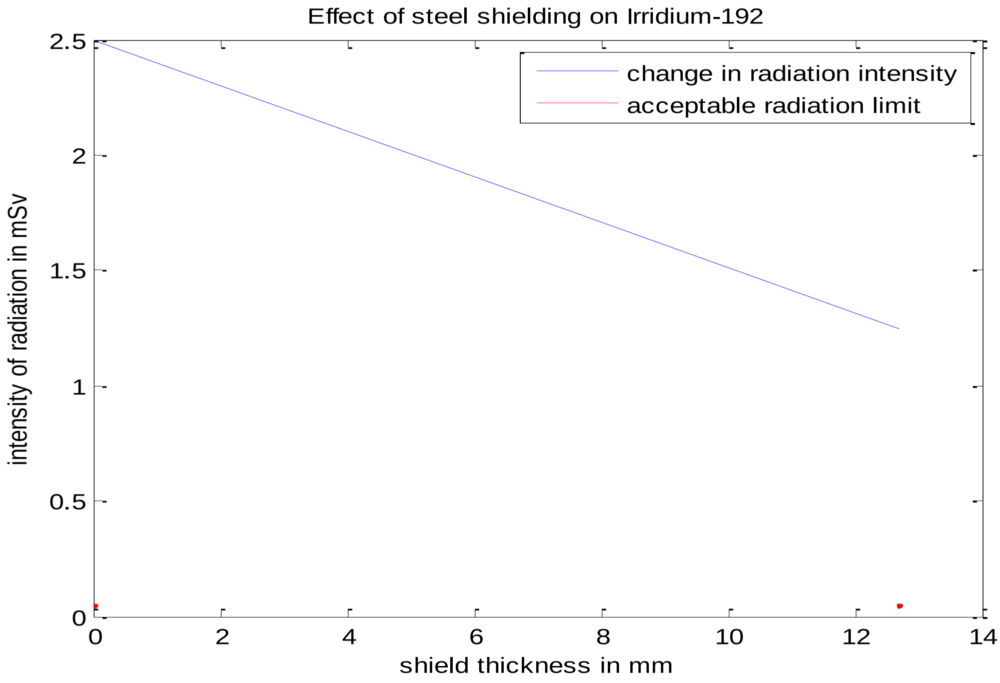


Figure 7.36: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv

Figure 7.37 illustrates the impact of radiation intensity of 2.5 mSv for lead shielding:

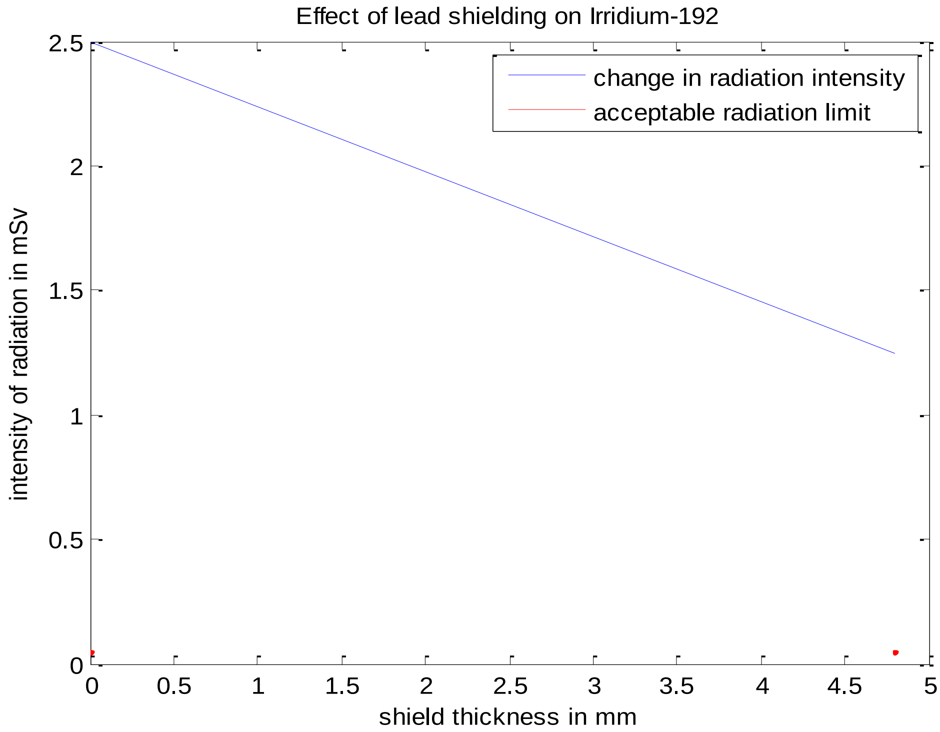


Figure 7.37: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv

The result of radiation intensity of 2.5 mSv for Tungsten shielding is as shown in Figure 7.38 below:

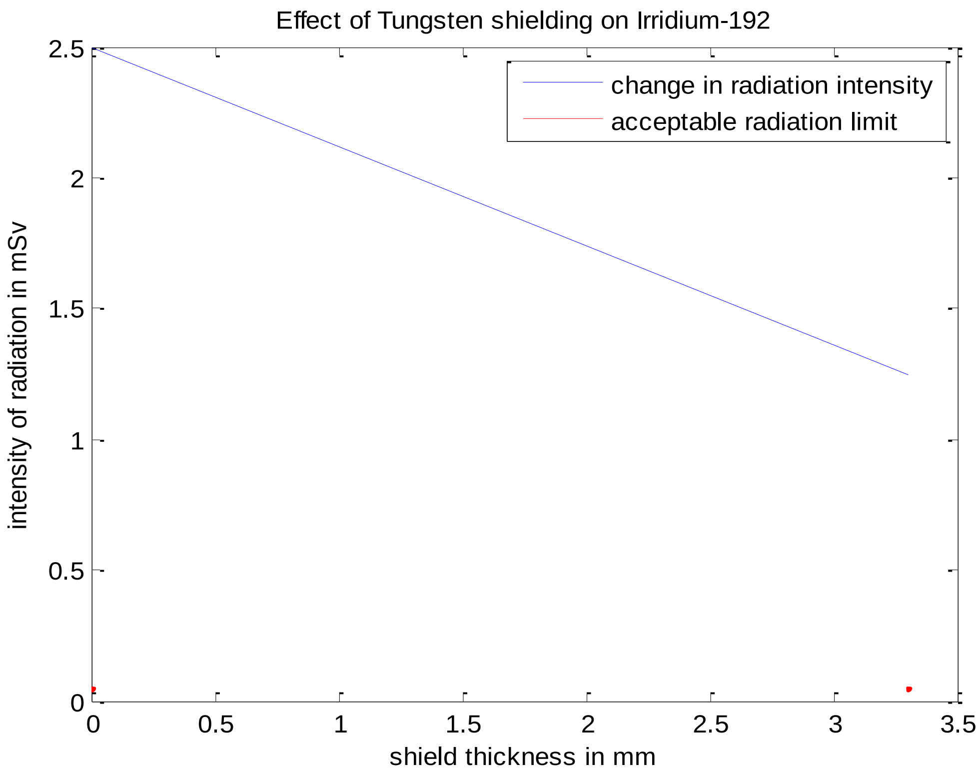


Figure 7.38: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv

With the radiation intensity increased to 2.5 mSv for Uranium shielding, the result is as shown in Figure 7.39 below:

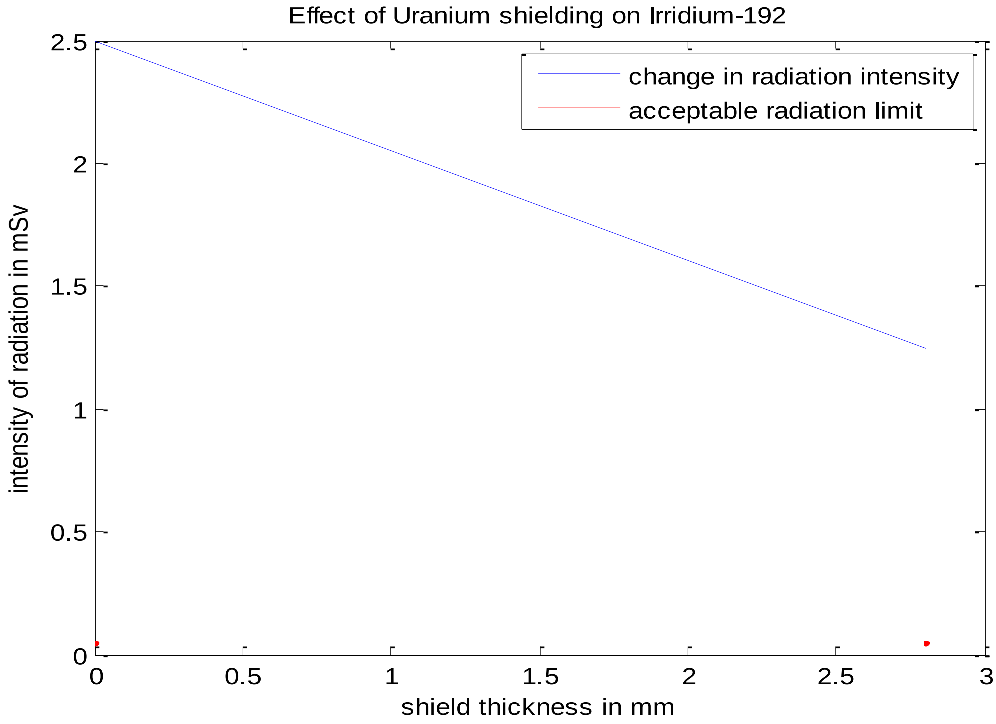


Figure 7.39: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 2.5 mSv

7.4.5 Cobalt-60 with Radiation Intensity of 2.5 mSv

The result for increased radiation intensity to 2.5 mSv for concrete shielding is as shown in Figure 7.40 below:

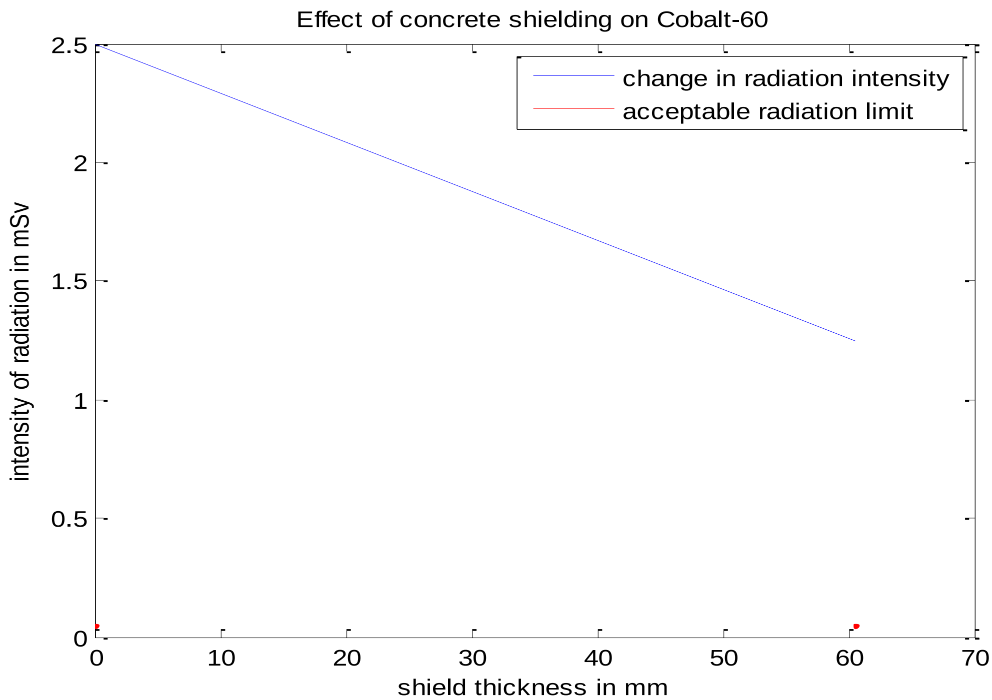


Figure 7.40: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv

With an increase of radiation intensity to 2.5 mSv on steel shielding, the result is as illustrated in Figure 7.41 below:

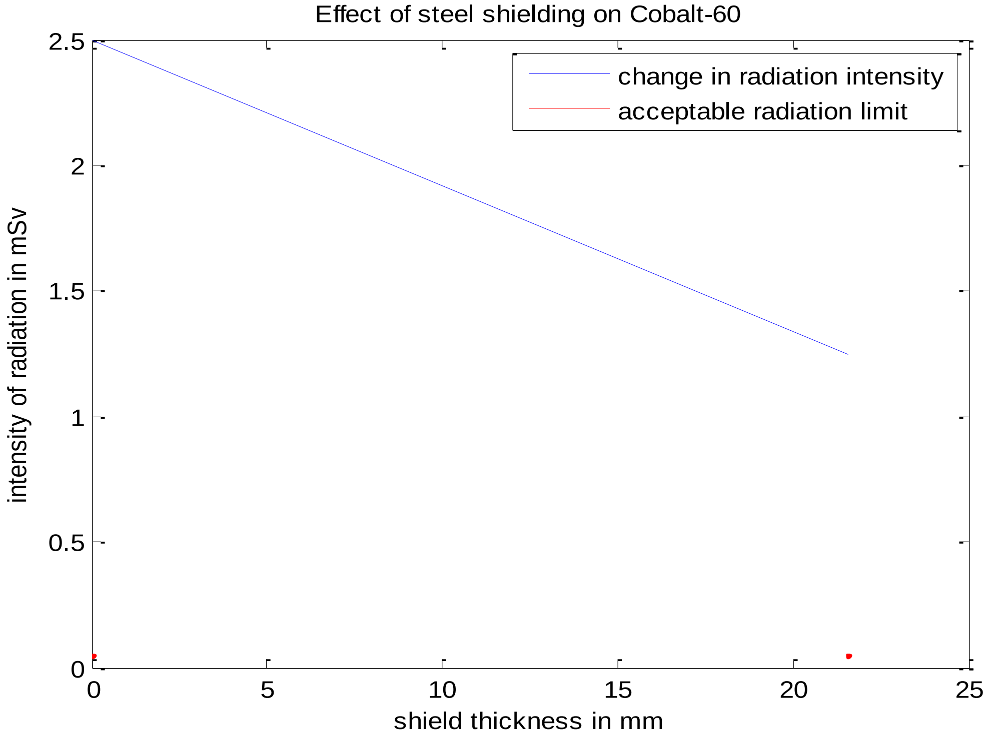


Figure 7.41: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv

The result for the increase of radiation intensity to 2.5 mSv on Lead shielding is as shown in Figure 7.42 below:

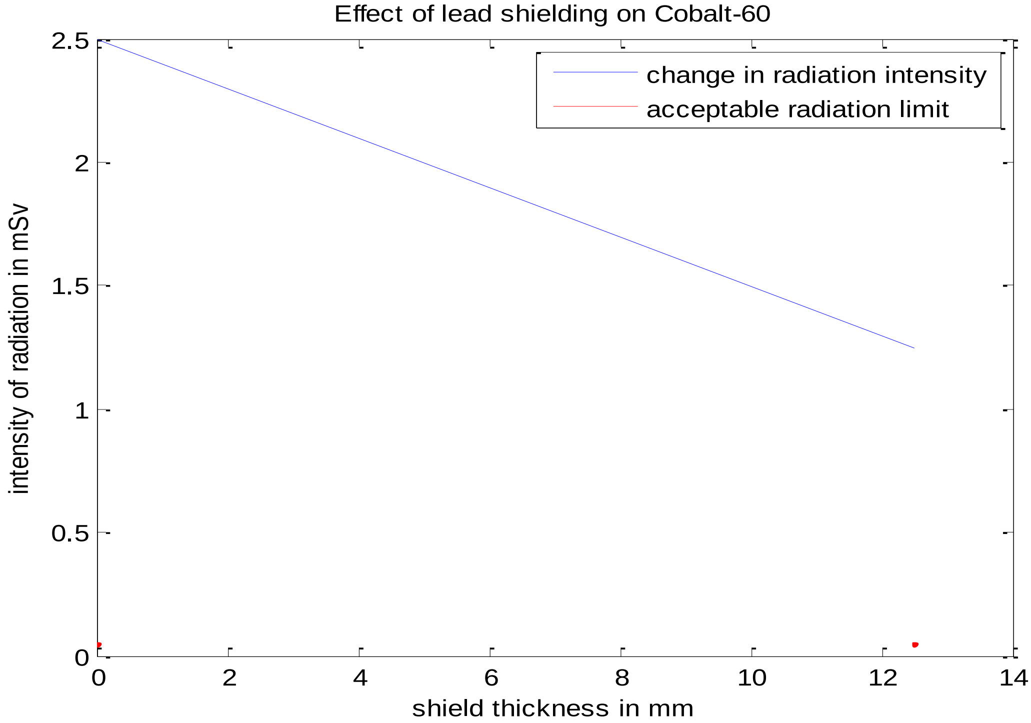


Figure 7.42: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv

Figure 7.43 below is the result for the increased radiation intensity to 2.5 mSv on Tungsten shielding:

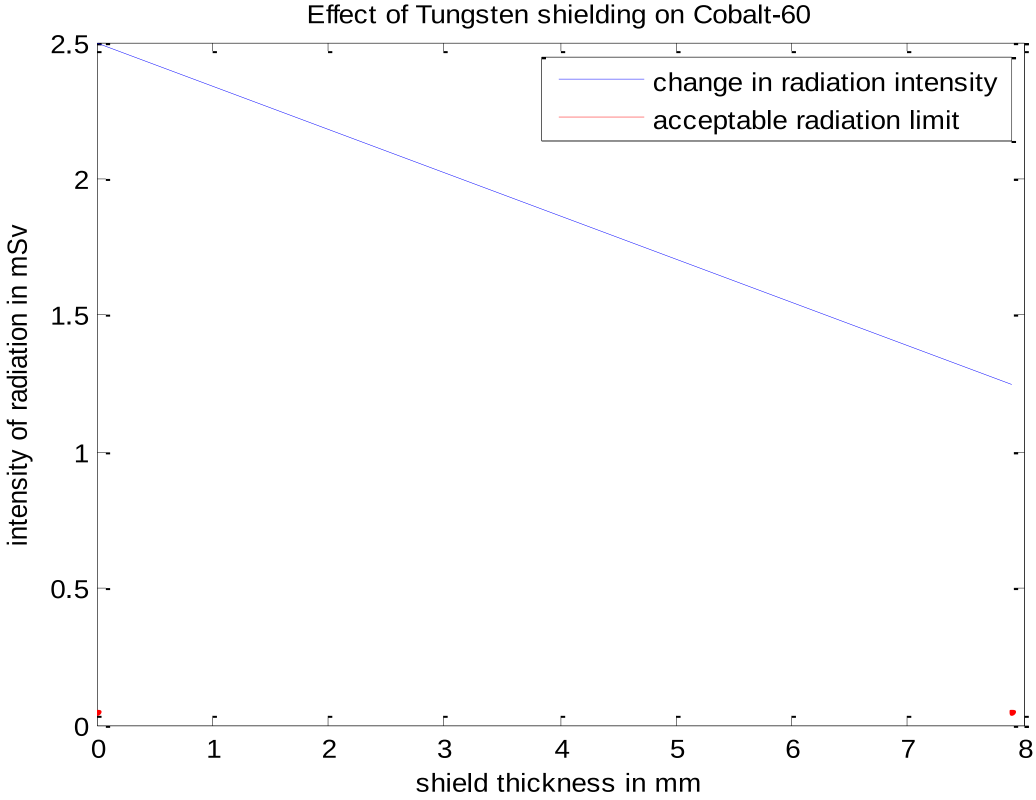


Figure 7.43: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv

The result for increased radiation intensity to 2.5 mSv on Uranium shielding is as shown in Figure 7.44 below:

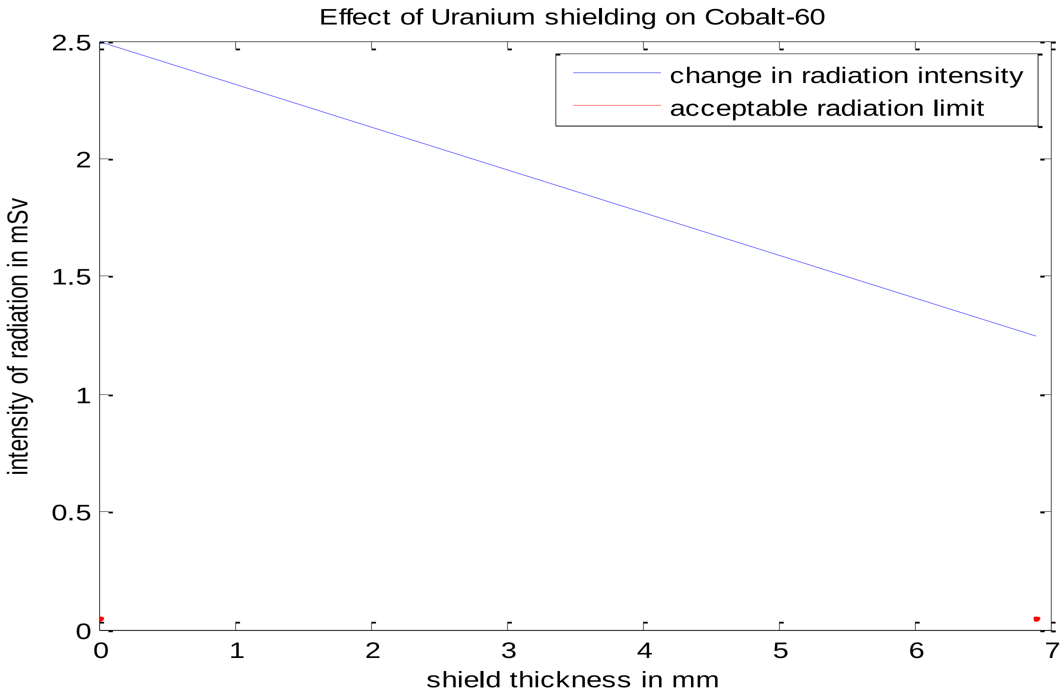


Figure 7.44: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 2.5 mSv

7.4.6 Summary at 2.5 mSv

The above illustrations were the results of the increase of radiation intensity to 2.5mSv, with Irridium-192 and Cobalt-60 for Concrete, Steel, Lead, Tungsten and depleted Uranium. However, Concrete and Steel as shown in Figures 7.35, 7.36, 7.40 and 7.41 still seemed **NOT** to be very effective in shielding radiation as compared to Lead, Tungsten and depleted Uranium as shown in Figures 7.37, 7.38, 7.39, 7.42, 7.43 and 7.44.

7.4.7 Irridium-192 with Radiation Intensity of 20 mSv

The result of using Concrete with HVL of 44.5 mm for shielding, with increased radiation intensity of 20 mSv and radiation limit of 0.05 mSv is as shown in Figure 7.45 below:

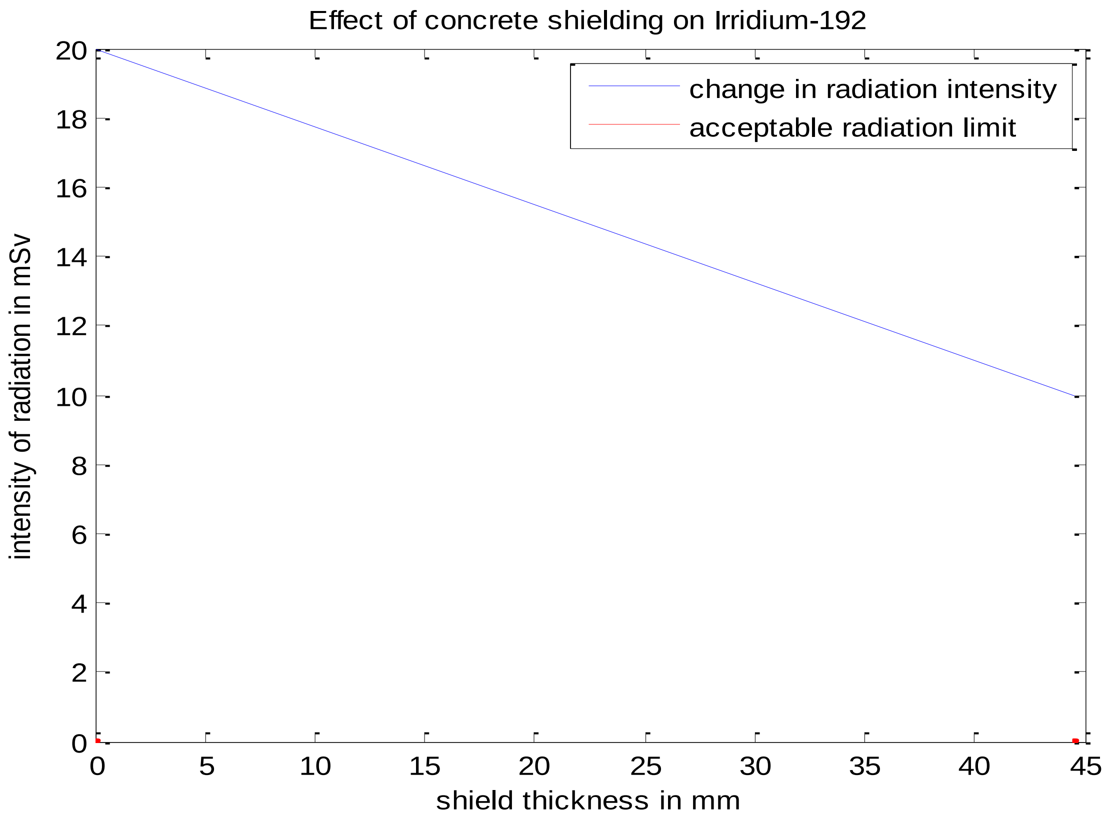


Figure 7.45: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 20 mSv

With the increase of radiation intensity of 20 mSv for steel shielding, the result is as shown in Figure 7.46 below:

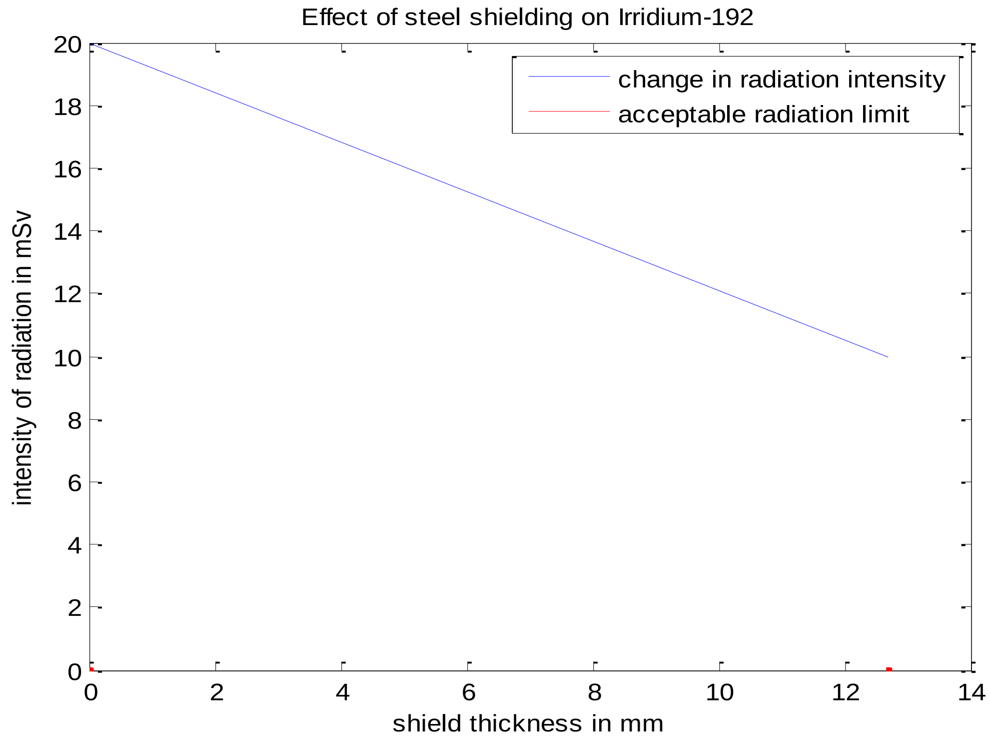


Figure 7.46: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 20 mSv

The result of using radiation intensity to 20 mSv for lead shielding is as shown in Figure 7.47 below:

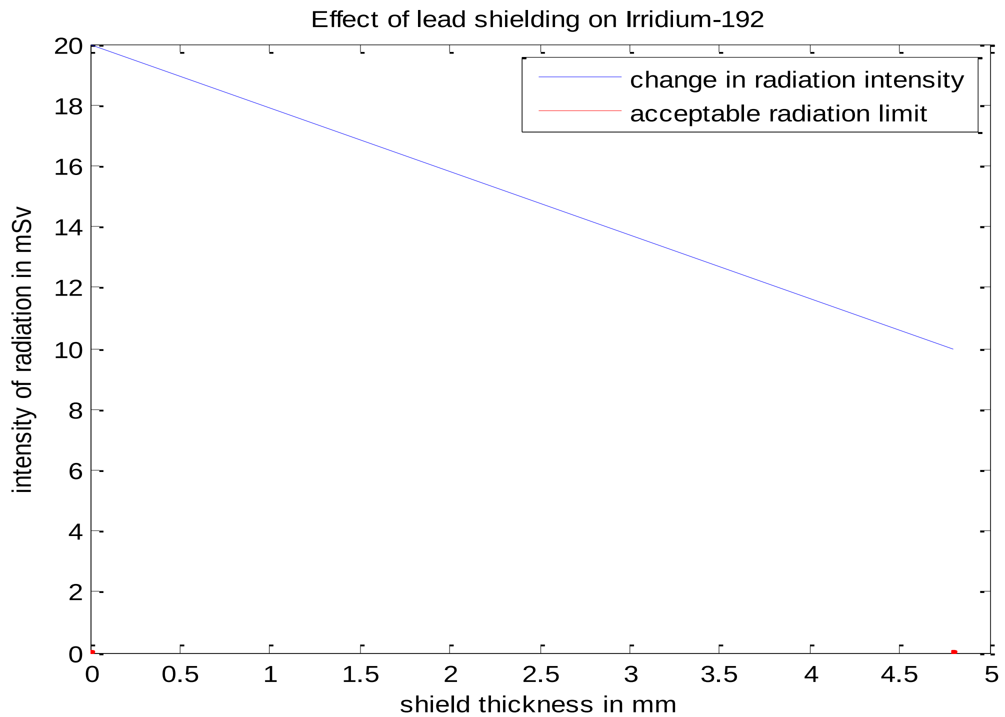


Figure 7.47: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 20 mSv

The result of using increased radiation intensity to 20 mSv for Tungsten shielding is as shown in Figure 7.48 below:

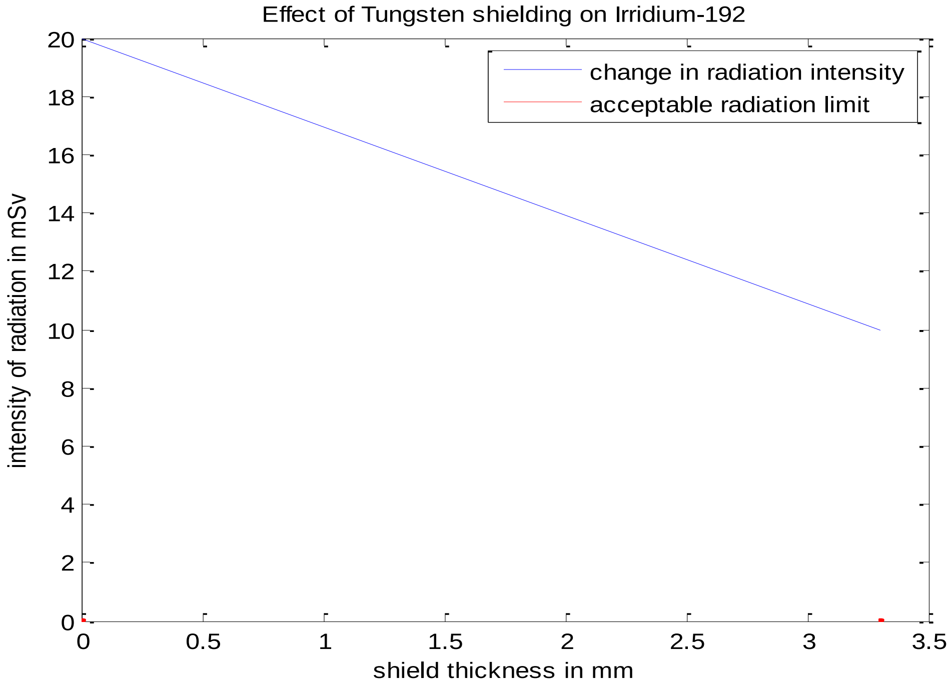


Figure 7.48: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 20 mSv

With increased radiation intensity to 20 mSv for Uranium shielding, the result is as in Figure 7.49 below:

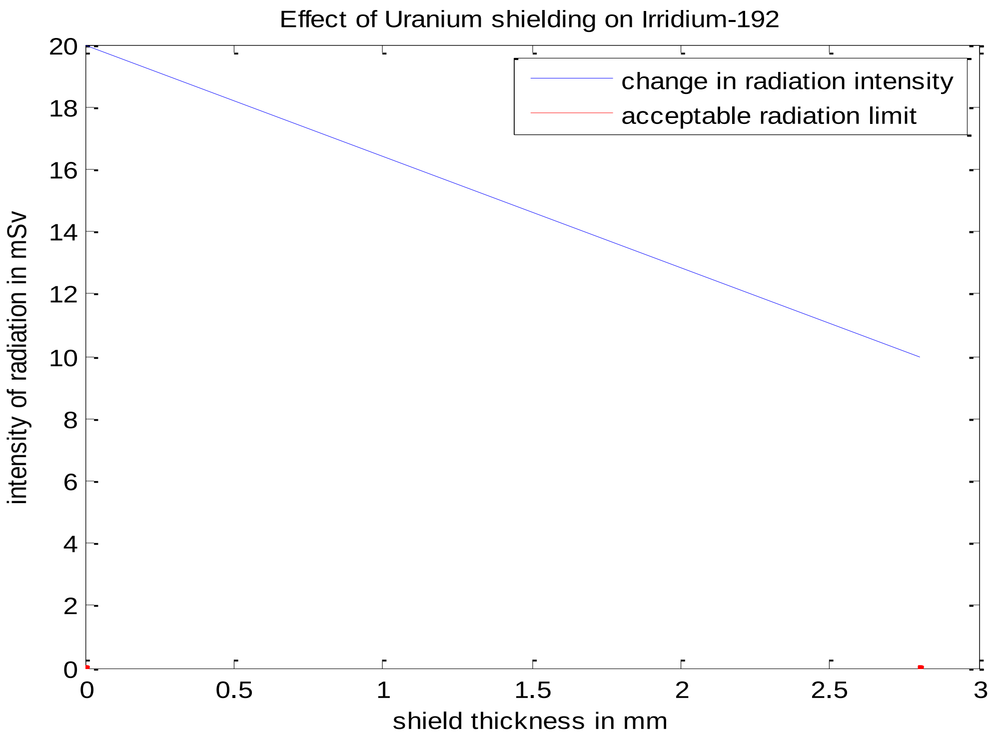


Figure 7.49: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 20 mSv

7.4.8 Cobalt-60 with Radiation Intensity of 20 mSv

The result of using increased radiation intensity to 20 mSv for concrete shielding is as in Figure 7.50 below:

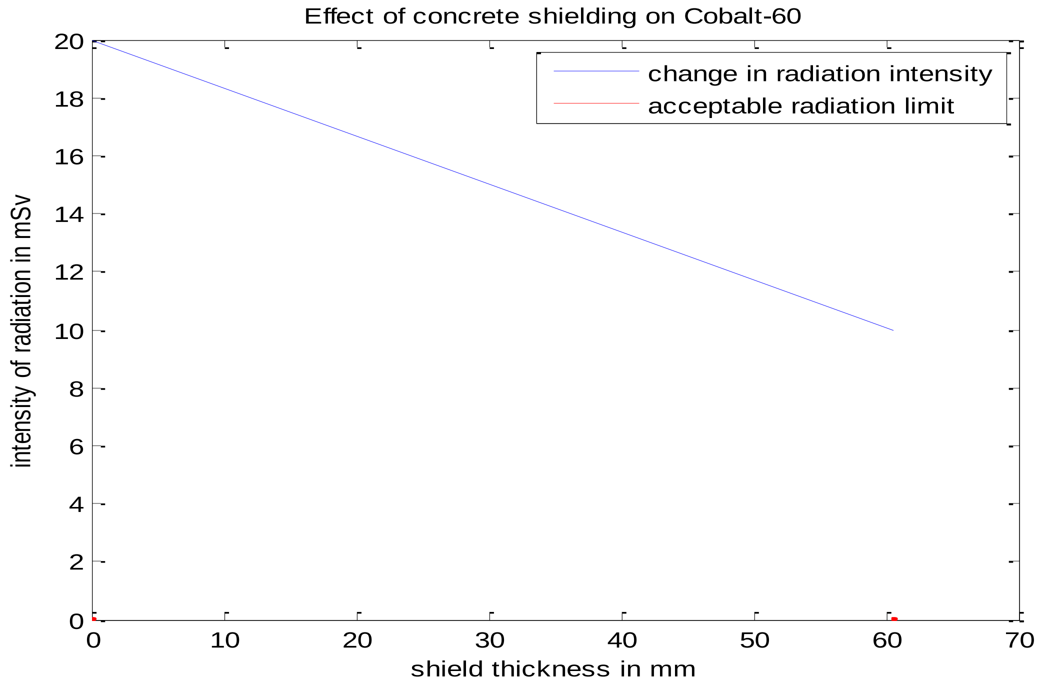


Figure 7.50: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 20 mSv

Figure 7.51 below shows the result for the increased radiation intensity to 20 mSv on steel shielding

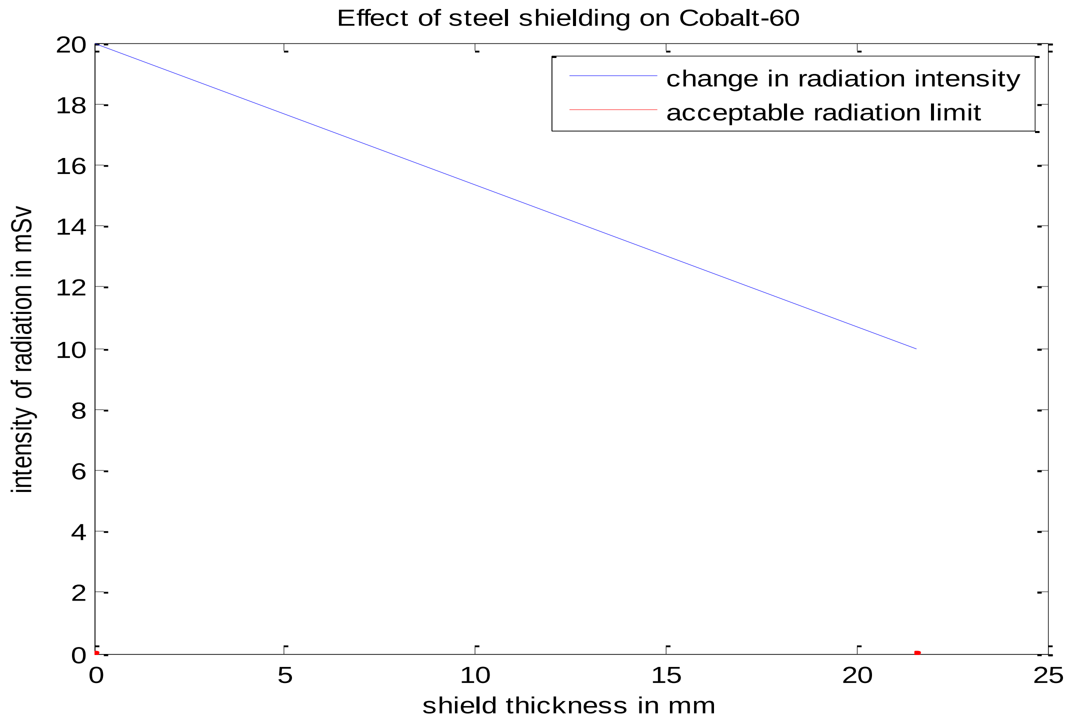


Figure 7.51: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 20 mSv

The result of using increased radiation intensity to 20 mSv on Lead shielding is as shown in Figure 7.52 below:

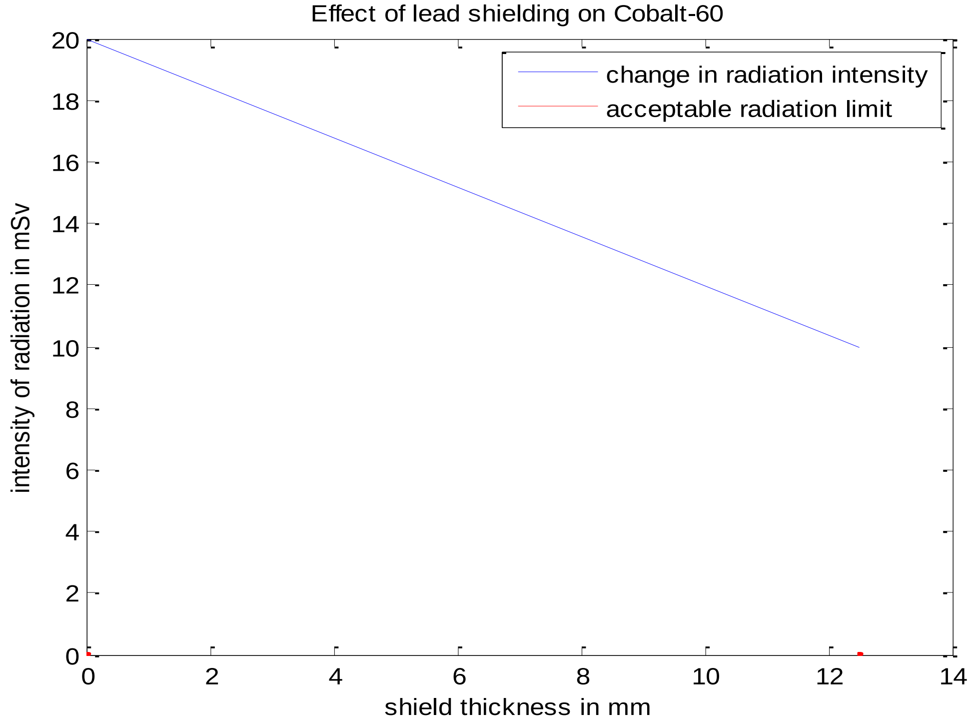


Figure 7.52: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 20 mSv

With increased radiation intensity to 20 mSv on Tungsten shielding, the result is as shown in Figure 7.53 below:

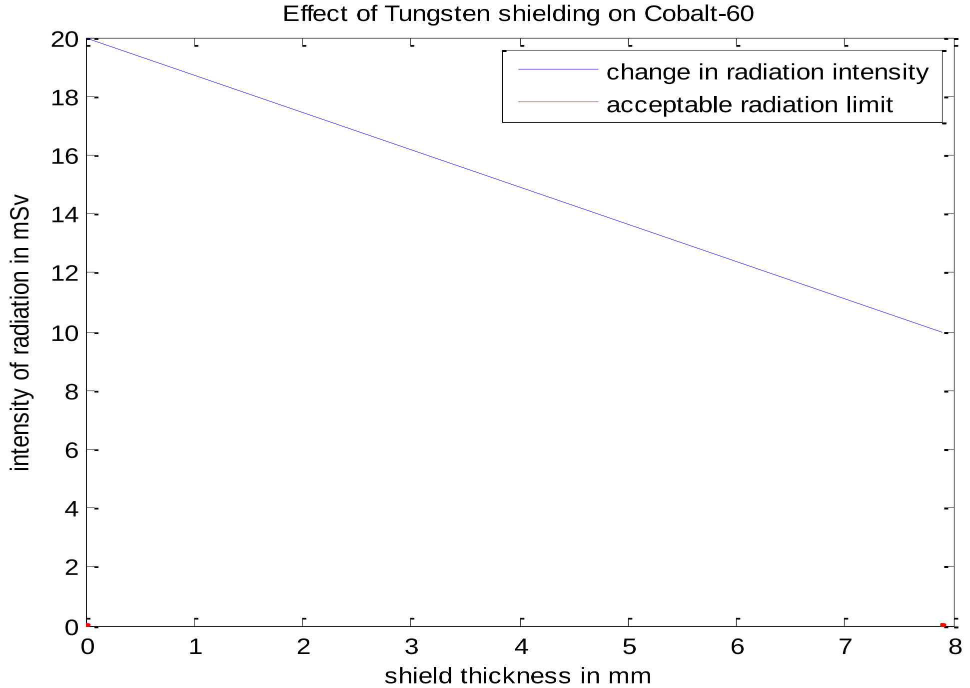


Figure 7.53: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 20 mSv

The result of using increased radiation intensity to 20 mSv on Uranium shielding is as shown in Figure 7.54 below:

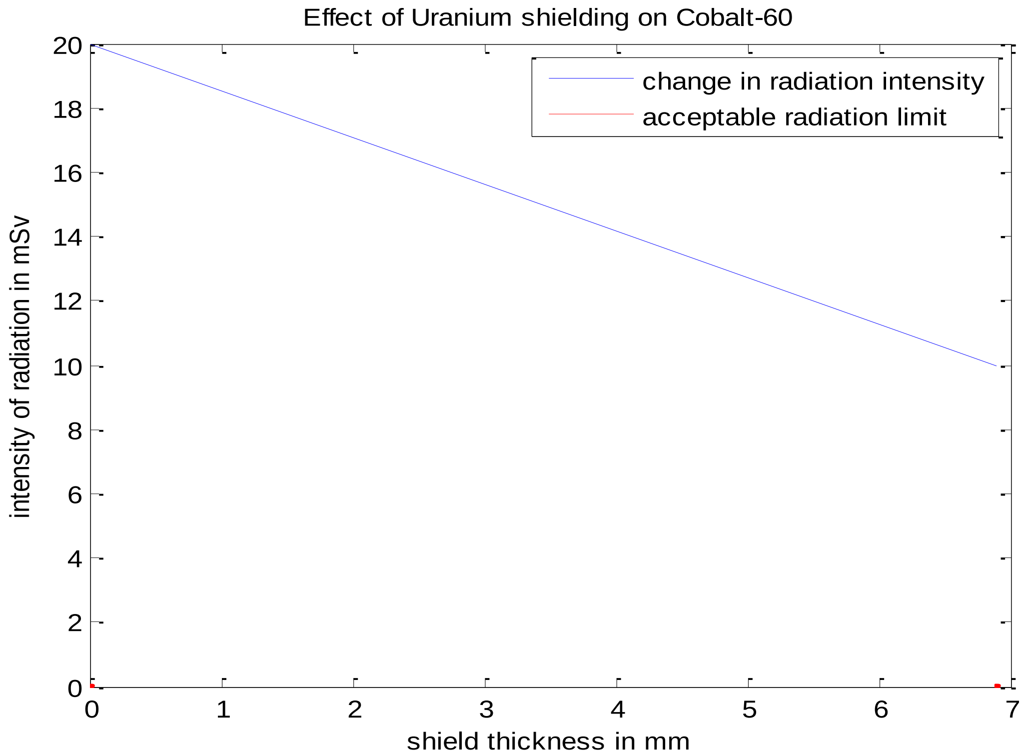


Figure 7.54: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 20 mSv

7.4.9 Summary at 20 mSv

From the above illustrations with the increase of radiation intensity to 20mSv, with Irridium-192 and Cobalt-60 for Concrete, Steel, Lead, Tungsten and depleted Uranium. Concrete and Steel as shown in Figures 7.45, 7.46, 7.50 and 7.51 also seemed **NOT** to be very effective in shielding radiation as compared to Lead, Tungsten and depleted Uranium as shown in Figures 7.47, 7.48, 7.49, 7.52, 7.53 and 7.54 as shown earlier with 0.05 mSv and 2.5 mSv respectively

7.4.10 Irridium-192 with Radiation Intensity of 250 mSv

Figure 7.55 is the result for a Concrete with HVL of 44.5 mm for shielding, with increased radiation intensity of 250 mSv and radiation limit of 0.05 mSv:

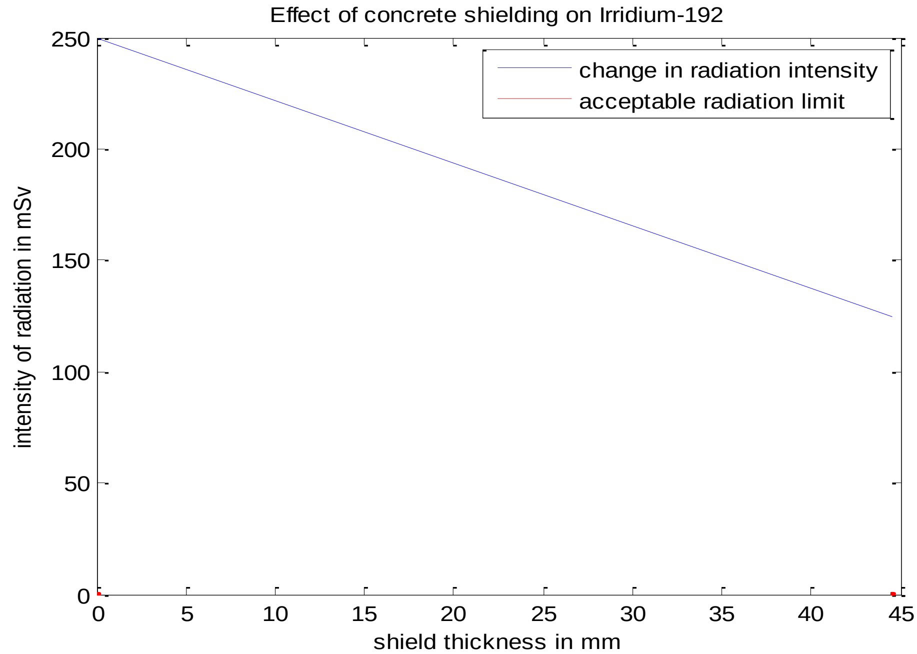


Figure 7.55: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 250 mSv

Figure 7.56 is the result for increased radiation intensity to 250 mSv for steel shielding:

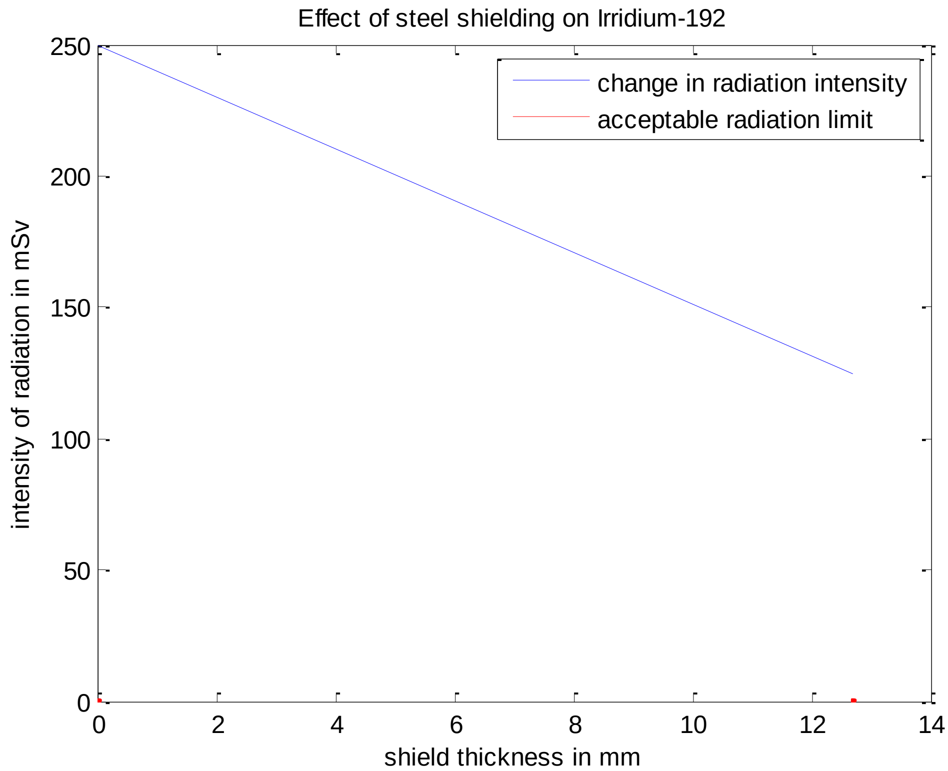


Figure 7.56: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 250 mSv

Figure 7.57 is the result for the increased radiation intensity to 250 mSv for lead shielding:

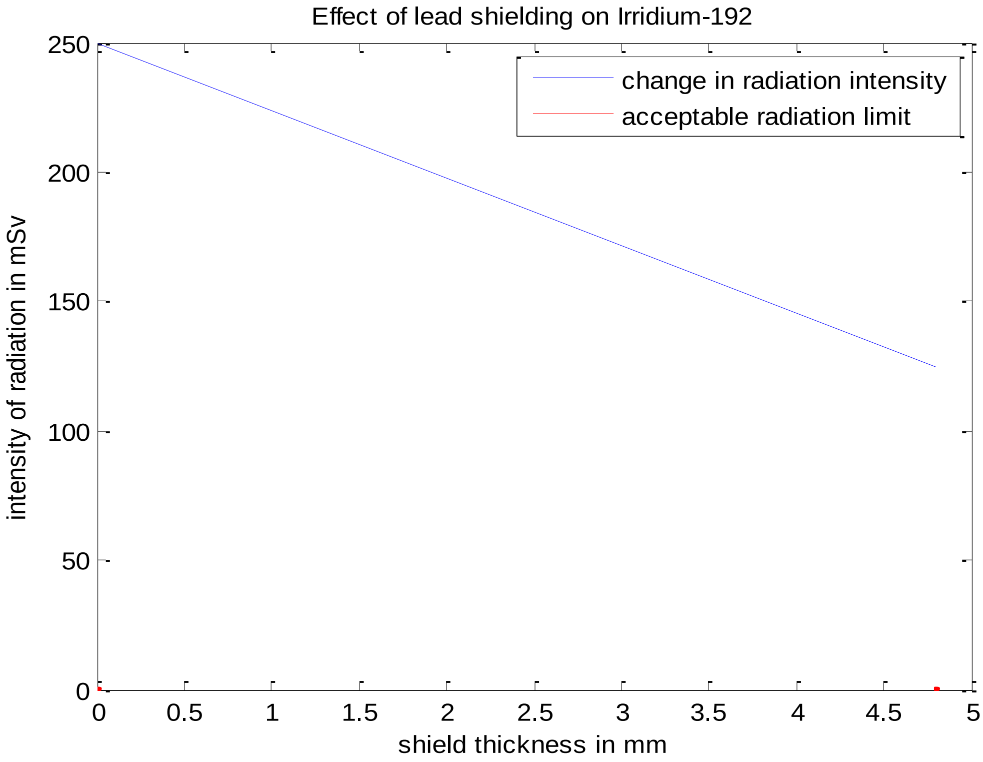


Figure 7.57: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 250 mSv

Figure 7.58 is the result for increased radiation intensity to 250 mSv for Tungsten shielding:

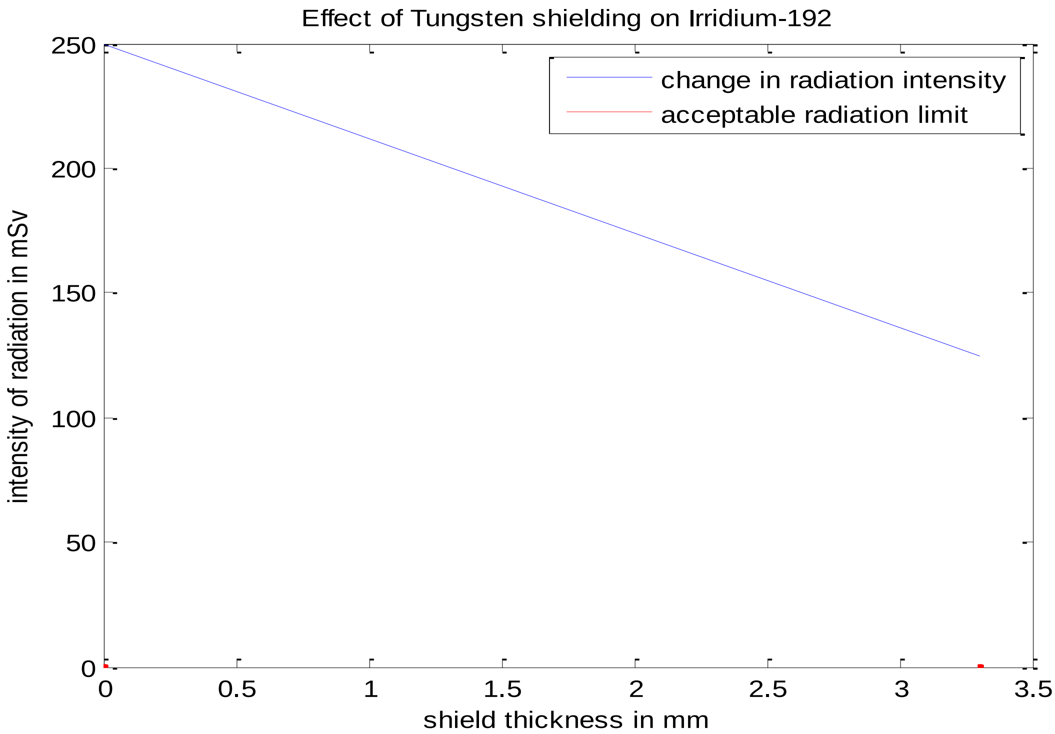


Figure 7.58: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 250 mSv

Figure 7.59 below is the result for increased radiation intensity to 250 mSv for Uranium shielding:

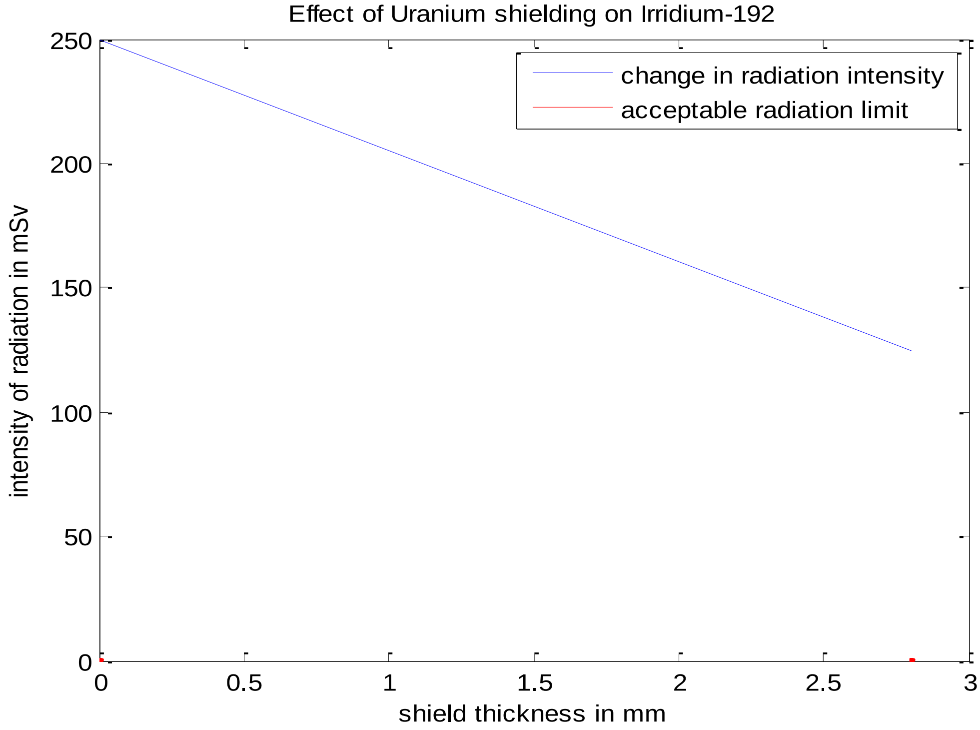


Figure 7.59: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 250 mSv

7.4.11 Cobalt-60 with Radiation Intensity of 250 mSv

Figure 7.60 is the result of increased radiation intensity to 250 mSv for concrete shielding:

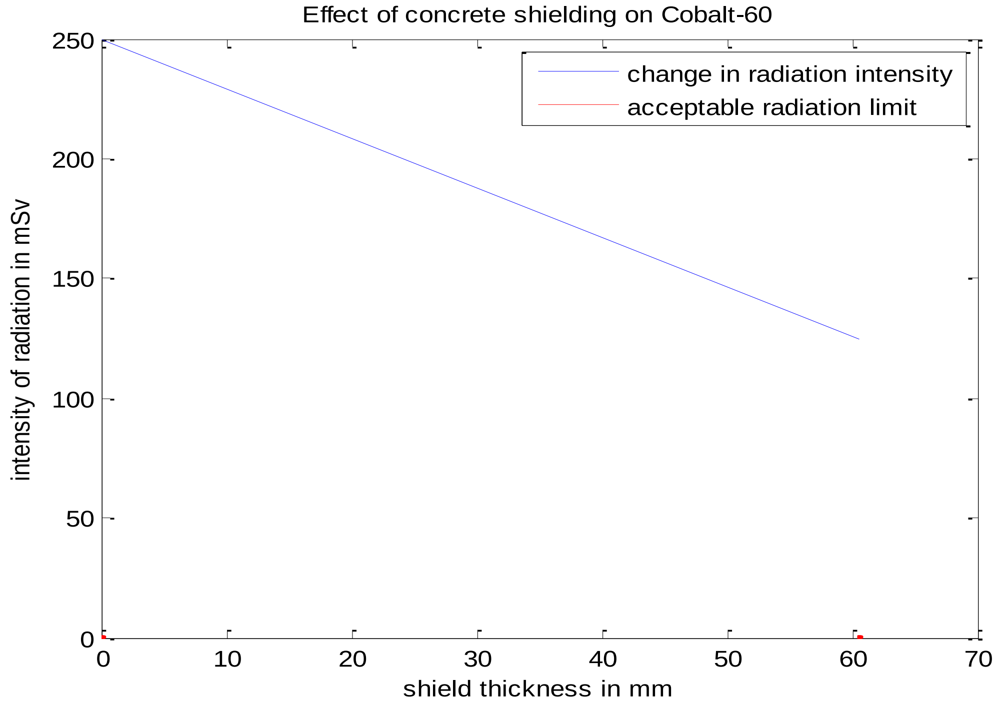


Figure 7.60: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 250 mSv

Figure 7.61 is the result of increased radiation intensity to 250 mSv on steel shielding:

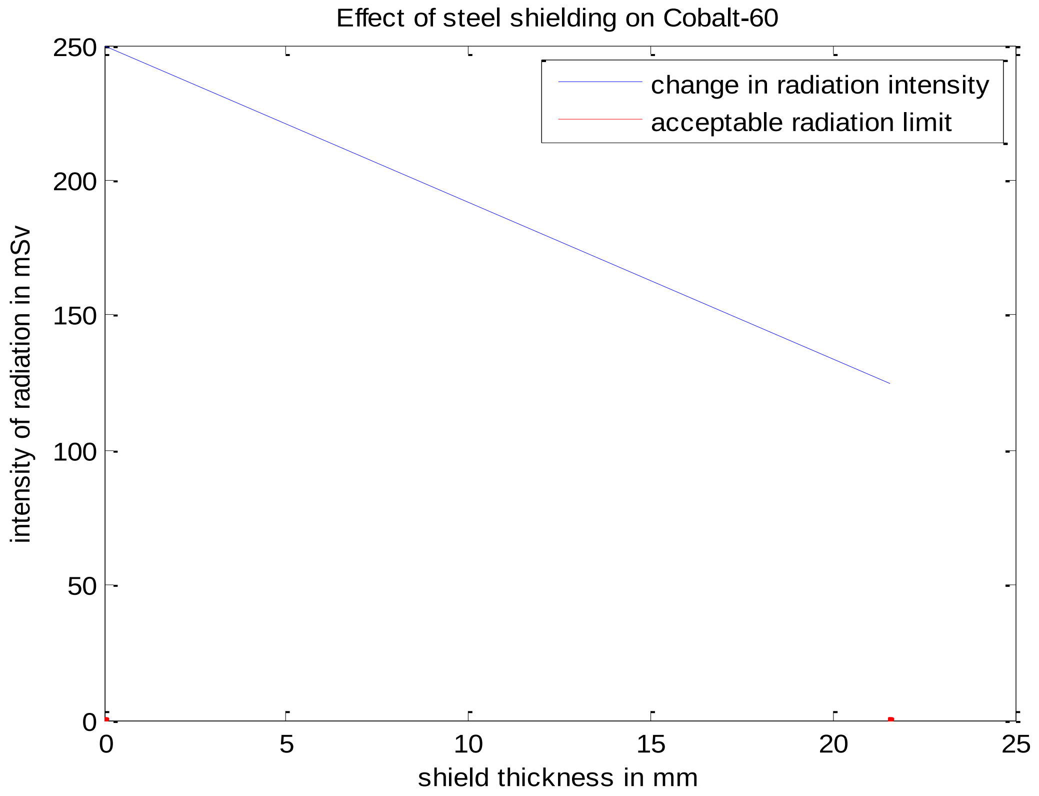


Figure 7.61: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 250 mSv

Figure 7.62 is the result of increased radiation intensity to 250 mSv on Lead shielding:

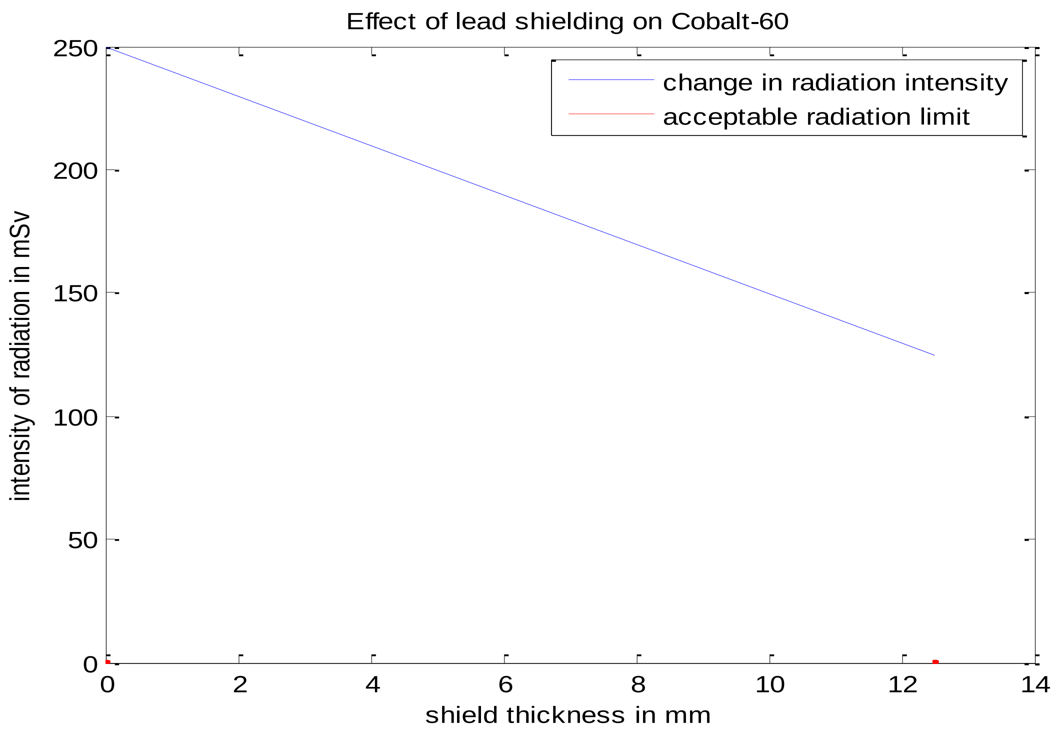


Figure 7.62: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 250 mSv

Figure 7.63 is the result of increased radiation intensity to 250 mSv on Tungsten shielding:

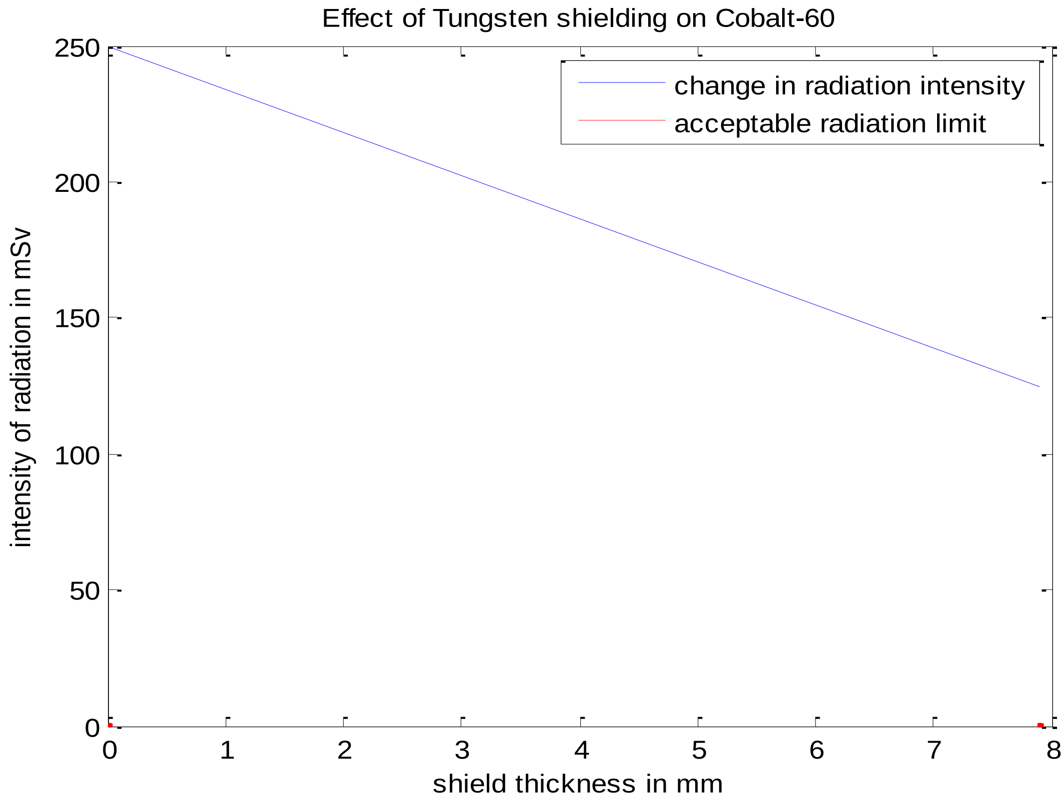


Figure 7.63: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 250 mSv

Figure 7.64 is the result of increased radiation intensity to 250 mSv on Uranium shielding:

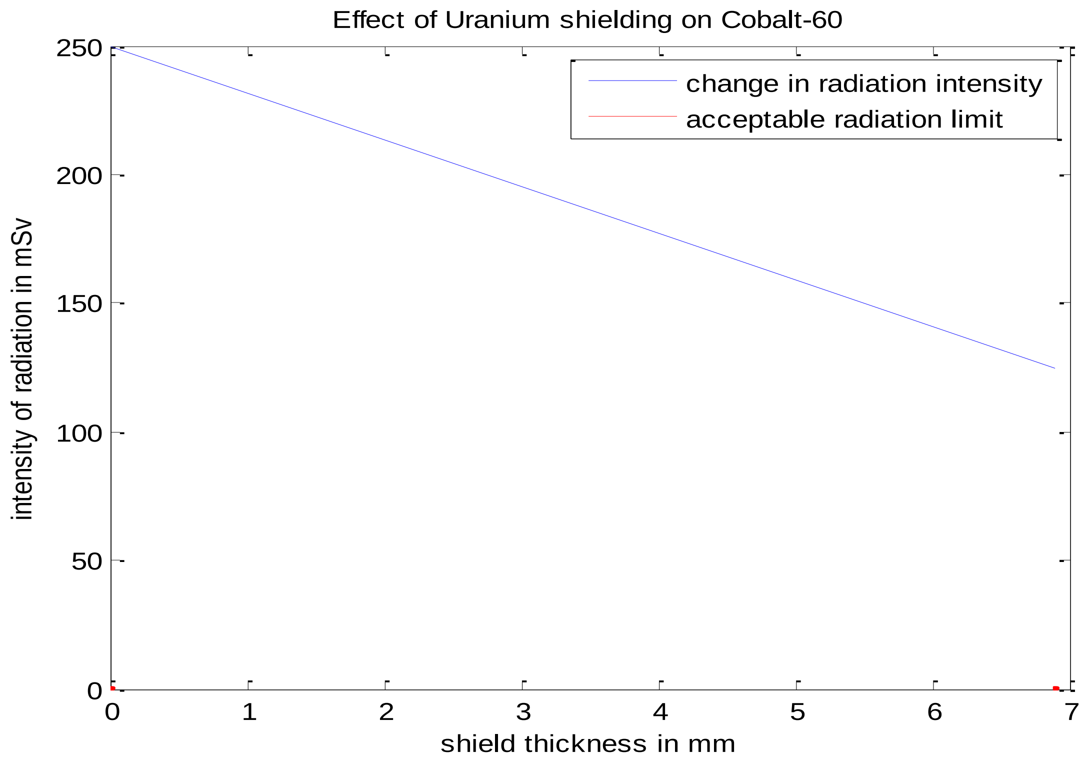


Figure 7.64: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 250 mSv

7.4.12 Summary at 250 mSv

The above illustrations were for the increase of radiation intensity to 250mSv, with Irridium-192 and Cobalt-60 for Concrete, Steel, Lead, Tungsten and depleted Uranium. Still, Concrete and Steel as shown in Figures 7.45, 7.46, 7.50 and 7.51, also seemed **NOT** to be very effective in shielding radiation as compared to Lead, Tungsten and depleted Uranium as shown in Figures 7.47, 7.48, 7.49, 7.52, 7.53 and 7.54.

7.4.13 Irridium-192 with Radiation Intensity of 1000 mSv

The result of using Concrete with HVL of 44.5 mm for shielding, with increased radiation intensity of 1000 mSv and radiation limit of 0.05 mSv is as shown in Figure 7.65 below:

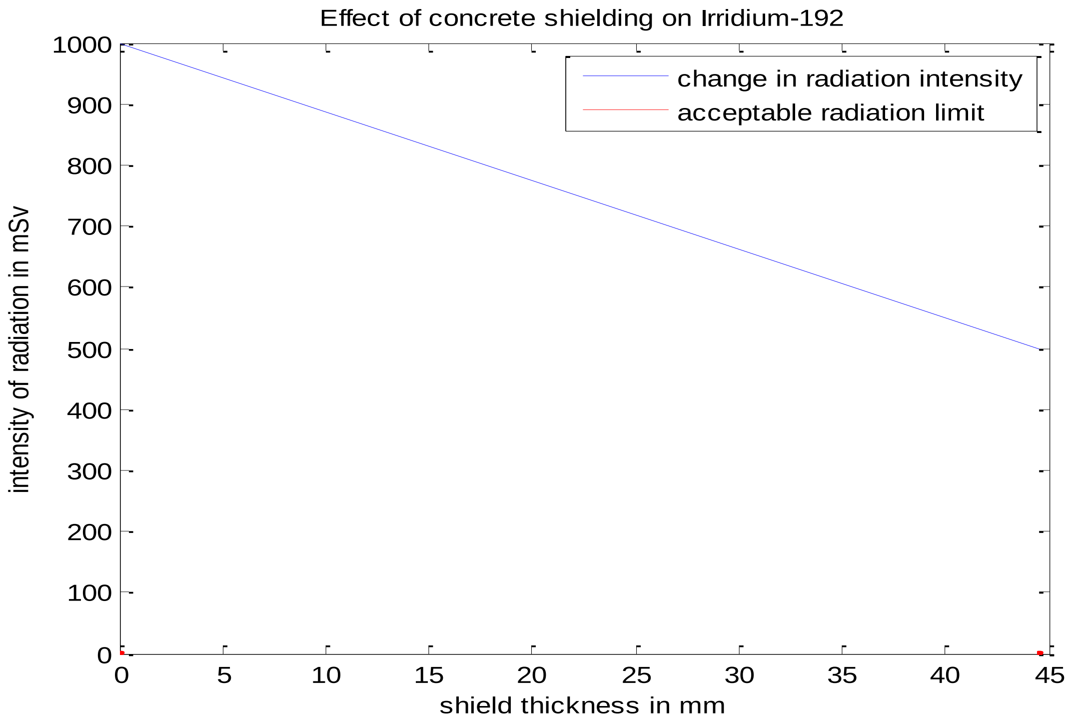


Figure 7.65: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 1000 mSv

Figure 7.66 is the result of increased radiation intensity to 1000 mSv for steel shielding:

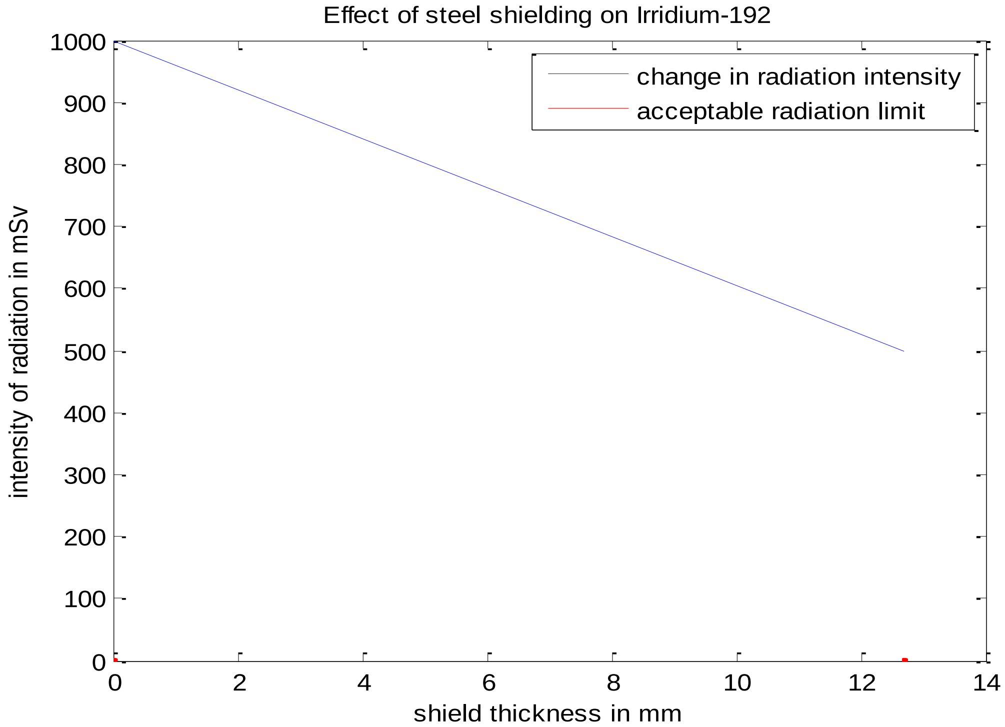


Figure 7.66: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 1000 mSv

Figure 7.67 is the result of increased radiation intensity to 1000 mSv for lead shielding:

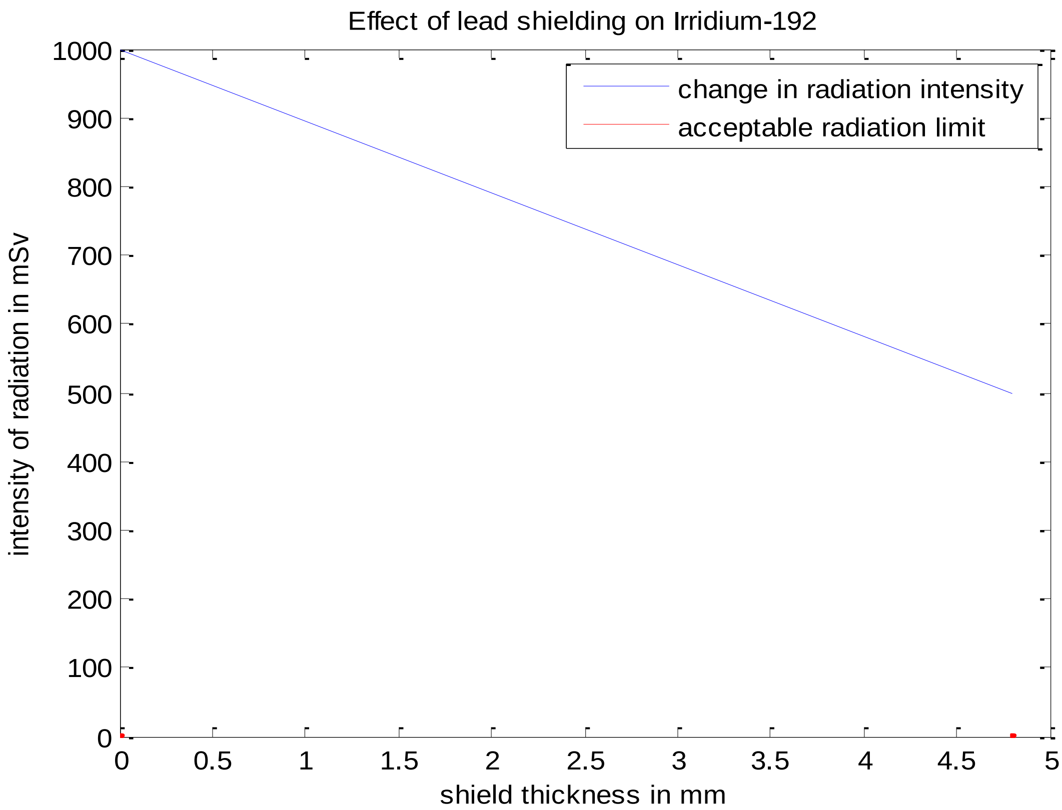


Figure 7.67: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 1000 mSv

Figure 7.68 is the result for increased radiation intensity to 1000 mSv for Tungsten shielding:

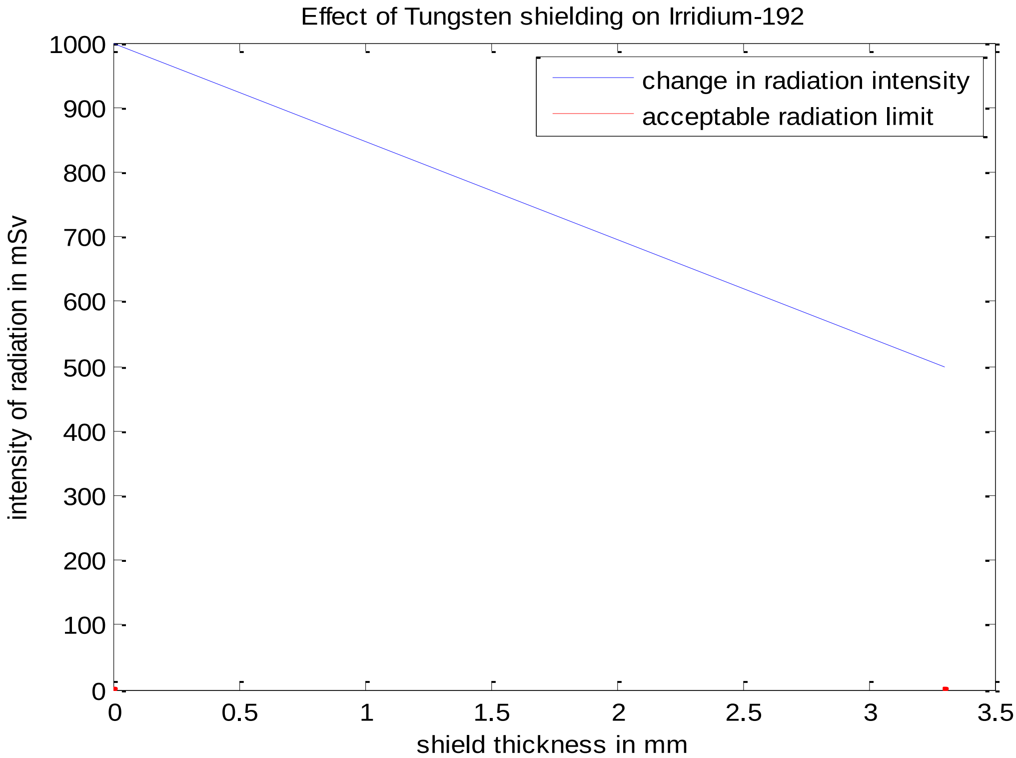


Figure 7.68: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 1000 mSv

Figure 7.69 is the result for increased radiation intensity to 1000 mSv for Uranium shielding:

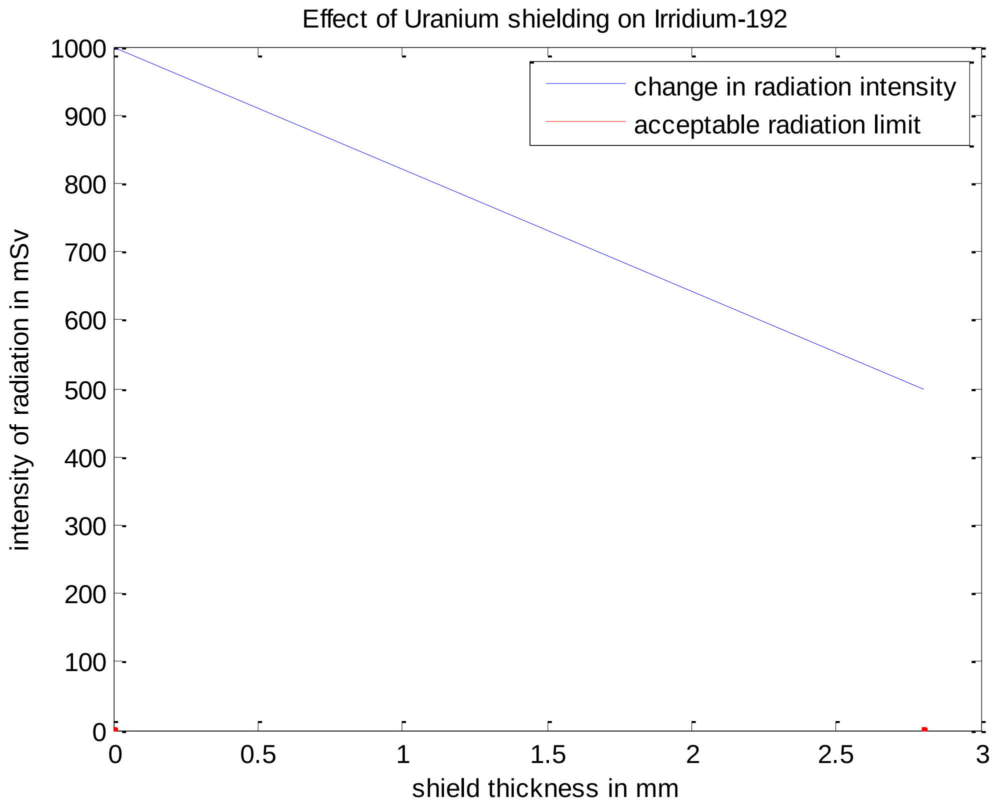


Figure 7.69: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 1000 mSv

7.4.14 Cobalt-60 with Radiation Intensity of 1000 mSv

Figure 7.70 is the result for the increased radiation intensity to 1000 mSv for concrete shielding:

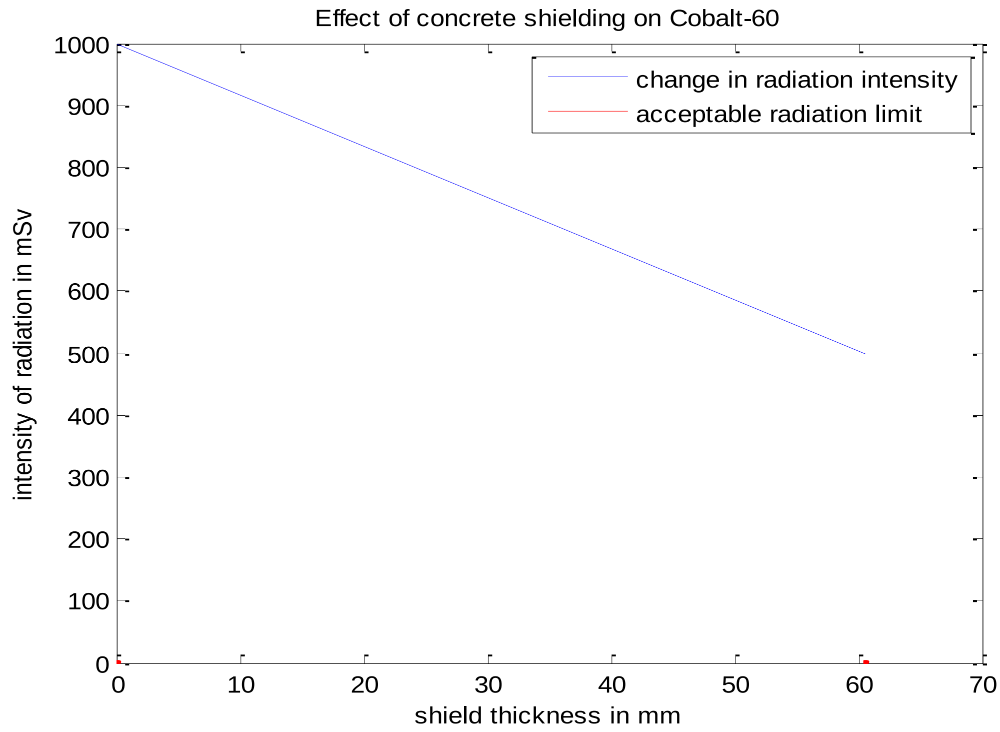


Figure 7.70: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv

Figure 7.71 is the result for the increased radiation intensity to 1000 mSv on steel shielding:

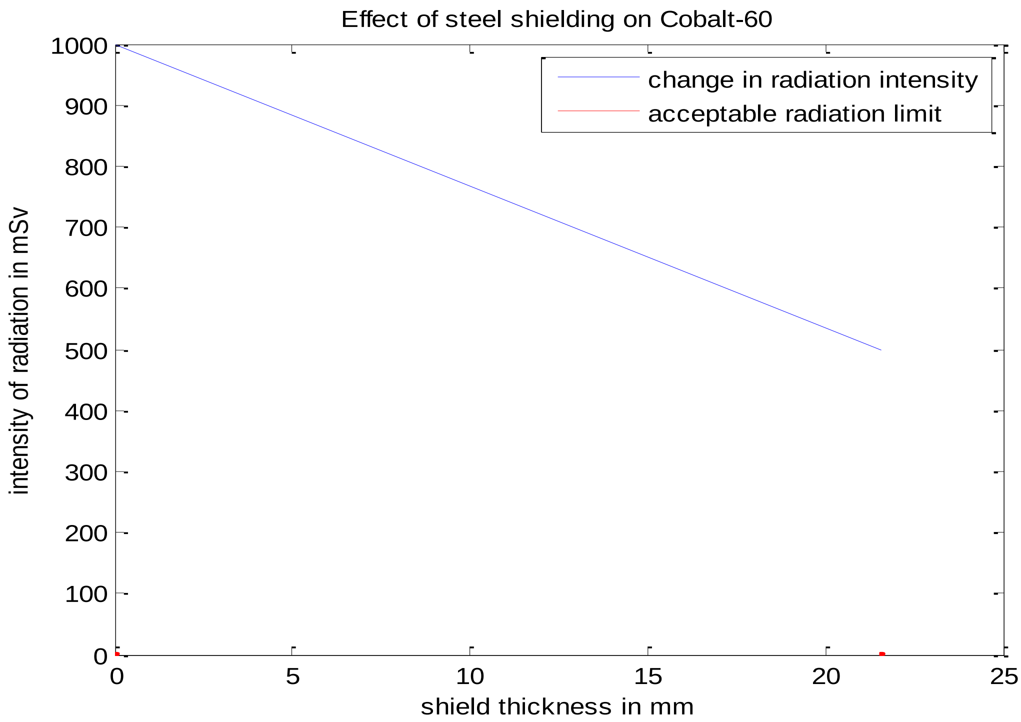


Figure 7.71: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv

Figure 7.72 is the result for increased radiation intensity to 1000 mSv on Lead shielding:

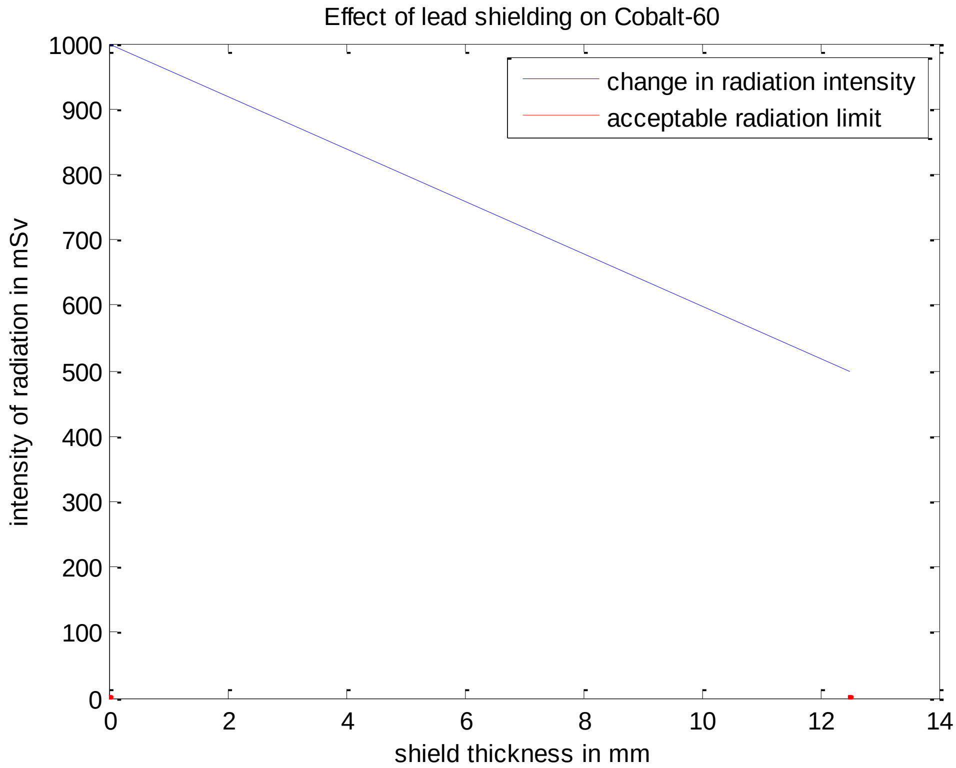


Figure 7.72: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv

Figure 7.73 is the result for the increased radiation intensity to 1000 mSv on Tungsten shielding:

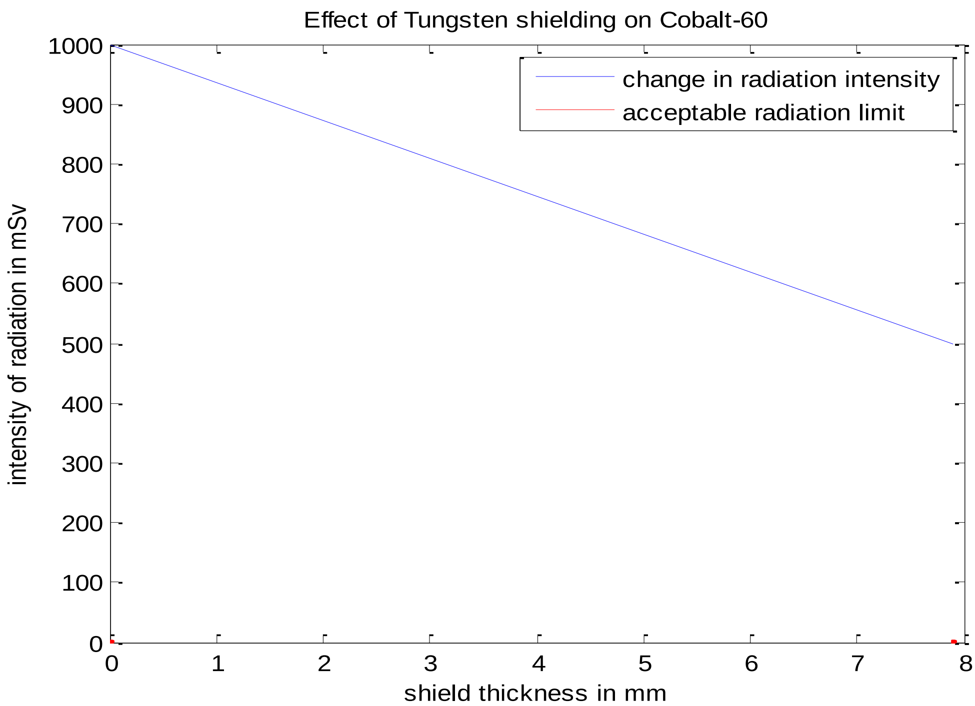


Figure 7.73: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv

Figure 7.74 is the result of increased radiation intensity to 1000 mSv on Uranium shielding:

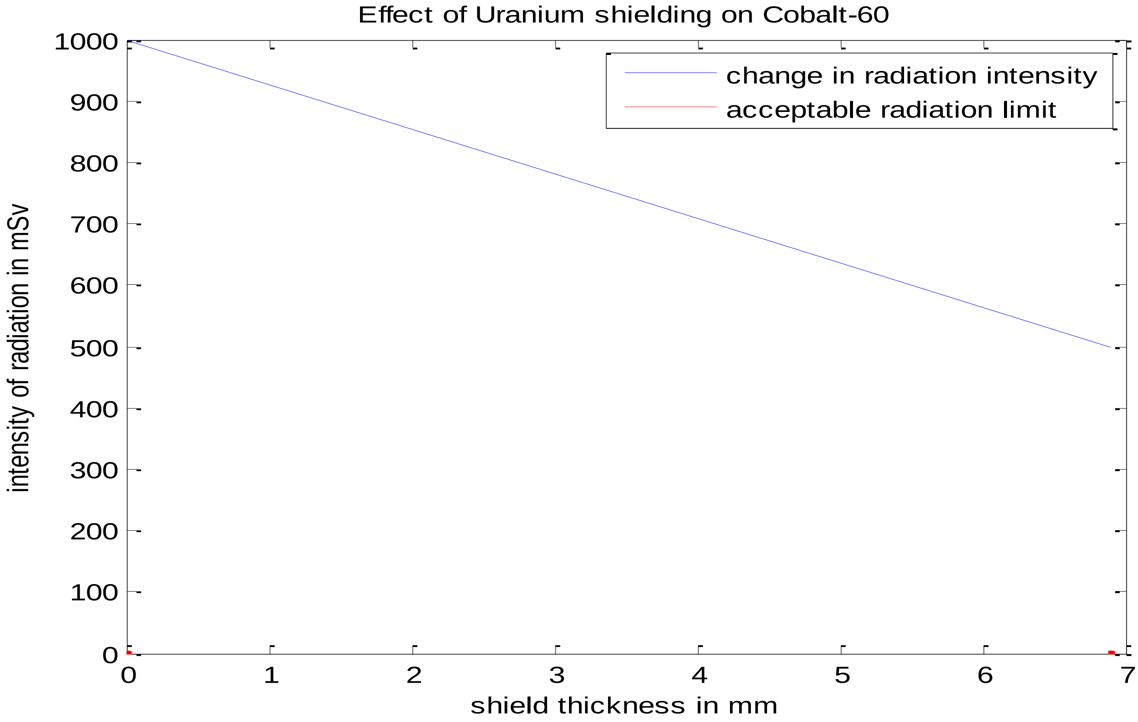


Figure 7.74: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 1000 mSv

7.4.15 Summary at 1000 mSv

The same effect after subjecting radiation intensity of 0.05 mSv, 2.5 mSv , 20 mSv and 250 mSv with Irridium-192 and Cobalt-60 for Concrete, Steel, Lead, Tungsten and depleted Uranium was also experienced. Concrete and Steel as shown in Figures 7.65, 7.66, 7.70 and 7.71 were **NOT** as effective in shielding radiation as compared to Lead, Tungsten and depleted Uranium as shown in Figures 7.67, 7.68, 7.69, 7.72, 7.73 and 7.74.

7.4.16 Irridium-192 with Radiation Intensity of 10000 mSv

The result of using Concrete with HVL of 44.5 mm for shielding, with increased radiation intensity of 10000 mSv and radiation limit of 0.05 mSv is as shown in Figure 7.75 below:

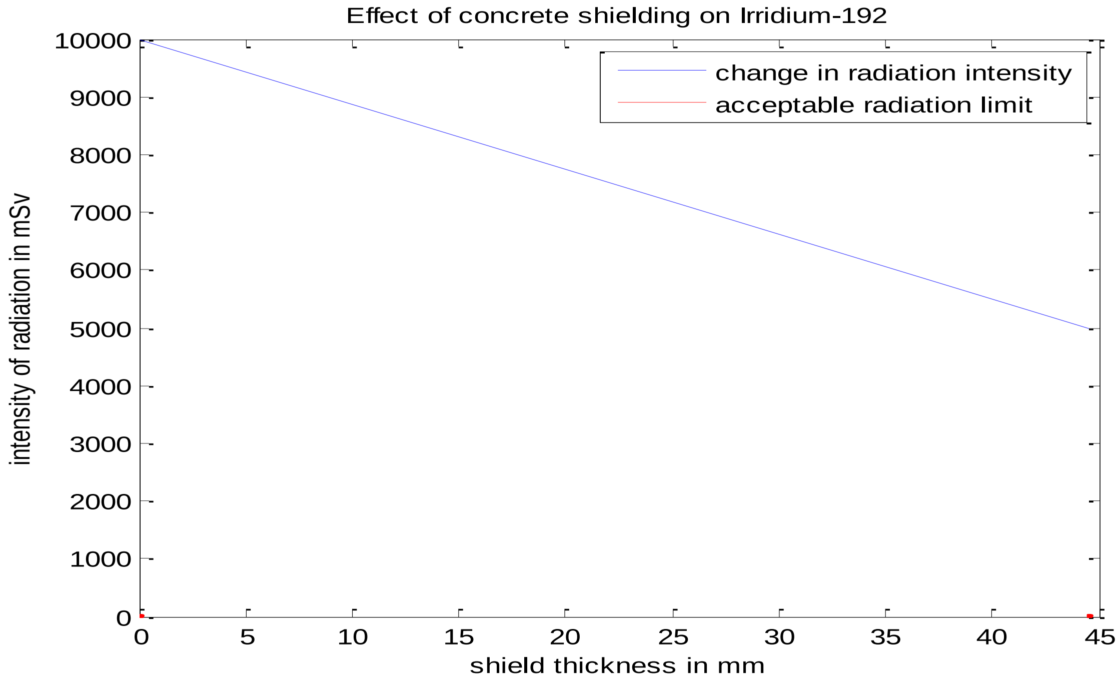


Figure 7.75: Effect of Concrete Shielding on Irridium-192 with Radiation Intensity of 10000 mSv

Figure 7.76 is the result for the increased radiation intensity to 10000 mSv for steel shielding:

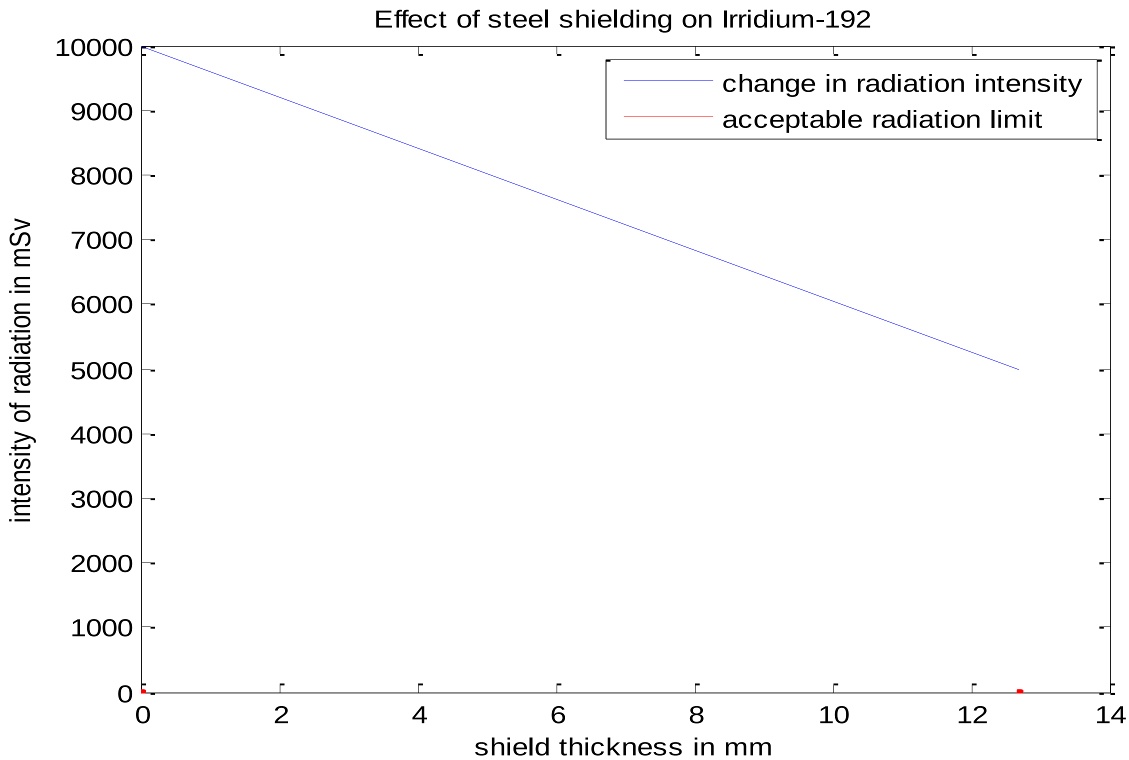


Figure 7.76: Effect of Steel Shielding on Irridium-192 with Radiation Intensity of 10000 mSv

Figure 7.77 is the result for the increased radiation intensity to 10000 mSv for lead shielding:

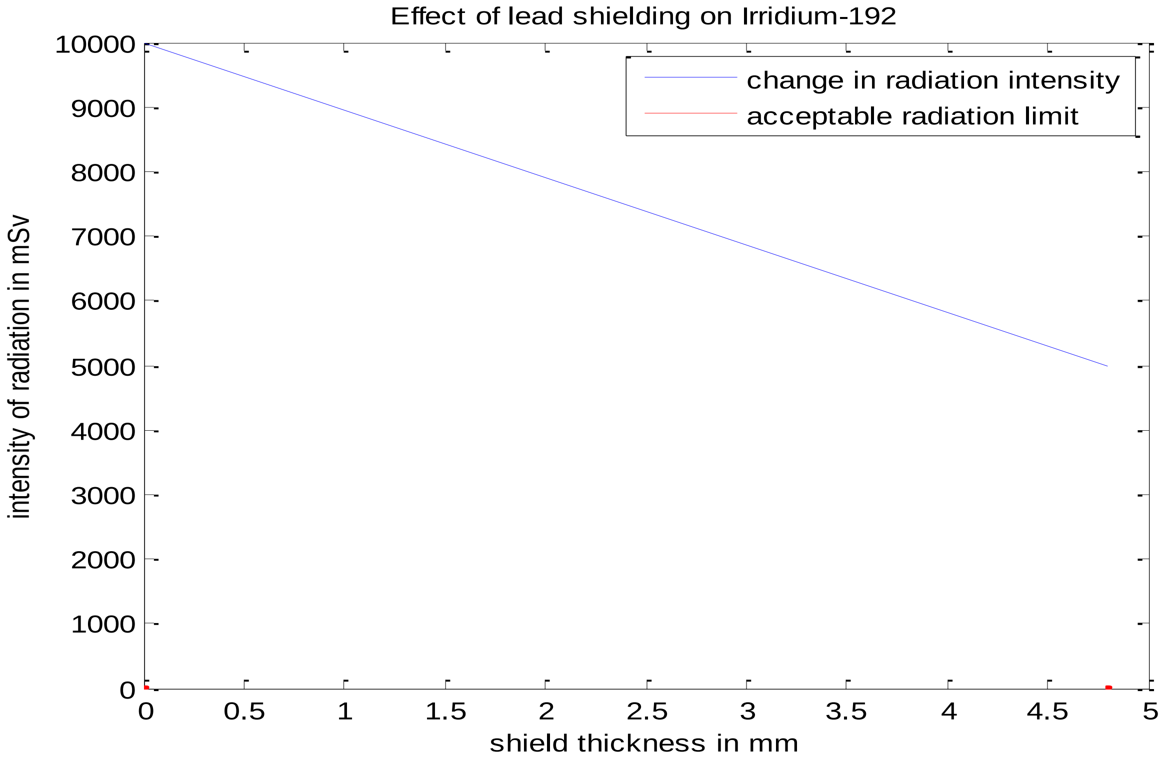


Figure 7.77: Effect of Lead Shielding on Irridium-192 with Radiation Intensity of 10000 mSv

Figure 7.78 is the result for the increased radiation intensity to 10000 mSv for Tungsten shielding:

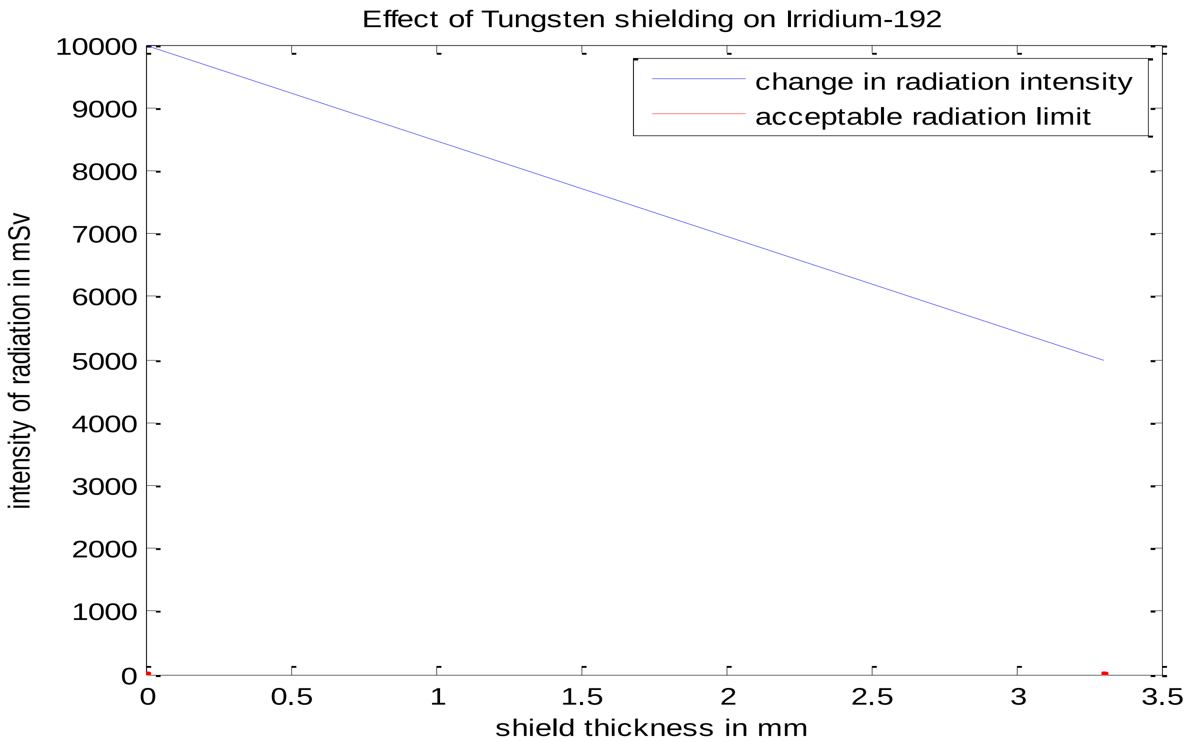


Figure 7.78: Effect of Tungsten Shielding on Irridium-192 with Radiation Intensity of 10000 mSv

Figure 7.79 is the result of the increased radiation intensity to 10000 mSv for Uranium shielding:

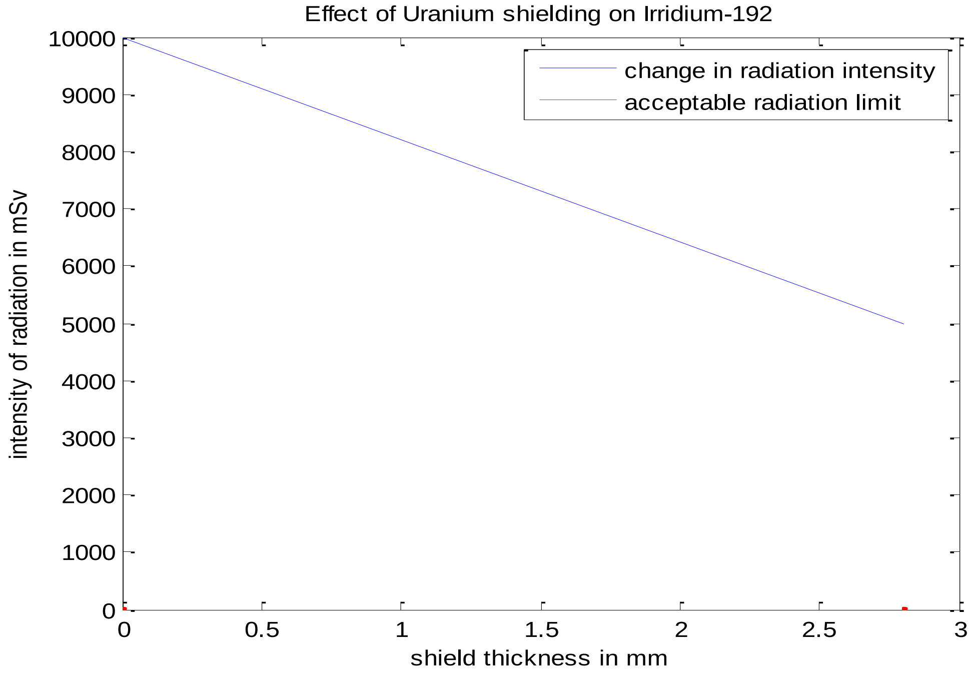


Figure 7.79: Effect of Uranium Shielding on Irridium-192 with Radiation Intensity of 10000 mSv

7.4.17 Cobalt-60 with Radiation Intensity of 10000 mSv

Figure 7.80 is the result of increased radiation intensity to 10000 mSv for concrete shielding:

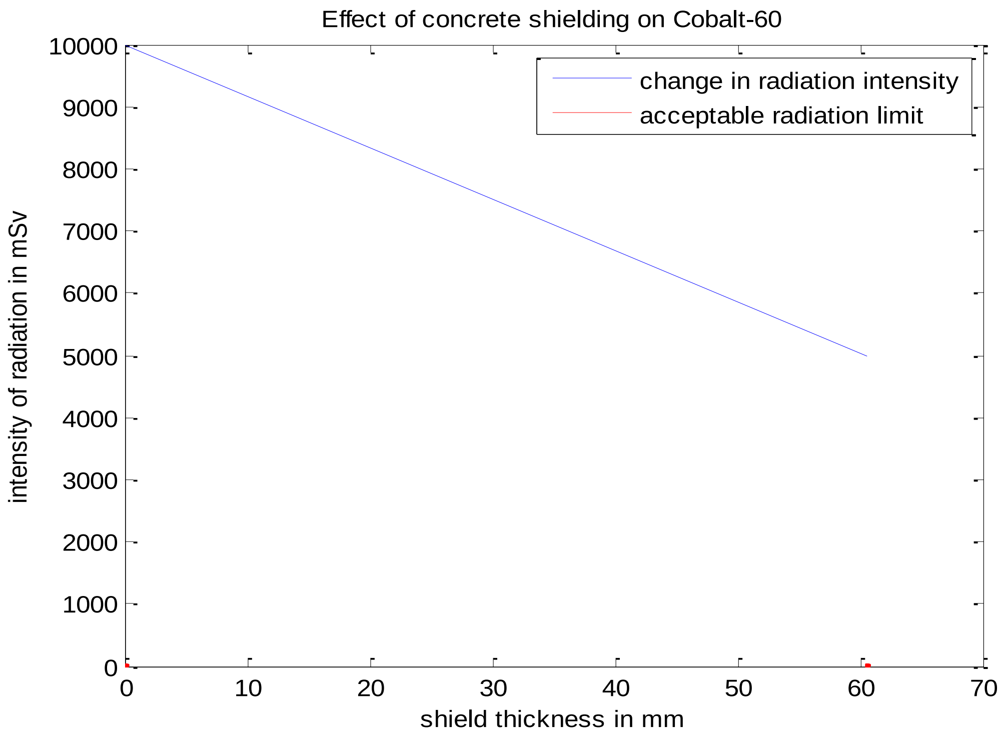


Figure 7.80: Effect of Concrete Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv

Figure 7.81 is the result of increased radiation intensity to 10000 mSv on steel shielding:

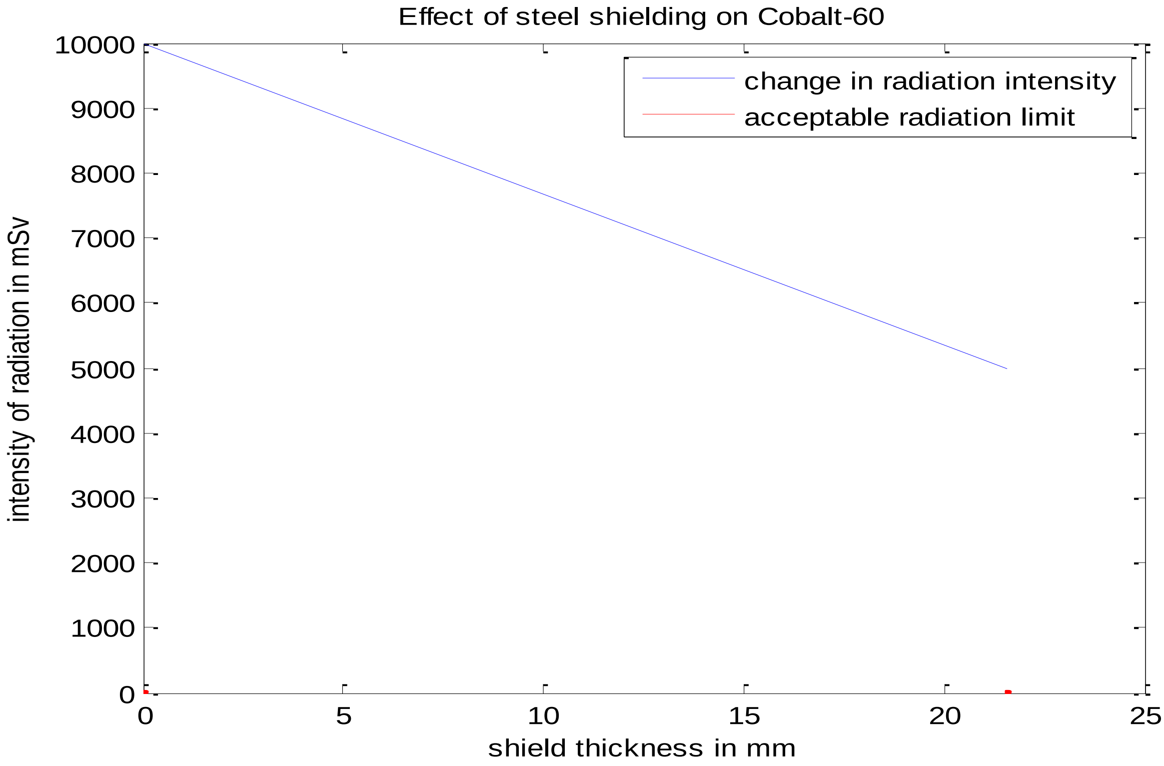


Figure 7.81: Effect of Steel Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv

Figure 7.82 is the result of increased radiation intensity to 10000 mSv on Lead shielding:

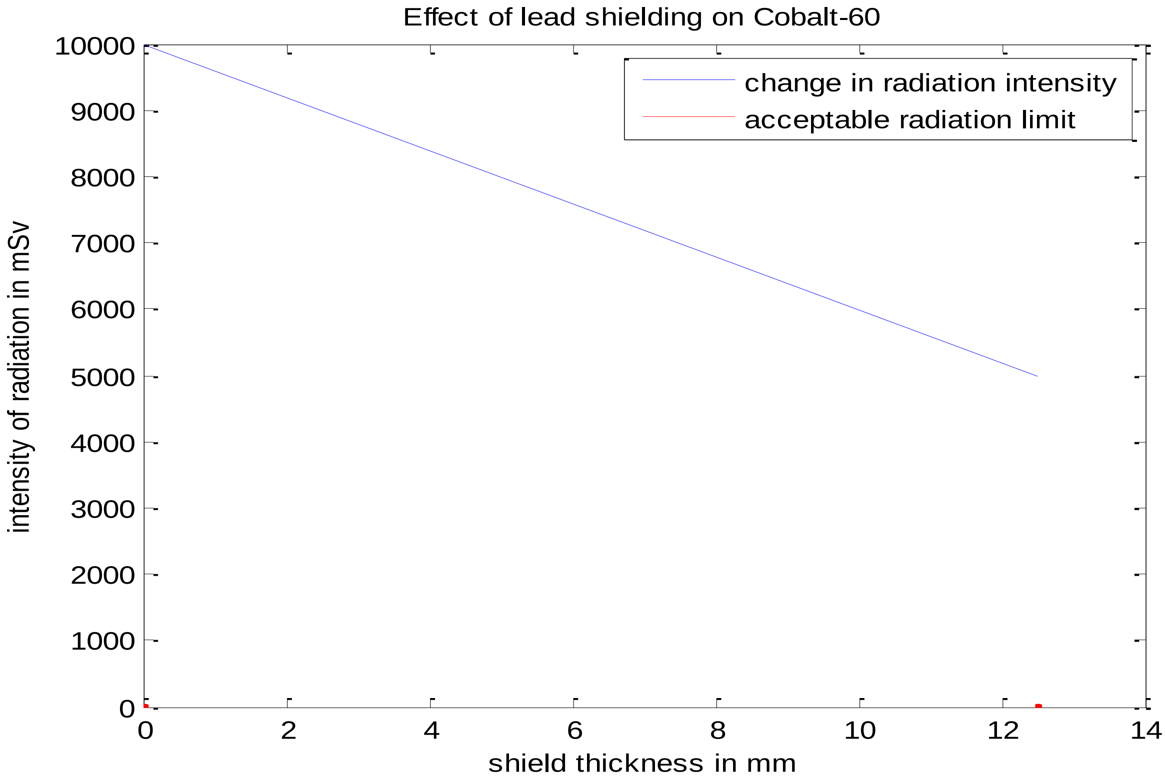


Figure 7.82: Effect of Lead Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv

Figure 7.83 is the result of increased radiation intensity to 10000 mSv on Tungsten shielding:

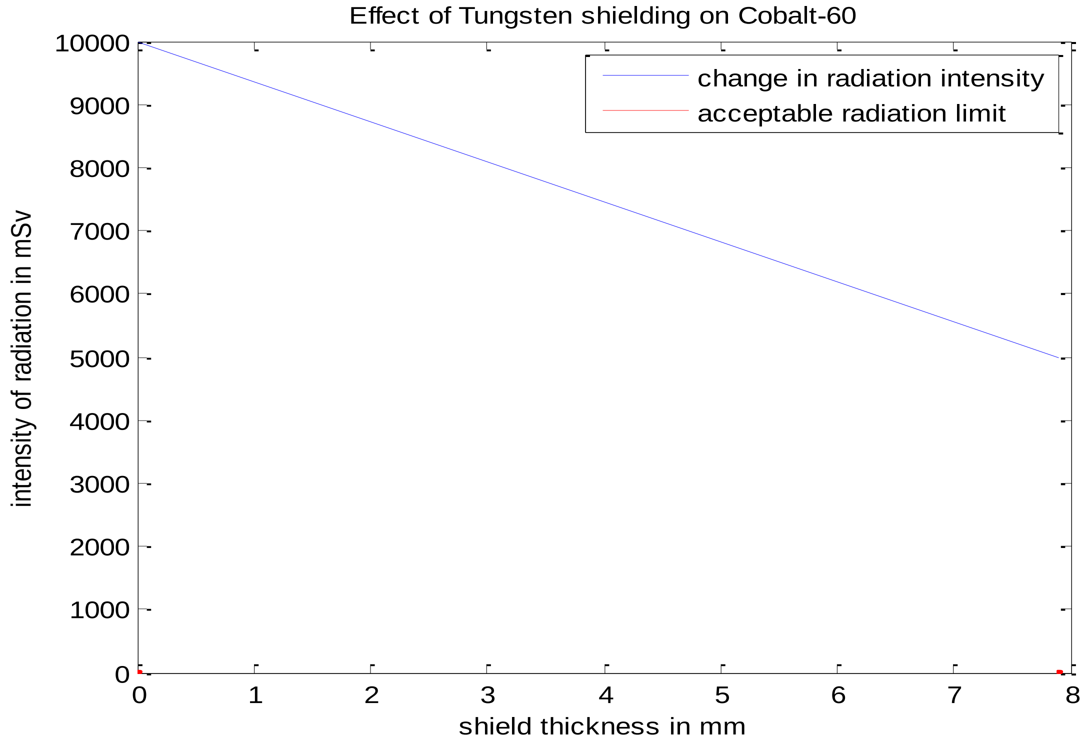


Figure 7.83: Effect of Tungsten Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv

Figure 7.84 is the result of increased radiation intensity to 10000 mSv on Uranium shielding:

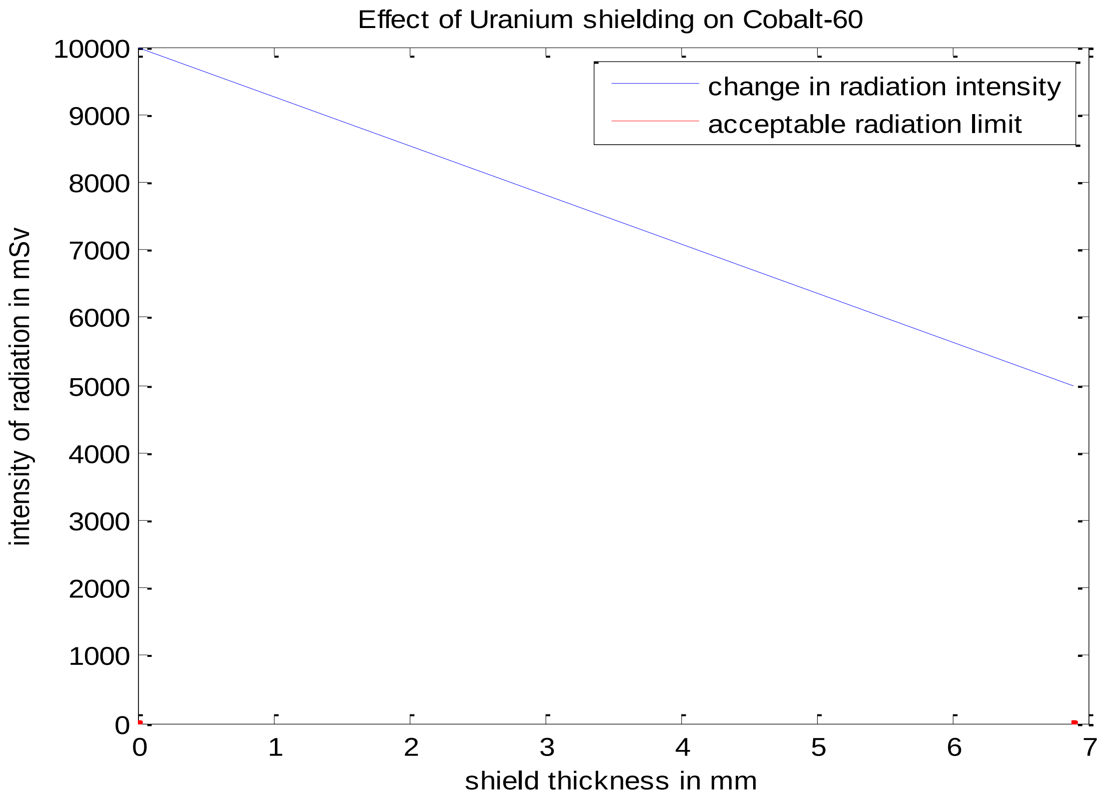


Figure 7.84: Effect of Uranium Shielding on Cobalt-60 with Radiation Intensity of 10000 mSv

7.4.18 Summary at 10000 mSv

Finally, the results of radiation intensity of 0.05 mSv, 2.5 mSv, 20 mSv, 250 mSv, 1000 mSv and, 10000 mSv with Irridium-192 and Cobalt-60 for Concrete, Steel, Lead, Tungsten and depleted Uranium were as shown above. However, Concrete and Steel as shown in Figures 7.75, 7.76, 7.80 and 7.81 were **NOT** very effective in shielding radiation as compared to Lead, Tungsten and depleted Uranium as shown in Figures 7.77, 7.78, 7.79, 7.82, 7.83 and 7.84.

7.5 RADIATION MONITORING SYSTEM ANALYSIS

In proposing any radiation monitoring system, the three basic concepts of radiation protection (Distance, Time and Shielding) must be considered and adhered to for robust and effective design. Building of the data centre that will host all the communication devices needs to be built with concrete walls - the localization of the monitoring centre needs to be at a distance from the main facility which also serves as a measure in controlling the Time spent if it has to be manual monitoring. This is necessary as the essence of the design is for the protection of life, properties and environment from the harmful effects of ionizing radiation. Consequently, a comparison was made between mesh topology and star topology in this simulation as shown in Case 1 and Case 2 below:

7.5.1 CASE 1: Mesh Topology with faulty Node 1 of Radiation Strength of 0.05 mSv

A fault on Node 1 with radiation intensity of 0.05 mSv does not have any effect on the data transmission to the server as shown below in Figure 7.85

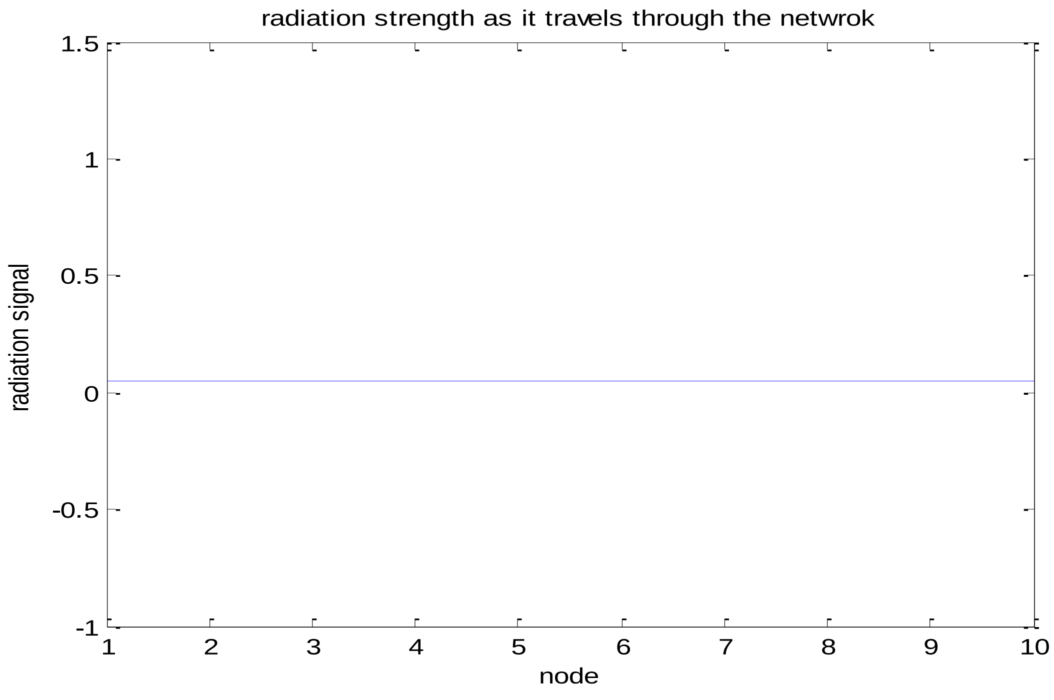


Figure 7.85: Effect of Mesh Topology on Wireless Mesh Network (WMN) with Radiation Strength of 0.05 mSv

7.5.1.1. Star Topology with faulty Node 1 of Radiation Strength of 0.05 mSv

As seen in Figure 7.86 below, a faulty Node 1 with radiation intensity of 0.05 mSv will block the transmission of data to the server.

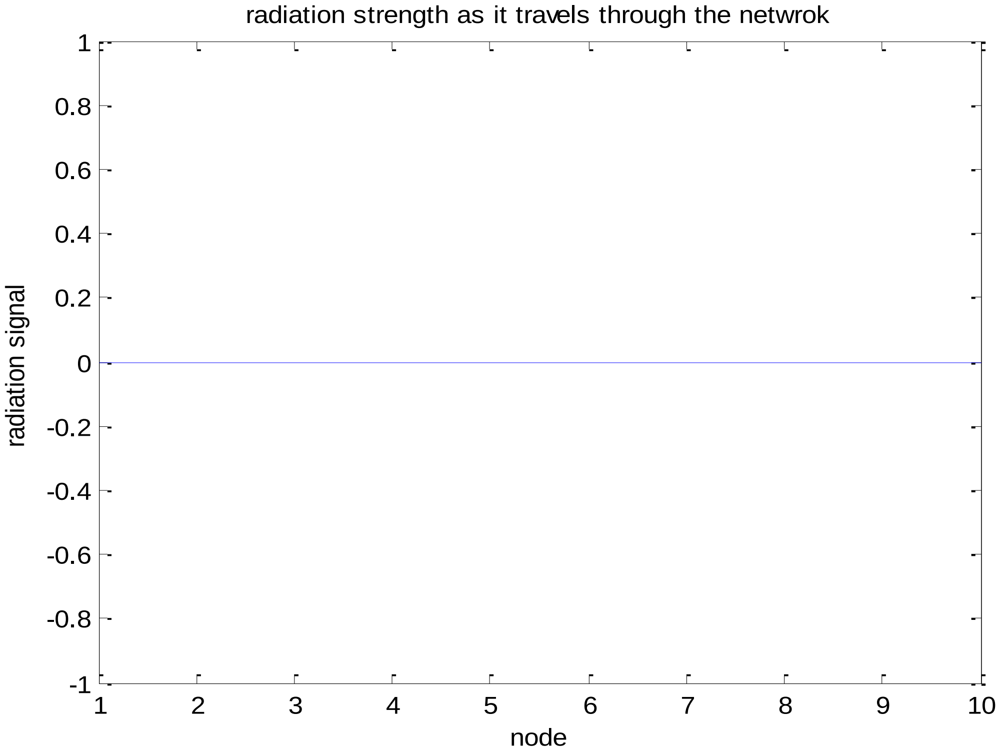


Figure 7.86: of Star Topology on WMN with Radiation Strength of 0.05 mSv

7.5.2 CASE 2: Mesh Topology with faulty Node 2 and an increased radiation Strength of 2.5 mSv

Similar effect was also noticed after an increase of radiation intensity to 2.5 mSv on mesh topology as shown below in Figure 7.87. However, no disruption of transmission to the server was noticed.

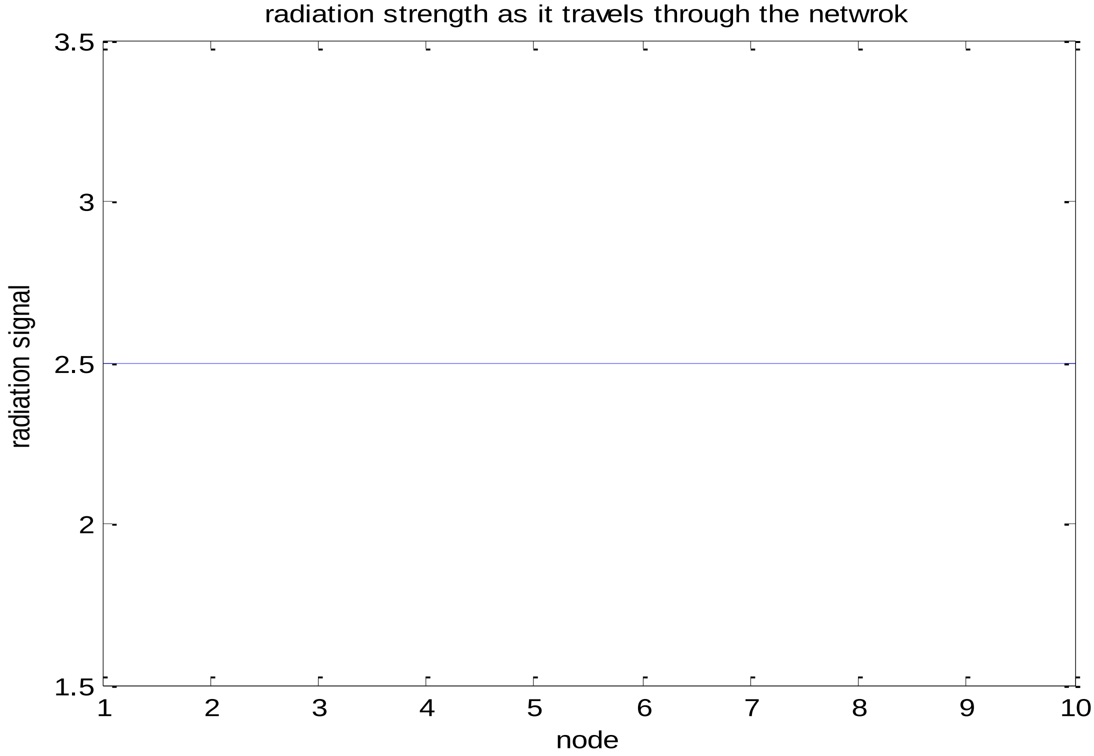


Figure 7.87: Effect of Mesh Topology on WMN with Radiation Strength of 2.5 mSv

7.5.2.1 Star Topology with faulty Node 2 of Radiation Strength of 2.5 mSv

With faulty Node 2 as shown in Figure 7.88 below, disruption of transmission was observed.

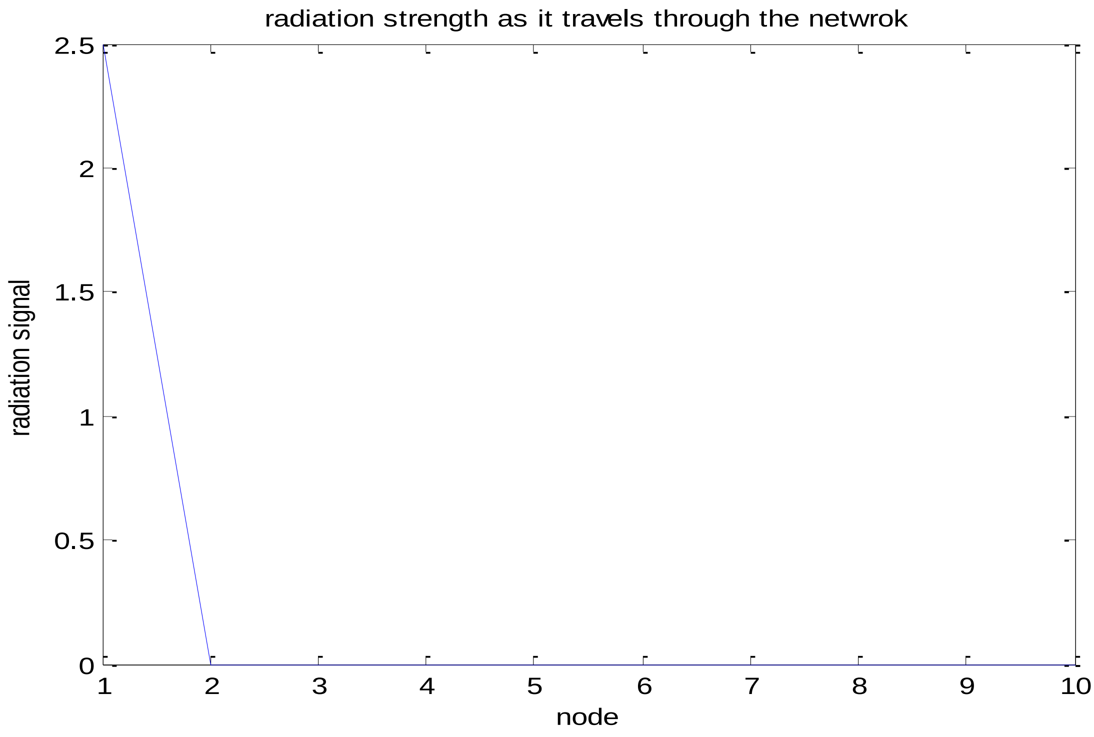


Figure 7.88: Effect of Star Topology on WMN with Radiation Strength of 2.5 mSv

7.5.2 CASE 3: Mesh Topology with faulty Node 3 and an increased radiation Strength of 20 mSv

The same was observed with Node 3. When radiation intensity was increased to 20 mSv, no data loss was noticed as shown in Figure 7.89 below:

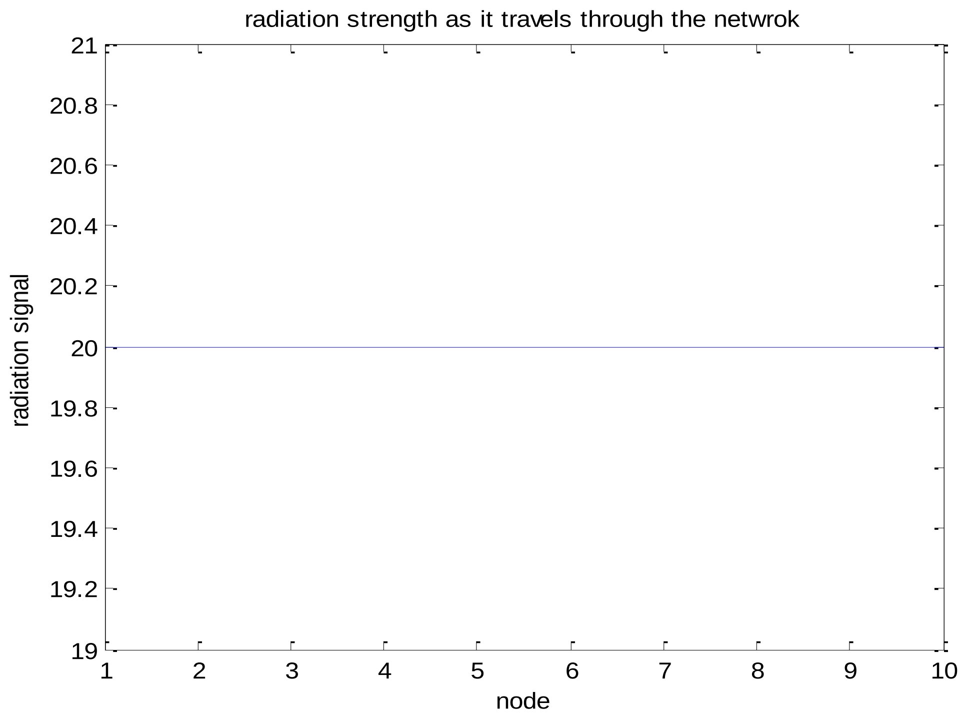


Figure 7.89: Effect of Mesh Topology on WMN with Radiation Strength of 20 mSv

7.5.2.1 Star Topology with faulty Node 3 of Radiation Strength of 20 mSv

As shown below for Node 3 in Figure 7.90, there was disruption in data transmission.

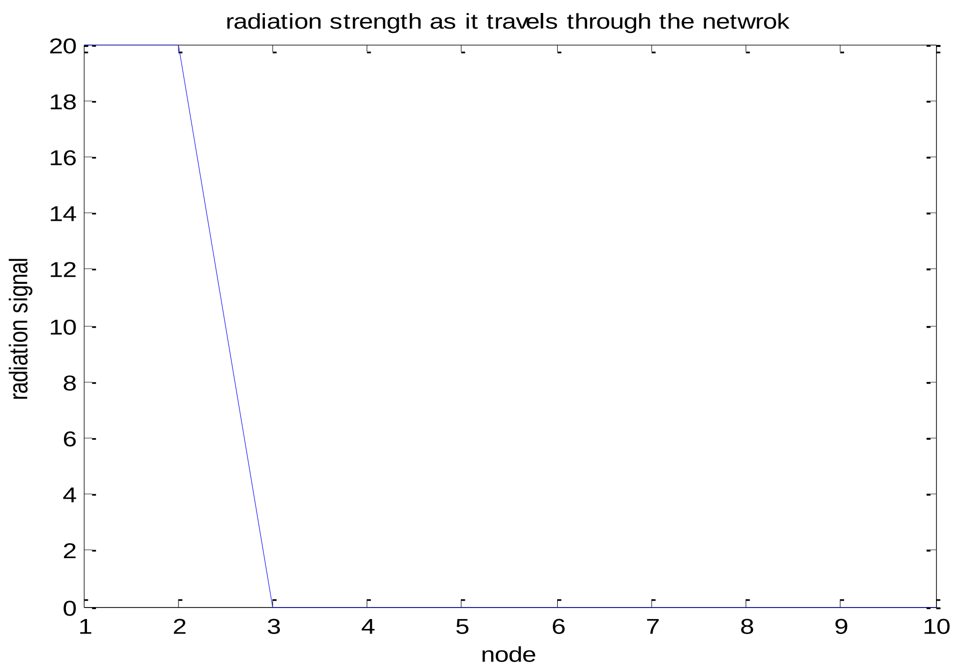


Figure 7.90: Effect of Star Topology on WMN with Radiation Strength of 20 mSv

7.5.4 CASE 4: Mesh Topology with faulty Node 4 and an increased radiation Strength of 250 mSv

With radiation intensity also increased to 250 mSv on Node 4, no disruption of data transmission noticed also as shown in the Figure 7.91 below:

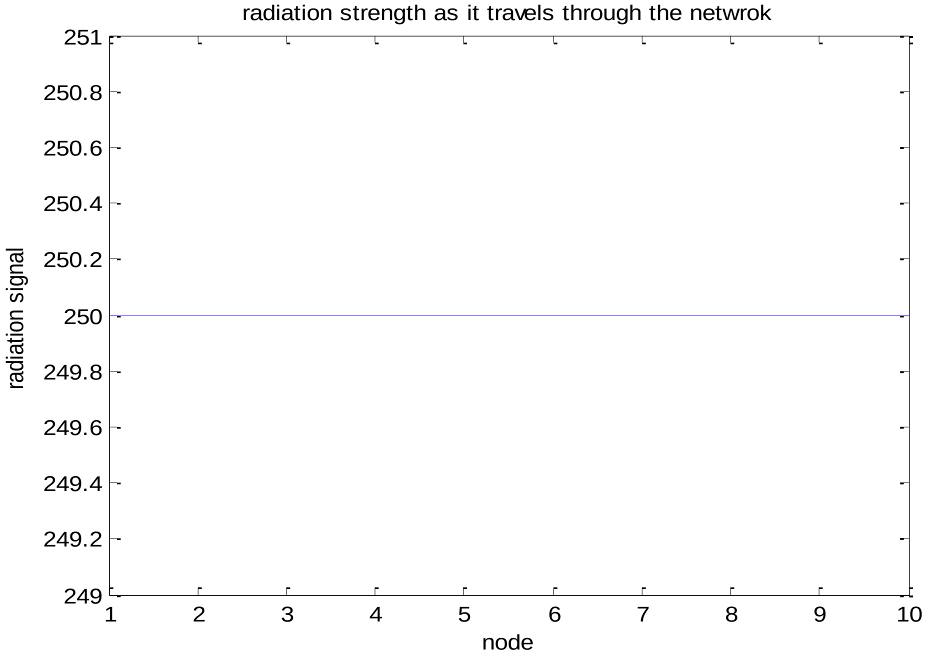
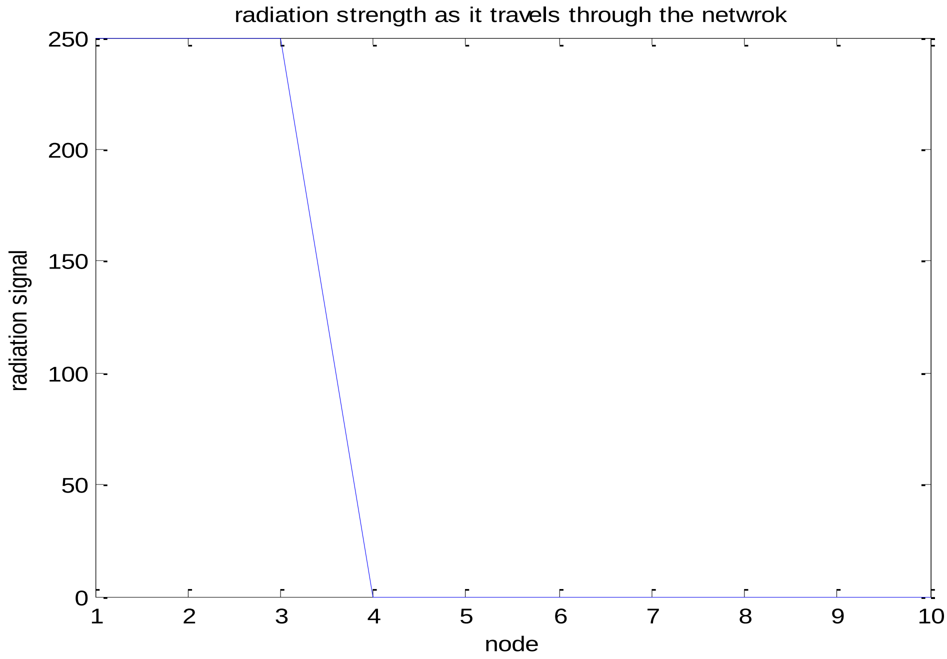


Figure 7.91: Effect of Mesh Topology on WMN with Radiation Strength of 250 mSv

7.5.4.1 Star Topology with faulty Node 4 of Radiation Strength of 250 mSv

But with the corresponding star topology of radiation intensity of 250 mSv on Node 4, there was break in the data transmission as in Figure 7.92 below.



.

Figure 7.92: Effect of Star Topology on WMN with Radiation Strength of 250 mSv

7.5.5 CASE 5: Mesh Topology with faulty Node 5 and an increased radiation Strength of 1000 mSv

With an increased radiation intensity to 1000 mSv, no break in the transmitted data as shown below in Figure 7.93.

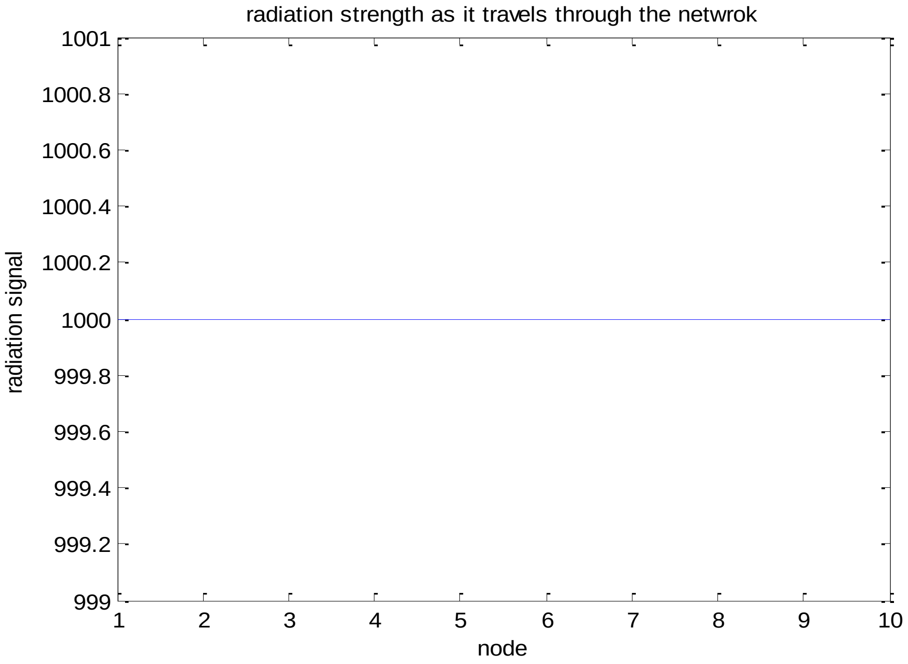


Figure 7.93: Effect of Mesh Topology on WMN with Radiation Strength of 1000 mSv

7.5.5.1Star Topology with faulty Node 5 of Radiation Strength of 1000 mSv

But at 1000mSv on Node 5, there was data disruption compared to the mesh topology as shown below in Figure 7.94:

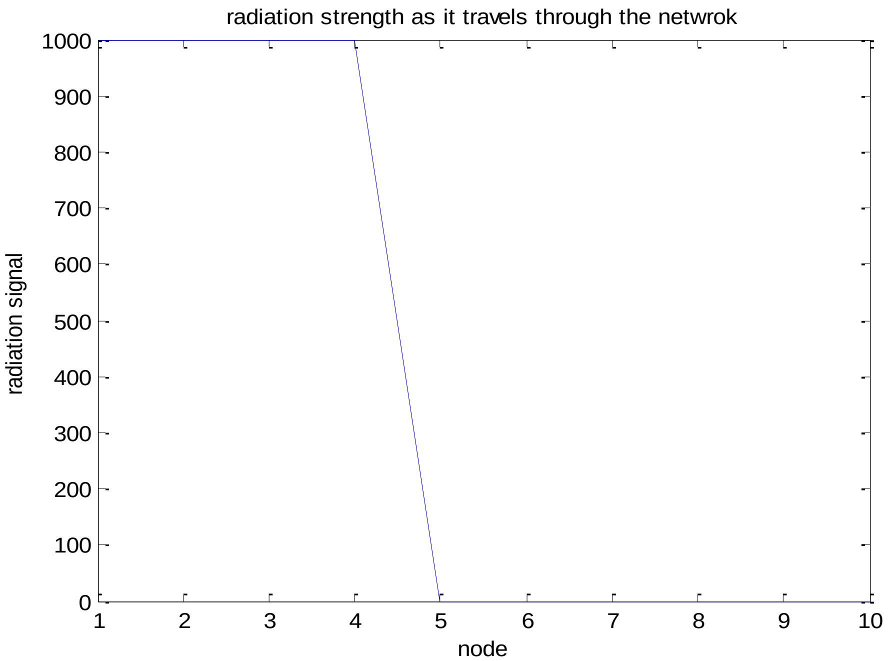


Figure 7.94: Effect of Star Topology on WMN with Radiation Strength of 1000 mSv

7.5.6 CASE 6: Mesh Topology with faulty Node 6 and an increased radiation Strength of 10000 mSv

At 10000 mSv with faulty Node 6, data flows on mesh to the server without disruption as in Figure 7.95.

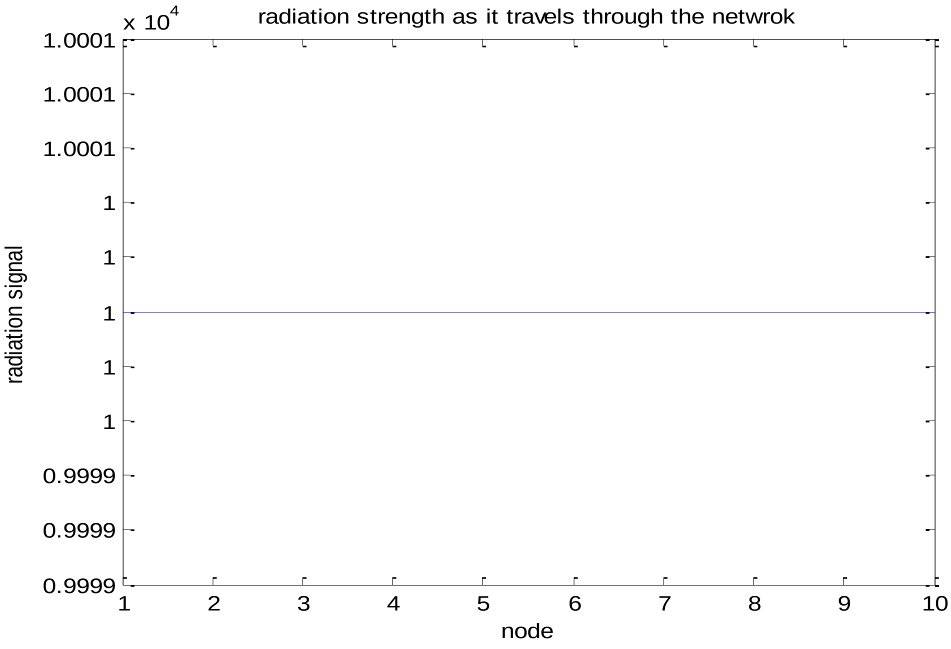


Figure 7.95: Effect of Mesh Topology on WMN with Radiation Strength of 10000 mSv

7.5.6.1 Star Topology with faulty Node 6 of Radiation Strength of 10000 mSv

Unlike Mesh topology, faulty Node 6 also disrupts data flow to the server.

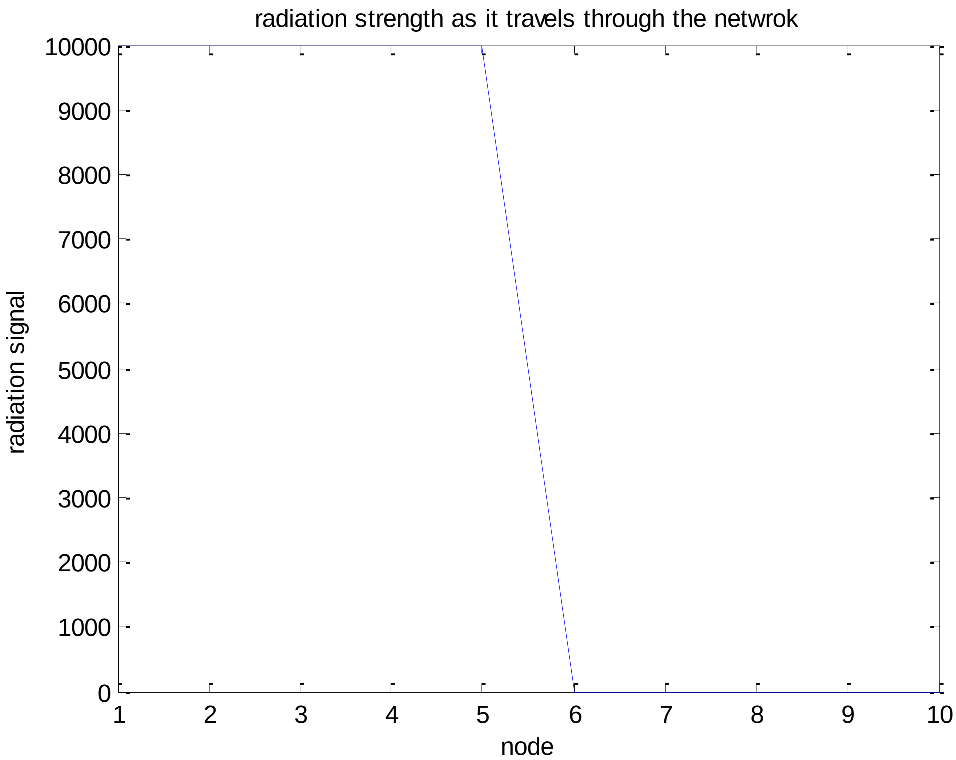


Figure 7.96: Effect of Star Topology on WMN with Radiation Strength of 10000 mSv

7.6 Conclusion:

Based on the above simulations, mesh network proposed for the radiation monitoring system is highly recommended since the fault from any node does not have effect on the data flow from any other nodes to the server unlike its counter network topology of star.

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATIONS

8.1 Introduction

This chapter draws various conclusions from the research executed so far with appropriate recommendations.

8.2 Conclusion

The world needs to generate sufficient energy at a reasonable cost to raise the living standards of billions of people, which do not have access to cheap and abundant electricity but without environmental damage, in a safe and secure manner in the coming decades to meet the needs of a growing population. Globally access to electricity improvement is critical to alleviating poverty and nuclear energy has the potential to make a significant contribution to meet the world's growing energy needs because of its competitively priced, base load electricity that is essentially free of GHG emissions combined with its role in enhancing security of energy supplies. These and more increase the prospects for growth and development of nuclear power generation. However, despite recent declines from the global economic and financial crisis, world demand for electricity is expected to continue to grow significantly over the next several decades to foster economic growth and to meet the needs of an increasing population. Since the first controlled nuclear chain reaction and with a total of 435 nuclear power generating plants now in operation in 31 countries with an installed capacity of almost 373 GW (e) of electricity, nuclear power has been harnessed and developed into a major source of energy globally. Therefore, this huge expansion of technology and infrastructure has brought both benefits, in terms of available electric power for an improved standard of living as well as challenges in terms of nuclear safety, used fuel management, and nuclear proliferation risk. Due to continued research and technological improvements, many weaknesses in Generation I and II plant designs have being resolved. The resulting Generation III designs are expected to be simpler, safer, and more economical to build and to operate. Results from some of the first Generation III plants already built support this expectation and Gen IV – plants of the future are now being developed to operate safely and economically as well as to answer the most difficult of the remaining challenges in nuclear industry such as waste management and proliferation risk.

Similarly, the environmental resources available to man, animals, plants and the entire ecosystem is very vulnerable and requires strategic planning to cater for our generation and subsequent ones and the secret also is to imbibe the concept of sustainable development – a return to a clean energy that are sustainable, that does not contribute to environmental degradation. And for nuclear energy to significantly contribute to sustainable energy development, we cannot depend on burner reactors that will quickly use earth's uranium

resources, rather R&D of safer breeder reactors will be necessary and to intensify more on the research on HTR which is an advanced reactor concept that can meet the energy and environmental needs of future generations. However, to avoid large stockpiles of weapons-grade plutonium, which is being inevitably accumulated, one alternative for the management of Plutonium is to incinerate it in the reactors with a thorium based fuel cycle which is suitable for burning Plutonium most effectively, as well as to minimize the amount to be disposed. A Thorium based fuel cycle would produce small amount of toxic fuel waste or long-lived radiotoxic waste, both of which contribute substantially to anxieties about disposal of nuclear waste.
However, radiation and radioactive substances are natural and permanent features of the environment, and the risks associated with radiation exposure can only be restricted, not eliminated entirely. Hence, long term epidemiological studies of populations exposed to radiation exposure, such as the production, use of radiation sources and radioactive materials, and the operation of nuclear installations, including the management of radioactive waste, be subjected to certain standards of safety in order to protect individuals from radiation exposure. Furthermore, the use of human made radiation is widespread and sources of radiation are essential to modern health care especially disposable medical supplies sterilized by intense radiation have been central to combating disease, radiology is a vital diagnostic tool and radiotherapy is commonly part of the treatment of malignancies. Whereas the use of nuclear energy and applications of its by-products for radiation and radioactive substances, continue to increase around the world, nuclear techniques are in growing use in industry, agriculture, medicine and many fields of research, benefiting hundreds of millions of people and giving employment to millions of people in the related occupations. Irradiation is likewise used around the world to preserve foodstuffs and reduce wastages while sterilization techniques have been used to eradicate diseases carrying insects and pests. To examine welds and detect cracks and help prevent the failure of engineered structures, industrial radiography is still not left out. Therefore, the acceptance by society of risks associated with radiation is conditional on the benefits to be gained from it. Hence, the risks must be restricted and protected against by the application of radiation safety standards which provide desirable international consensus. The outcome of these standards was from extensive research and development work by scientific and engineering organizations, at national and international levels, which was based on experiences in many countries in the use of radiation and nuclear techniques, the health effects of radiation, techniques for the safe design and operation of radiation sources.

In line with application of radiation safety standards, the environmental radiation monitoring of a nuclear facility is an important component of nuclear accident emergency system. Even though the controlled release of radionuclide’s to the atmosphere and aquatic environments is a legitimate waste management practice in the nuclear industry and its related facilities, its uncontrolled releases to the atmospheric, aquatic and terrestrial environments may occur as a result of nuclear or radiological accidents. Therefore, an important and essential element in the control of the discharges is regular monitoring at the source of the discharge as well as the receiving environment for public protection, assessment on longer term as well as on emergency which involves the collection of radiation data accurately on real-time and sending to the data processing centres for necessary emergency decision. This ensures the protection of the public and the environment against the effect of ionizing radiation and as a basis for restoration of normal activities.

8.3 Recommendations:

- The radiation monitoring system design with the use of wireless IEEE 802.11n mesh solution is of better improvement than the wired network due to low upfront cost, reliability on coverage, easy network maintenance, robustness and self healing. Because of the importance attached to protection of life, property and environment in a nuclear facility, this design is recommended as a secondary monitoring system for the nuclear facility if the embedded primary monitoring system fails.

- Activities in the nuclear facility and management of radioactive waste must be subjected to standards of 3S and to achieve this interface, their synergy must be integrated into the operation, maintenance and management of nuclear and radiological facilities. This will therefore increase the level of confidence with the populace on the safe operation and the fear of sabotage, theft of nuclear facilities and radiological materials, trafficking and the danger of terrorism.

8.4 Publications:

The following publications emanated from this research work:

Zakariya, N. I & Kahn, MTE, 2014. Safety, Security and Safeguard, Elsevier, Volume 75, pp 292–302.

Zakariya, N. I & Kahn, MTE, 2014. Benefits and Biological Effects of Ionizing Radiation, SASpublisher, Volume 2, Issue 9, pp 583 – 591.

Zakariya, N. I & Kahn, MTE, 2014. Nuclear Energy, Environmental Protection and Sustainable Development. Proceeding of the 2nd International Conference on Sustainable Environment and Agriculture (ICSEA), San Diego, USA, 29 – 30 October, Vol. 76, pp 57 – 61.

REFERENCES

Abbott, D., 2012. Limits to growth: Can nuclear power supply the world's needs? Bulletin of the Atomic Scientists, Vo. 68, Issue 5, pp 23-32

Adee, S and Guizot, E., 2010. Nuclear Reactor Renaissance, Nuclear reactor design is poised for a desperately needed revival. Here are seven contenders, IEEE Spectrum, http://spectrum.ieee.org/energy/nuclear/nuclear-reactor-renaissance [01 July 2014]

AGBOM, 2004. How Ozone is destroyed by CFCs, http://www.bom.gov.au/lam/Students_Teachers/ozanim/ozoanim.shtml [01 May 2014]

AGDOH, 2012. Australian Clinical Guidelines for Radiological Emergencies, Acute Radiation Syndrome, Commonwealth of Australia http://www.health.gov.au/internet/publications/publishing.nsf/Content/ohp-radiological-toc~ohp-radiological-06-rad-protection [01 July 2014]

Agg'elou, G., 2009. Wireless Mesh Networking, McGraw-Hill, USA
Agostini, P and Sepielli, M, 2013. ESNII, the European Sustainable Nuclear Industrial Initiative, EURATOM in Horizon 2020, Roma, 18 December http://www.apre.it/media/169478/esnii-miur-sepielli_agostini.pdf [01 July 2014]

Airberry, 2012. Introduction to Mesh Networks, http://airberry.com/downloads/airberry_Whitepaper_EN_02_Wireless_Mesh.pdf [08 August 2014]

Akashi, M., Tamura, T., Tominaga, T., Abe, K., Hachiya, M and Nakayama, F., 2006. Radiation Damage in the Human Body Acute Radiation Syndrome and Multiple Organ Failure, Department of Radiation Emergency Medicine, Research Centre for Radiation Emergency Medicine, National Institute of Radiological Sciences, Chiba, Japan http://www.kns.org/jknsfile/v38/JK0380231.pdf [16 July 2014]

Akyildiz, I. F., Wang, X and Wang, W., 2005. Wireless mesh networks: a survey, Computer Networks, Elsevier, Vol.47, pp. 445–487

ALGER, J., 2008. A Guide to Global Nuclear Governance: Safety, Security and Non-proliferation, the Centre for International Governance Innovation (CIGI), Ontario, Canada http://www.cigionline.org/sites/default/files/a_guide_to_nuclear_power.pdf [01 May 2014]

Al Kaabi, H, 2011. United Arab Emirates and the experience of a nuclear newcomer, Bulletin of the Atomic Scientists, Vol. 67, Issue 4, pp. 52-59

Alshamali, 2008. Gsm based remote ionized radiation monitoring system, International Conference on Advances in Electronics and Micro-electronics, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4641254 [31 July 2014]

Amano, Y., 2013. Nuclear Security Plan 2014–2017, IAEA press, Austria, Vienna http://www.iaea.org/About/Policy/GC/GC57/GC57Documents/English/gc57-19_en.pdf [01 May 2014]

Amory B. Lovins, A.B., 2013. The economics of a US civilian nuclear phase-out, Bulletin of the Atomic Scientists, Vol. 69, Issue 2, pp 44-65

ARM, 2014, Cortex-A9 Processor, http://www.arm.com/products/processors/cortex-a/cortex-a9.php [08 August 2014]

ARPANSA, 2012. Radiation Basics - Ionising and Non Ionising Radiation, The electromagnetic spectrum, Commonwealth of Australia, Yallambie, Australia http://www.arpansa.gov.au/radiationprotection/basics/ion_nonion.cfm [11 July 2014]

ARPANSA, 2014. Understanding Radiation Health Risks, Risk and potential health effects, Australian Radiation Protection and Nuclear Safety Agency, Yallambie, Australia http://www.arpansa.gov.au/pubs/factsheets/jpn_risks.pdf [20 July 2014]

Attix, F. H., 2003. Introduction to Radiological Physics and Radiation Dosimetry, WILEY-VCH, Morlenbach, Germany

Badia, L., Erta, A., Lenzini, L and Zorzi, M., 2008. Scheduling, Routing, and Related Cross-Layer Management through Link Activation Procedures in Wireless Mesh Networks, In Hossain, E and Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

Baiamonte, V., Casetti, C., Chiasserini, C. F and Fiore, M., 2008. Cross-layer Solutions for Traffic Forwarding in Mesh Networks, In Hossain, E and Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

Bakr, W. F and Hamed, A. A., 2009. Radiological Regulations and Emergency Division National Centre for Nuclear Safety and Radiation Control, Journal of Physical Security, Vol. 3(1), p. 9-16

Batra, A and Nelson, P., 2012. Safety, Safeguards and Security in Indian Civil Nuclear Facilities, Of Literature Otherwise Not Discussed, p.8, 40 &48, NSSPI, India. http://nsspi.tamu.edu/media/1354465/threesreport_nsspi.pdf [10 June 2014]

BBC, 2014.Wylfa nuclear power station closed for five months, http://www.bbc.com/news/uk-wales-north-west-wales-27917859 [01 July 2014]

Benkrid, M., Mebhah, D., Djeffal, S and Allalou, A., 1992. Environmental Gamma Radiation Monitoring by means of TLD and Ionizing Chamber, Radiation protection Dosimetry, Vol. 45, No. 1-4, p.78, Nuclear Technology Publishing, Alger

Bento, L., 2009. Searching for Intergenerational Green Solutions: The Relevance of the Public Trust Doctrine to Environmental Preservation, Social Science Electronic Publishing, Inc., Rochester, NY, USA http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1709104 [07 April 2014]

Bonin, B., 2010. The Scientific Basis of Nuclear Waste Management, In Cacuci, D.G (ed), 2010. Handbook of Nuclear Engineering - Nuclear Engineering Fundamentals, Vol.1, Springer, New York, USA

Botkin, D.B and Keller, E.A., 2003. Environmental science- earth as a living planet, 4th ed., Hoboken-NJ: WILEY

Botkin, D.B and Keller, E.A., 2011. Environmental science- earth as a living planet, 8th ed., WILEY Hoboken-NJ, USA

Boureston, J and Semmel, A. K., 2010.The IAEA and Nuclear Security: Trends and Prospects, the Stanley Foundation, Muscatine, USA http://psaonline.org/downloads/The%20IAEA%20and%20Nuclear%20Security.pdf [11 May 2014]

Boyer, B and Schanfein, M., 2008. International Safeguards Inspection: An Inside Look at the Process, In Doyle, J. (ed.), 2008. Nuclear Safeguards, Security, and Non-proliferation Achieving Security with Technology and Policy Elsevier Inc, Burlington, USA

Bradford, P.A., 2013. How to close the US nuclear industry: Do nothing, Bulletin of the Atomic Scientists, Vol. 69, Issue 2, pp 12-21

Brayon, F.C.M., *n.d*. Physical Protection principles, Atomic Energy Licensing Board (AELB), Selangor, Malaysia
http://www.aelb.gov.my/events/lamanweb2/docs/5%20%20Physical%20Protection%20Prinsiples%20%282%29.pdf [16 May 2014]

BRC, 2012. Report to the secretary of energy, Stakeholder participation, p.68, USDOE, Washington, USA
http://cybercemetery.unt.edu/archive/brc/20120620220235/http:/brc.gov/sites/default/files/documents/brc_finalreport_jan2012.pdf [19 May 2014]

Brechignac, F and Doi, M, 2009. Challenging the current strategy of radiological protection of the environment: Arguments for an ecosystem approach, Elsevier, Vol. 100, p. 1125–1134

Bruneton, P., 2013. Uranium Resources Global Outlook, UNFC Workshop, Chile, 9-12 July 2013
http://www.unece.org/fileadmin/DAM/energy/se/pp/unfc_egrc/unfc_ws_IAEA_CYTED_UNECE_Santiago_July2013/10_July/1_Bruneton_Ursources.pdf [03 July 2014]

Buchtela, K, 1998. Gas Ionization Detectors, In L' Annunziata, M.F. (Ed.), 1998, Handbook in radioactivity analysis, Elsevier, USA

Carmona, L.V., 2005. The International Regime on the Physical Protection of Nuclear Material and the Amendment to the Convention on the Physical Protection of Nuclear Material, Nuclear Law Bulletin, p.1-18
https://www.oecd-nea.org/law/nlb/nlb-76/031_045.pdf [11 May 2014]

Carolissen, A., *n.d*., The Future of Radioactive Waste Management In South Africa, http://www.radwaste.co.za/NLM%20presentation.pdf [04 July 2014]

CBD, 1993. Introduction,
http://www.cbd.int/intro/default.shtml [04 April 2014]

CCEI, 2014. What energy sources are used to generate electricity?
http://www.centreforenergy.com/AboutEnergy/Electricity/Generation/Overview.asp?page=2 [16 May 2014]

CCSA, 2014. Why CCS?
http://www.ccsassociation.org/why-ccs/ [17 May 2014]

CDCP, 2006. Emergency Preparedness and Response*,* Acute Radiation Syndrome: A Fact Sheet for Clinicians,
http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp [20 July 2014]

Chen, M., 2014. Radiation Protection and Regulations for the Nuclear Medicine Physician, Elsevier, Vol.44, pp 215-228

Chiejina, A., 2012. Right step towards improving power supply in Nigeria?
http://chiejinaalex.blogspot.com/2012/06/right-step-towards-improving-power.html?spref=bl [20 May 2014]

Cisco, 2007. Cisco Wireless Control System (WCS), http://www.baien-shop2.de/pdf_/226935.pdf [03 August 2014]

Cisco, 2012. Cisco Wireless Control System (WCS), http://www.cisco.com/c/en/us/products/collateral/wireless/wireless-control-system/product_data_sheet0900aecd802570d0.pdf [03 August 2014]

Cisco, 2011. Getting Started Guide, Cisco 2500 Series Wireless Controller, http://www.cisco.com/c/dam/en/us/td/docs/wireless/controller/2500/quick/guide/ctr2504_q_s.pdf [23 August 2014]

Cisco, 2012. Cisco Wireless Mesh Access Points, Design and Deployment Guide, Release 7.3, Cisco Systems, http://www.cisco.com/c/en/us/td/docs/wireless/technology/mesh/7-3/design/guide/Mesh.pdf [23 August 2014]

Cisco, 2013. Cisco Aironet 1550 Series Outdoor Mesh Access Point Hardware Installation Guide, Cisco Systems, https://www.arp.com/webmedias/datasheet/14440411.pdf [25 August 2014]

CNND, 2013. Nuclear Weapons: The State of Play, Thakur, R and Evans, G (eds.), Chapter 3, Paragon, Canberra, Australia http://cnnd.anu.edu.au/files/2013/state-of-play-report/12305-State-of-Play-report-4-internals-FA2-B.pdf [11 May 2014]

Coertze, R. J., 2011. The regulation of radioactive waste in South Africa, http://dspace.nwu.ac.za/bitstream/handle/10394/7000/Coertze_RJ.pdf?sequence=2 [12 July 2014]

Cohen, B.L., 1983. Before It's Too Late – A Scientist's Case for Nuclear Energy, 1st ed., PLENUM PRESS New York, USA

Conti, M., Das, S. K., Lenzini, L and Skalli, H., 2008. Channel Assignment Strategies for Wireless Mesh Networks, In Hossain, E and Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

Cordato, R., 2001. The Polluter Pays Principle: A Proper Guide for Environmental Policy, Executive Summary, the Institute for Research on the Economics of Taxation (IRET), Washington, D.C, USA http://iret.org/pub/SCRE-6.PDF [06 April 2014]

Cosma, C., 2000. Strontium-90 measurement after the Chernobyl accident in Romanian samples without chemical separation, Elsevier, Vol. 55, pp.1165-1171

Crick, M. J., 2010. Levels and Effects of Ionizing Radiation: The Latest UNSCEAR Reports, Strengthening Radiation Protection Worldwide: Highlights-Global Perspective and Future Trends, 12th Congress of the International Radiation Protection Association (IRPA12), Buenos Aires, Argentina, 19–24 October 2008 http://www-pub.iaea.org/MTCD/publications/PDF/Pub1460_web.pdf [11 July 2014]

CSD, 2014. Commission on Sustainable Development (CSD), http://sustainabledevelopment.un.org/csd.html [08 April 2014]

CTBTO, 2010. Who we are, CTBT, http://www.ctbto.org/specials/who-we-are/ [09 April 2014]

Cumo, M., 2010. Decommissioning of Nuclear Plants, In Cacuci, D. (Ed.), 2010, Handbook of Nuclear Engineering – Nuclear Engineering Fundamentals, Vol. 1, Springer Science, New York, USA

Cunningham, W. P and Cunningham, M. A., 2011a. Principles of Environmental SCIENCE – Inquiry and Applications, Natural selection and adaptation modify species, 6th Edition, McGraw-Hill, New York, USA

Cunningham, W. P and Cunningham, M. A., 2011b. Principles of Environmental SCIENCE – Inquiry and Applications, Low doses can have variable effects, 6th Edition, McGraw-Hill, New York, USA

Cunningham, W.P and Cunningham, M.A., 2012. Environmental SCIENCE A Global Concern, Chapter 19, pp (437-441), McGraw-Hill, New York, USA

Das, R.S., *n.d*. Wireless Mesh Networking, http://www.ieee.li/pdf/viewgraphs/wireless_mesh_networking.pdf [03 August 2014]

Dasnois, N., 2012. A Continent at the Centre of a Global Nuclear Renaissance, SAIIA, Johannesburg, South Africa

Disosway, J, 2006, Generations: The Nuclear Family Comes of Age, IEEE Power and Energy Magazine, November, pp. 18–24
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4012692 [16 July 2014]

DOE, *n.d*. Nuclear Energy in Everyday Life, Department of Energy, Pretoria, South Africa
http://www.energy.gov.za/files/media/Pub/NuclearEnergyInEverydayLife_Booklet.pdf [7 July 2014]

DOS, 2014. Delivering effective Nuclear Verification for World Peace, Safeguards, IAEA, Vienna, Austria
http://www.iaea.org/safeguards/index.html [06 May 2014]

Doyle, J., 2008. Nuclear Safeguards, Security, and Non-proliferation Achieving Security with Technology and Policy, Elsevier Inc, Burlington, USA

DME, 2005. Understanding Radioactivity & Radiation in Everyday Life, What is radiation? , p. 1-34, DME, South Africa
http://www.gov.za/documents/download.php?f=107435 [7 July 2014]

Drexhage, J and Murphy, D., 2010. Sustainable Development: From Brundtland to Rio 2012. p. 1-26 United Nations Headquarters, New York
http://www.un.org/wcm/webdav/site/climatechange/shared/gsp/docs/GSP1-6_Background%20on%20Sustainable%20Devt.pdf [01 Sept 2012]

dtcae, 2014. HP ProLiant ML350p Gen8 E5-2609 (470065-762) TOWER SERVER
http://uae.dtcae.com/product/hp-proliant-ml350p-gen8-e52609-470065762-tower-server-4122/ [03 September 2014]

EC, 2013. The different "generations" of nuclear technology,
http://ec.europa.eu/research/energy/euratom/index_en.cfm?pg=fission&section=generation [12 July 2014]

Echávarri, L. E., 2014. Nuclear energy: Towards sustainable development,
http://www.oecdobserver.org/news/archivestory.php/aid/2076/Nuclear_energy:_Towards_sustainable_development.html [03 August 2014]

Embest, 2011. ARM Cortex-A9 MPCore,
http://www.embedinfo.com/en/ARM_Cortex-list.asp?id=15 [13 September 2014]

Endo, T., 2009. Countries Planning to Introduce Nuclear Power Generation and the 3Ss - Making the 3Ss an International Standard, ICNND, Barton, Australia
www.icnnd.org/Documents/endo_3s_int_standard.pdf [01 May 2014]

EPA, 2013. Radiation Protection, Sources of Radiation Exposure,
http://epa.gov/rpdweb00/sources/index.html [28 July 2014]

EPA, 2013. Ionizing & Non-Ionizing Radiation,
http://www.epa.gov/rpdweb00/understand/ionize_nonionize.html [25 July 2014]

EPA, 2013. Carbon Dioxide Capture and Sequestration,
http://www.epa.gov/climatechange/ccs/#CO2Capture [25 May 2014]

EPA, 2012. Radiation Protection Basics,
http://www.epa.gov/rpdweb00/understand/protection_basics.html [24 July 2014]

EPA, 2012. Acid Rain, What is Acid Rain?
http://www.epa.gov/acidrain/what/index.html [17 April 2014]

EPA, 2010. Ozone Science: The Facts behind the Phase-out,
http://www.epa.gov/ozone/science/sc_fact.html [18 April 2010]

Eskom, 2014. Koeberg Power Station,
http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/KoebergNuclearPowerStation/Pages/Koeberg_Power_Station.aspx [13 July 2014]

Eskom, 2014. Fact Sheet,
http://www.eskom.co.za/AboutElectricity/FactsFigures/Documents/NU0002NuclearWasteRev6.pdf [11 July 2014]

Eskom, 2014. COP17 Fact Sheets, Underground Coal Gasification,
http://www.eskom.co.za/AboutElectricity/FactsFigures/Documents/Underground_Coal_Gasification_UCG.pdf [11 May 2014]

Eskom, 2012. Facts and Figures,
http://www.eskom.co.za/AboutElectricity/FactsFigures/Documents/GX_0001GenPlantMixRev13.pdf [11 May 2014]

Everton, C., Bayer, S and Carlson, J., 2010. Australian Safeguards and Non-Proliferation Office, Barton, Australia
https://www.dfat.gov.au/asno/publications/developments-in-the-iaea-INFCIRC225.pdf [05 May 2014]

Faro, A., 2013. The legalities of leaving nuclear, Bulletin of the Atomic Scientists, Vol. 69, Issue 1, pp 36-42

Fetter, S., 2009. How long will the world's uranium supplies last? , Scientific American,
http://www.scientificamerican.com/article/how-long-will-global-uranium-deposits-last/ [10 July 2014]

Frischknecht, R., Braunschweig, A., Hofstetter, P and Suter, P., 2000. Human health damages due to ionizing radiation in life cycle impact assessment, Elsevier, Vol. 20. p. 159–189

FrontierPC, 2013, Cisco Aironet 1552E IEEE 802.11n 300 Mbps Wireless Access Point http://www.frontierpc.com/wireless-networking/wifi-wireless-access-points/wireless-access-point/cisco/aironet-1550/aironet-1552e-wireless-access-point-air-cap1552e-e-k9-1019786250.html [[03 September 2014]

Gandhi, S and Kang, J., 2013. Nuclear safety and nuclear security synergy, Elsevier, p. 1-5

Gandhi, V.P., 1996. Why is the IMF interested in the environment? http://www.imf.org/external/pubs/ft/exrp/environ/#2 [02 April 2014]

Garcia, M.L., 2008. Physical Protection. In Doyle, J. (ed.), 2008. Nuclear Safeguards, Security, and Non-proliferation Achieving Security with Technology and Policy Elsevier Inc, Burlington, USA

GEA, 2012. Toward a Sustainable Future, p.34, International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1,Laxenburg, Austria http://www.globalenergyassessment.org/ [21 April 2014]

Geier, J., 2010. Designing and Deploying 802.11n Wireless Networks, Cisco Press, Indianapolis, USA

Geier, J.T., 2005. Wireless Networking Handbook, Macmillan, UK
GHKSAR, 2010. Wireless Networking Security, the Government of the Hong Kong Special Administrative Region, http://www.infosec.gov.hk/english/technical/files/wireless.pdf [25 August 2010]

Glasstone, S and Dolan, P. J., 1977. The Effects of Nuclear Weapons, Atomic Structure and Isotopes, http://www.deepspace.ucsb.edu/wp-content/uploads/2013/01/Effects-of-Nuclear-Weapons-1977-3rd-edition-complete.pdf [24 July 2014]

Glatz, E., *n.d*. Wireless Mesh Networks: Introduction, Basic Concepts, http://www.csg.ethz.ch/education/lectures/ATCN/ws06_07/doc/WMN-BasicsWS0607-print.pdf [25 August 2014]

GNSSN, 2014. Education and Training, paragraph 2, Atomic Energy Agency, http://gnssn.iaea.org/Pages/education_training.aspx [11 June 2014]

Goldberg, S.M and Rosner, R., 2011. Nuclear Reactors: Generation to Generation, American Academy of Arts and Sciences, Cambridge, UK http://www.amacad.org/pdfs/nuclearreactors.pdf [12 July 2014]

Gonzalez, A., J., 2002. Occupational Radiation Protection: Protecting Workers Against Exposure To Ionizing Radiation, Proceedings of an International Conference, Geneva, 26–30 August

GQE, 2014. GQ GMC-320 Plus Geiger Counter User Guide, http://www.gqelectronicsllc.com/GMC320PlusUserGuide.pdf [22 August 2014]

GQE (2012), Latest model: GMC-320 Plus, http://www.gqelectronicsllc.com/comersus/store/comersus_viewItem.asp?idProduct=4579 [04 August 2014]

GQE (2012), GQ Geiger counters Selection, http://www.gqelectro nicsllc.com/support/GMC_Selection_Guide.htm [04 August 2014]
Gungor, V. C., Natalizio, E., Pace, P and Avallone, S., 2008. Challenges and Issues in Designing Architectures and Protocols for Wireless Mesh Networks. In Hossain, E and

Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

Hall, E.J., 2012. Background Radiation, World Nuclear Association, London, UK
http://www.world-nuclear.org/info/Safety-and-Security/Radiation-and-Health/Radiation-and-Life/ [5 July 2014]

Hanke, S., 1987. The Economics of Canadian Municipal Water Supply: Applying the User-Pay Principle, Kent, C (ed.), Chapter 12, Social Science Electronic Publishing, Inc, Baltimore, USA
http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2232996 [09 April 2014]

Hanks, D.H., 2013. Managing Safety, Security, and Safeguards (3S) Relationship: A National Regulatory Authority Perspective United States Nuclear Regulatory Commission, 54th Annual Meeting of Institute of Nuclear Materials Management, Palm Desert, July 14-18, Deerfield, Illinois, USA

Harris, A and Venables, M., 2011. Nuclear Power, Engineering & Technology, E and T magazine, pp 46-49
http://eandt.theiet.org/magazine/2011/06/nuclear-power-nein-danke.cfm [09 July 2014]

Hashemian, H.M., 2011. What You Need to Know about Sensor Reliability Before and after an accident, IAEA, Vienna, Austria
http://www.iaea.org/NuclearPower/Downloadable/Meetings/2011/2011-05-24-05-26-TWG-NPPIC/Day-3.Thursday/IC-performance/What-you-need-to-know.pdf [10 August 2014]

Helsinki, 1992. The Convention on the Protection and Use of Transboundary Watercourses and International Lakes,
http://www.unece.org/env/water [12 April 2014]

Heslet, L., Bay, C., and Nepper-Christensen, S., 2012. Acute radiation syndrome (ARS) – treatment of the reduced host defence, International Journal of General Medicine, Dove press, Vol. 5, PP 105–115

Hibbs, M., 2012. Nuclear energy 2011:A watershed year, Bulletin of the Atomic Scientists, Vol. 68, Issue 1, pp 10-19

Hippel, F., 2010. Overview: The Rise and Fall of Plutonium Breeder Reactors, In Fast Breeder Reactor Programs: History and Status, International Panel on Fissile Materials (IPFM), Princeton, USA
http://fissilematerials.org/library/rr08.pdf [11 July 2014]

Hong, C., Yongwei, Y., Xingqing, j and Yunlin, X., 2006. Thorium-Based Fuel Cycles in the Modular High Temperature Reactor, Volume 11, Number 6, p. 731-732, Elsevier, Philadelphia, USA

Hossain, E and Leung, K., 2008. A Brief Journey through “Wireless Mesh Networks: Architectures and Protocols. In Hossain, E and Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

Hou, J. C., Park, K.J., Kim, T.S and Kung, L.C., 2008. Medium Access Control and Routing Protocols for Wireless Mesh Networks. In Hossain, E and Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

HPS, 2012. Fact Sheet, Background Radiation, pp. 1-4, Health Physics Society, McLean, Virginia
http://hps.org/documents/background_radiation_fact_sheet.pdf [13 July 2014]

Huang, F and Sun, T., 2011. Design and Implementation of Radiation Dose Monitoring System Based on Wireless Sensor Network, The design of radiation dose monitoring system, International Conference on Future Information Technology IPCSIT vol.13, Article 84, pg. 430, IACSIT Press, Singapore

Huang, J.H., Wang, L.C and Chang, C.J., 2008. Architectures and Deployment Strategies for Wireless Mesh Networks. In Hossain, E and Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

IAEA, 1996. Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations- Code and Safety Guides Q1-Q14, Management, p.8 & 13, IAEA, Vienna, Austria
http://www.lei.lt/insc/quality/PDF-Files/SS-50-C-SG-Q-CD.pdf [07 June 2014]

IAEA, 1996a. International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Radiation Effects, IAEA, Vienna, Austria
http://www.ilo.org/wcmsp5/groups/public/@ed_protect/@protrav/@safework/documents/publication/wcms_152685.pdf [10 July 2014]

IAEA, 1996b. International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Justification of Practice, IAEA, Vienna, Austria
http://www.ilo.org/wcmsp5/groups/public/@ed_protect/@protrav/@safework/documents/publication/wcms_152685.pdf [20 July 2014]

IAEA, 1999.The Physical Protection of Nuclear Material and Nuclear Facilities, Objectives, p.4, Vienna, Austria
http://www.iaea.org/Publications/Documents/Infcircs/1999/infcirc225r4c.pdf [26 May 2014]

IAEA, 2000. Generic procedures for assessment and response during a radiological emergency, IAEA, Vienna, Austria.
http://www-pub.iaea.org/MTCD/publications/PDF/te_1162_prn.pdf [03 August 2014]

IAEA, 2004. Radiation, People and the Environment,
http://www.iaea.org/Publications/Booklets/RadPeopleEnv/pdf/radiation_low.pdf [10 July 2014]

IAEA, 2005. Safety Standards, Safety Guide, No. RS-G-1.8, Vienna

IAEA, 2008. Preventive And Protective Measures against Insider Threats, Objective and Scope, p.2, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/pub1359_web.pdf [16 May 2014]

IAEA, 2008. IAEA Safety Standards for protecting people and the environment. Safety Guide, No. NS-G-4.6, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1369_web.pdf [03 August 2014]

IAEA, 2009. Development, Use and Maintenance of The Design Basis Threat, Purpose of a Design Basis Threat, p.7 & 8, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1386_web.pdf [14 June 2014]

IAEA, 2009. Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Power Plants, Introduction, p.1, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/Publications/PDF/te_1624_web.pdf [15 June 2014]

IAEA, 2009. Fast Reactors And Related Fuel Cycles: Challenges And Opportunities (FR09), Proceedings of an International Conference Kyoto, Japan, 7–11 December 2009d http://www-pub.iaea.org/mtcd/publications/pdf/pub1444_web.pdf [16 July 2014]

IAEA, 2010. Radiation Biology: A Handbook for Teachers and Students – Training Course Series 42, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/TCS-42_web.pdf [6 July 2014]

IAEA, 2010.Programmes and Systems for Source and Environmental Radiation Monitoring, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/pub1427_web.pdf [03 August 2014]

IAEA, 2011. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, Background, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/p1531interim_web.pdf [03 August 2014]

IAEA, 2011a. Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), p.14, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1481_web.pdf [13 June 2014]

IAEA, 2011a. Computer Security at Nuclear Facilities, Definitions, p.2, 60 & 68, IAEA, Vienna Austria
http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1527_web.pdf [13 June 2014]

IAEA, 2011b. IAEA International Fact Finding Expert Mission of the Fukushima Dai-ichi NPP accident following the great east Japan earthquake and Tsunami, IAEA, Vienna Austria
http://www-pub.iaea.org/MTCD/meetings/PDFplus/2011/cn200/documentation/cn200_Final-Fukushima-Mission_Report.pdf [17 August 2014]

IAEA, 2012. Nuclear Security Culture, IAEA Nuclear Security Series No. 7, Nuclear Security and Nuclear Security Culture, p.3, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1347_web.pdf [19 June 2014]

IAEA, 2013. Nuclear Share of Electricity Generation in 2011, IAEA, Vienna-Austria
http://www.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx [10 March 2013]

IAEA, 2013. Support for Innovative Fast Reactor Technology Development and Deployment. IAEA, Vienna-Austria
http://www.iaea.org/NuclearPower/FR/index.html [5 March 2013]

IAEA, 2013a. International Safeguards in Nuclear Facility Design and Construction, IAEA press, Austria, Vienna
http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1600_web.pdf [13 May 2014]

IAEA, 2013b. Objective and Essential Elements of a State's Nuclear Security Regime Nuclear Security Fundamentals, IAEA Nuclear Security Series No. 20, IAEA, Vienna, Austria

IAEA, 2014. Operational & Long-Term Shutdown Reactors
http://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx [03 August 2014]

IAEA, 2014. About the IAEA, the "Atoms for Peace" Agency, IAEA, Vienna, Austria. 2014
http://www.iaea.org/About/about-iaea.html [24 April 2014]

IAEA, 2014. Concepts and terms, complementarity of safety and security, IAEA, Vienna, Austria
http://www-ns.iaea.org/standards/concepts-terms.asp [21 May 2014]

IAEA-NSS, 2012. Seoul Communiqué, paragraph 6, p.1-6
https://www.nss2014.com/sites/default/files/documents/seoul_communique_final.pdf [11 May 2014]

IEA, 2006. World Energy Outlook, IEA, Paris, France

IEA, 2012. Key World Energy Statistics, IEA, Paris, France

IEA, 2014. CO_2 storage captures Durban, IEA, Paris, France
http://www.iea.org/techinitiatives/fossilfuels/carboncaptureandstorage/ [07 May 2014]

IEE, 2005. Nuclear Reactor Types, IEE, London, UK.
http://large.stanford.edu/courses/2013/ph241/kallman1/docs/nuclear_reactors.pdf [08 July 2014]

IET, 2008. Nuclear Reactor Types, 3rd edition. IET, Stevenage, UK

IIED, 2014. About us, who we are,
http://www.iied.org/about-us [06 April 2014]

ILO, 2014. Radiation Protection,
http://www.ilo.org/safework/areasofwork/radiation-protection/lang--en/index.htm [5 July 2014]

INPRO-IAEA, 2013, INPRO: Enhancing Global Nuclear Energy Sustainability,
http://www.iaea.org/INPRO/publications/INPRO-2012-Rev_Feb2013.pdf [25 July 2014]

INSAG, 2010.The interface between safety and security at nuclear power plants, Purpose and Scope, p.3, 13, IAEA, Vienna, Austria
http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1472_web.pdf [19 May 2014]

IRSN, 2009. Monitoring Radioactivity in the environment, IRSN Press

Ishii, M., Revankar, S.T., Downar, T., Xu, Y., Yoon, H.J, Tinkler, D and Rohatgi, U.S., 2003. Modular and Full Size Simplified Boiling Water Reactor Design with Fully Passive Safety Systems, Significance of the Project, p.1, Brookhaven National Laboratory, Uptown, NY, USA
http://www.osti.gov/scitech/servlets/purl/811897 [20 June 2014]

IUCN, 2014. About IUCN, What is IUCN?
http://www.iucn.org/about/ [12 April 2014]

Joseph, N and Phalen, J M.D., 2006. Cardinal Principles of Radiation Protection,
https://www.ceessentials.net/article4.html [03 September 2014]

Jun, J and Sichitiu M. L., 2008. MRP: Wireless mesh networks routing protocol, Elsevier,
http://www4.ncsu.edu/~mlsichit/Research/Publications/mrpCC.pdf [08 August 2014]

Karam, P.A., 2006. How do fast breeder reactors differ from regular nuclear power plants? Scientific American,
http://www.scientificamerican.com/article/how-do-fast-breeder-react/ [25 July 2014]

Kharecha, P and Hansen, J., 2013. Coal and gas are far more harmful than nuclear power,
http://climate.nasa.gov/news/903 [11 May 2014]

Kharecha, P and Hansen, J., 2013. Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power,
http://pubs.giss.nasa.gov/docs/2013/2013_Kharecha_Hansen_1.pdf [17 May 2014]

Khripunov, I., 2012. Nuclear and Radiological Security Culture: A Post-Seoul Summit Agenda, Security as a Subset of Organizational Culture, p.8, CITS, University of Georgia, USA
http://cits.uga.edu/uploads/documents/postseoul.pdf [30 June 2014]

Kim, T. K., 2013. GEN-IV Reactors. In Tsoulfanidis, N. (ed.), 2013. Nuclear Energy – Selected Entries from the Encyclopaedia of Sustainability Science and Technology, Springer, New York

Kim, D and Kang, J., 2012. Where nuclear safety and security meet, Sage pub., Vol. 68(1) 86–93, p1-9
http://bos.sagepub.com/content/68/1/86.full.pdf+html [15 May 2014]

Knief, R. A., 2013. Nuclear Fission Power Plants. In Tsoulfanidis, N. (ed.), 2013. Nuclear Energy – Selected Entries from the Encyclopaedia of Sustainability Science and Technology, Springer, New York

Kobayashi, H., Sakamaki, T and Masui, K, 2004. Environmental Radiation Measuring Equipment, In Radiation Monitoring System, Vol. 50, Issue No. 207, Fuji Electric Group, Tokyo, Japan

Kolver, L., 2013. Underground coal gasification holds significant opportunity for SA, http://www.engineeringnews.co.za/article/underground-coal-gasification-holds-significant-opportunity-for-sa-lennon-2013-10-10 [11 May 2014]

Komaki, A., 2013. Russia spearheads world's effort to develop fast-breeder reactors, Asahi Shimbun Company, *October 24,*
http://ajw.asahi.com/article/behind_news/social_affairs/AJ201310240004 [25 July 2014]

Kono, E., 2004. Current Trends in Radiation Monitoring Systems, In Radiation Monitoring System, Vol. 50, Issue No. 207, Fuji Electric Group, Tokyo, Japan

Korsah, K., Holcomb, D.E., Muhlheim, M.D., Mullens, J.A., Loebl, A., Bobrek, M., Howlader, M.K., Killough, S.M., Moore, M.R., Ewing, P.D., Sharpe, M., Shourbaji, A.A., Cetiner, S.M., Wilson, T.L., Jr., Kisner, R.A., 2009. Instrumentation and Controls in Nuclear Power Plants: An Emerging Technologies Update, USNRC, Washington, D.C., USA

Kroening, M., Sednev, D and Chumak, D., 2012. Nondestructive Testing At Nuclear Facilities as Basis For The 3S Synergy Implementation, 7th International Forum (IFOST), p 1-4
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6357725 [09 June 2014]

Krupa, A.S., 2003. The Oversight of Physical Security and Contingency Planning, SANS Institute, UK
http://www.sans.org/reading-room/whitepapers/recovery/oversight-physical-security-contingency-planning-557 [08 June 2014]

Lamarsh, J.R. & Baratha, A.J., 2001. Introduction to Nuclear Engineering. Nuclear Reactors and Nuclear Power. 3rd Edition p. 117 – 119, Prentice-Hall, Inc. Upper Saddle River, New Jersey)

L'annunziata, M. F., 2003. Handbook of Radioactivity Analysis, Half Life, Second Edition, Elsevier, USA

Lidskog, R and Andersson, A., 2001. The management of radioactive waste A description of ten countries, Swedish Nuclear Fuel and Waste Management Co, Stockholm, Sweden

Lincenergy, 2012. UCG-Underground coal gasification, http://www.lincenergy.com/underground_coal_gasification.php [20 May 2014]

Lindel, B., Dunster, H.J., and Velentin, J., *n.d*. International Commission on Radiological Protection: History-Policies-Procedures, Swedish Radiation Protection Institute, Stockholm, Sweden
http://www.icrp.org/docs/histpol.pdf [19 July 2014]

Lior, N., 2010. The Current Status and Possible Sustainable Paths to Energy “Generation (Proceedings of the 1st International Nuclear and Renewable Energy Conference (INREC10), Amman, Jordan, March 21-24, 2010. p. 1 – 19, IEEE Conference Publications

Liu, L., Yuan F.G and Zhang, F., 2005. Development of wireless smart sensor for structural health monitoring, Proceeding of SPIE, Bellingham, WA, Vol. 5765

Livescience, 2012. Global Warming: News, Facts, Causes & Effects, http://www.livescience.com/topics/global-warming/ [01 April 2014]

Lokhov, A., 2012. A Gradual Swiss Denuclearisation, the Journal of the International Energy Agency, p. 32, Issue 3, OECD/IEA, Paris Cedex 15, France
http://www.iea.org/media/ieajournal/Issue3_WEB.pdf [Autumn 2013]

Lovins, A. B., 2013. The economics of a US civilian nuclear phase-out, Bulletin of the Atomic Scientists, Vol. 69, Issue 2, pp 44-65

Macdonald, J. D., 2006. Safe and Secure, IEEE Power Engineering Review, December 2006, pp. 49–55.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4012696 [6 July 2014]

Macfarlane, A., 2011. It’s 2050: Do you know where your nuclear waste is? Bulletin of the Atomic Scientists, Vol. 67, Issue 4, pp 30-36

Maher, K., 2006. Basic Physics of Nuclear Medicine, Wiki books
http://upload.wikimedia.org/wikipedia/commons/a/a5/Basic_Physics_of_Nuclear_Medicine.pdf [14 July 2014]

Malcolmson, J., 2009. What is Security Culture? Does it differ in content from general Organizational Culture? Security Technology, 43rd Annual 2009 International Carnahan Conference, October 5-8
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5335511 [02 June 2014]

Markandya, A and Wilkinson, P., 2007. Energy and Health 2, Electricity generation and health, Lancet, Bath, UK
http://ac.els-cdn.com/S0140673607612537/1-s2.0-S0140673607612537-main.pdf?_tid=7256abca-cebc-11e3-a813-00000aacb35d&acdnat=1398679632_67e371578fcad85715dd7a20e76c71be [04 May 2014]

Martin, J. E., 2006. Physics for Radiation Protection- A Handbook, Second Edition, 2nd Edition, Wiley, Germany

Marquardt, P., 1994. Fordham International Law Journal, Subsidiarity and Sovereignty in the European Union, Article 7, Volume 18, Issue 2, PP.617, Berkeley Electronic Press (be press)
http://ir.lawnet.fordham.edu/cgi/viewcontent.cgi?article=1414&context=ilj [20 April 2014]

McGill, 2014.Environmental Health and Safety, Radiation dose limit, Rationale and Legal Basis of Dose-Equivalent Limits, McGill University
http://www.mcgill.ca/ehs/laboratory/radiation/manual/3 [10 July 2014]

Mecklin, J., 2012. The German nuclear exit: Introduction, Bulletin of the Atomic Scientists, Vol.68, Issue 6, pp 6-9

Mecklin, J., 2013. Introduction: A French nuclear exit? Bulletin of the Atomic Scientists, Vol. 69, Issue 1, pp 9-10

Mez, L., 2012. Germany's merger of energy and climate change policy, Bulletin of the Atomic Scientists, Vo. 68, Issue 6, pp 22-29

Micro Step-MIS, 2003. Why to measure radiation, http://www.microstep-mis.com/index.php?lang=en&site=src/products/radiation_monitoring/why [03 August 2014]

Millar, I., 2014. The Environmental Law Framework for Sustainable Development – Principles of Sustainable Development in International, National and Local Laws, Intergenerational and intragenerational equity, pp.3, Baker & McKenzie http://www.actpla.act.gov.au/__data/assets/pdf_file/0006/13893/Millar_paper.pdf [21 April 2014]

MIT, 2003. The Future of Nuclear Power, MIT, http://web.mit.edu/nuclearpower/pdf/nuclearpower-summary.pdf [27 July 2014]

Monti, S., 2013. Fast Reactors Provide Sustainable Nuclear Power for "Thousands of Years", http://www.iaea.org/newscenter/news/2013/fastreactors.html [13 March 2013]

Mitra, A., 2009. Lecture Notes on Mobile Communication, http://www.iitg.ernet.in/scifac/qip/public_html/cd_cell/EC632.pdf [03 August 2014]

Mok, A., Chen, D and Nixon, M., 2010. Real-Time Mesh Network for Industrial Automation, Springer, New York, USA

Monti, S., 2013, Fast Reactors Provide Sustainable Nuclear Power for "Thousands of Years". IAEA, Vienna-Austria http://www.iaea.org/newscenter/news/2013/fastreactors.html [5 March 2013]

Mooley, S., and van Weele, G., 2013. State of Environment Outlook Report for the Western Cape Province, City of Cape Town, South Africa http://eadp-westerncape.kznsshf.gov.za/sites/default/files/your-resource-library/WCSoEOR_08_Energy.pdf [17 May 2014]

Mosse, I. B., 2012. Genetic effects of ionizing radiation – some questions with no answers, Low radiation doses, Elsevier, Vol. 112, p. 70 -75

MRL, 2014. Measuring Radiation, p.1, Eastwood SA, Australia http://www.marathonresources.com.au/radiation.php [11 July 2014]

NDT, 2014. Controlling Radiation, https://www.nde-ed.org/EducationResources/CommunityCollege/RadiationSafety/safe_use/controlling_exposure.htm [03 September 2014]

NEA, 1994. Radiation protection overview- international aspects and perspective Issue Brief: An analysis of principal nuclear issues, An analysis of principal nuclear issues https://www.oecd-nea.org/brief/brief-10.html [16 July 2014]

NEA, 2007. Innovations in Nuclear Energy Technology, OECD, Paris, France https://www.oecd-nea.org/ndd/pubs/2007/6103-innovation-technology.pdf [28 July 2014]

NEA, 2010. Uranium 2009: Resources, Production and Demand, OECD Pub., Paris, France https://www.oecd-nea.org/ndd/pubs/2010/6891-uranium-2009.pdf [22 July 2014]

NEA, 2011. Trends towards Sustainability in the Nuclear Fuel Cycle, NEA, Paris, France http://www.oecd-nea.org/ndd/pubs/2011/6980-trends-fuel-cycle.pdf [15 July 2014]

NEA, 2012a. Nuclear Energy Today, 2nd ed., OECD, Issy-les-Moulineaux, France http://www.oecd-nea.org/pub/nuclearenergytoday/6885-nuclear-energy-today.pdf [20 July 2014]

NEA, 2012b. Uranium 2011: Resources, Production and Demand, OECD/NEA, Paris. France http://www.oecd-nea.org/ndd/pubs/2012/7059-uranium-2011.pdf [11 July 2014]

NEA, 2012c. Nuclear Energy and Renewable, OECD, Paris, France http://www.oecd-nea.org/ndd/pubs/2012/7056-system-effects.pdf [15 July 2014]

NEA, 2014. Nuclear energy and sustainable development, https://www.oecd-nea.org/sd/ [03 August 2014]

NECSA, *n.d.*, Vaalputs the National Radioactive Waste Disposal Facility, http://www.radwaste.co.za/vaalputs%20information%20pamflet.pdf [19 July 2014]

NECSA, 1985. Vaalputs the National Radioactive Waste Disposal Facility, http://www.radwaste.co.za/vaalputs%20information%20pamflet.pdf [16 May 2014]

NECSA, 1985. Overview of Repository Program at Vaalputs South Africa, http://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/IDN/idnfiles/Presentations-in-pdf-Necsa/Repository-Program-Vaalputs.pdf [22 May 2014]

NEI, 2014. The Yucca Mountain Program, Nuclear Energy Institute, Washington, DC 20004-1218, USA http://www.nei.org/Issues-Policy/Nuclear-Waste-Management/Disposal [06 April 2014]

NI, 2014. NI myRio Embedded Student Design Device, http://sine.ni.com/nips/cds/view/p/lang/en/nid/211694 [03 August 2014]

NNR, 2006. National Nuclear Regulator Act, 1999 – Act No. 47 of 1999, p.16, vol. 490, Government Printer, Pretoria, South Africa http://www.nnr.co.za/wp-content/uploads/2011/07/SSRP-April-2006.pdf [03 August 2014]

NNR, 2011. Second South African National Report on Compliance to Obligations under the Joint Convention on Safety of Spent Fuel Management and On the Safety of Radioactive Waste Management, NNR, Centurion, South Africa http://www.nnr.co.za/wp-content/uploads/2012/05/2nd%20SA%20National%20Report%20Final.pdf [20 May 2014]

Norway - Mission to the UN, 2009. Norway donor to new trust fund for carbon capture and storage, http://www.norway-un.org/NorwayandUN/Selected_Topics/Climate_Change/Norway-donor-to-new-trust-fund-for-carbon-capture-and-storage/#.U2wIoVdWE8A [28 May 2014]

NRC, 2006. Health Risks from Exposure to Low Levels of Ionizing Radiation, Series 7, Phase 2, National Academy of Sciences, USA

NSC, 2008. Guidelines for Environmental Radiation Monitoring, Nuclear Safety Commission of Japan
http://www.nsr.go.jp/archive/nsc/NSCenglish/guides/thematic/T-EN-II_02.pdf [03 August 2014]

NSSPI, 2014. Nuclear Safeguard Education Portal, Physical Protection Systems, NSSPI, Texas, USA
http://nsspi.tamu.edu/nsep/reference-modules/technical-safeguards-terminology/physical-protection-systems/physical-protection-systems [04 May 2014]

NSSPI, 2014. Nuclear Safeguard Education Portal, Introduction to Physical Protection Systems*,* p. 1-32, NSSPI, Texas, USA
http://nsspi.tamu.edu/nsep/courses/physical-protection-systems/introduction/introduction-to-physical-protection-systems [19 May 2014]

NU, 2010. Radiation Safety Handbook, Office for Research Safety, Evanston, Illinois, USA
http://www.research.northwestern.edu/ors/forms/radiation-safety-handbook.pdf [13 July 2014]

OECD, 2001. Environmental Degradation, Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York, 1997
https://stats.oecd.org/glossary/detail.asp?ID=821 [03 August 2014]

OECD, 2003. Environmental Protection, Definition,
http://stats.oecd.org/glossary/detail.asp?ID=836 [08 April 2014]

OECD, 2014. Technology Roadmap Update for Generation IV Nuclear Energy Systems
https://www.gen-4.org/gif/upload/docs/application/pdf/2014-03/gif-tru2014.pdf [6 July 2014]

OECD-NEA, 2014. The OECD Nuclear Energy Agency, Generation IV International Forum (GIF), OECD, Issy-les-Moulineaux, France
http://www.oecd-nea.org/pub/nea-brief.pdf [16 July 2014]

Ooi, K., Yasutomo, K and Suzuki, Z., *n.d*. Nuclear Facility Radiation Monitoring System, Vol. 53 No. 4 Fuji Electric Review
https://www.fujielectric.com/company/tech/pdf/r53-4/06.pdf [03 August 2014]

OPCW, 2010. About the OPCW,
http://www.opcw.org/about-opcw/ [20 April 2014]

Oyedepo, S. O., 2012. Energy and sustainable development in Nigeria:
the way forward. 2:15, p. 1 – 17, Energy, Sustainability and Society, Springer Open Journal
http://www.energsustainsoc.com/content/2/1/15 [16 May 2014]

Parsick, R and Sanborn, J., 1994. INFCIRC/153 as the Basis for Verification of a Special Nuclear Materials Production Cut-off Convention, Brookhaven National Laboratory,
http://www.osti.gov/scitech/servlets/purl/79010 [15 August 2014]

Pickard W.F., 2010. Finessing the fuel: Revisiting the challenge of radioactive waste disposal, Elsevier Vol. 38, Issue 2, Pages 709–714

Provantage, 2014a. Cisco Systems WS-C2960-24PC-L Catalyst 2960 24 10/100 PoE + 2 T/SFP LAN,
http://www.provantage.com/cisco-systems-ws-c2960-24pc-l~7CSCO2NJ.htm [05 August 2014]

Provantage, 2014b. Cisco 2504 Wireless Controller with 15 AP Licenses, http://www.provantage.com/cisco-systems-air-ct2504-15-k9~7AIRO0C5.htm

Provantage, 2014c. Cisco WS-C3560X-24P-E Catalyst 3560-x 24 Port Gbe PoE Ip Services http://www.provantage.com/cisco-systems-ws-c3560x-24p-e~7CSCO39F.htm [03 September 2014]

Pshakin, G., 2010. The USSR-Russia Fast-Neutron Reactor Program, In Fast Breeder Reactor Programs: History and Status, International Panel on Fissile Materials, http://fissilematerials.org/library/rr08.pdf [5 July 2014]

Rafferty, K., 2011. Environmental Effects of Nuclear Power, English Press, Delhi, India
Ramana, M. V., 2013. Nuclear policy responses to Fukushima: Exit, voice, and loyalty, Bulletin of the Atomic Scientists, Vol. 69, Issue 2, pp 66-76

RO, 1989. Environmental Radiation Monitoring in Hong Kong, Technical Report 1, http://www.hko.gov.hk/publica/rm/rm001.pdf [03 August 2014]

Rojavin, Y., Seamon, M.J., Tripathi, R.S., Papadimos, T.J., Galwankar, S., Kman, N., Cipolla, J.,Grossman, M.D., Marchigiani, R and Stawicki, S.P.A.,2011.Civilian nuclear incidents: An overview of historical, medical, and scientific aspects, Journal of Emergencies, Trauma, and Shock, Vol. 4(2), p.1-17
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3132367/ [15 May 2014]

Rom'an, M., 2011, Carbon capture and storage in developing countries: A comparison of Brazil, South Africa and India, CCS as a strategic tool for development, Environment, P.393, , Elsevier Ltd, Stockholm, Sweden

Rossnagel, A and Hentschel, A., 2012. The legalities of a nuclear shutdown, Bulletin of the Atomic Scientists, Vol. 68, Issue 6, pp 55-66

Rouault, J., Chellapandi, P., Raj, B., Dufour, P., Latge, C., Paret, L·, Lo Pinto, P·, Gilles, H. R., Gautier, G., Fiorini. G·, Pelletier, M·, Gosset, D., Bourganel, S., Mignot, G·, Varaine, F.,Valentin, B., Masoni, P., Martin, P., Queval, J., Broc, D., and Devictor, N., 2010. Sodium Fast Reactor Design: Fuels, Neutronics, Thermal-Hydraulics, Structural Mechanics and Safety. In Cacuci, D.G (ed), 2010. Handbook of Nuclear Engineering - Nuclear Engineering Fundamentals, Vol.1, Springer, New York, USA

SACCCS, 2014. Welcome to the South African Centre for Carbon Capture & Storage, http://www.sacccs.org.za/ [16 May 2014]

Sailor, W.C., 2010. Creating the ultimate reactor, Bulletin of the Atomic Scientists, July/ August 2010, vol. 66, Issue 4, pp. 23-32.

Schneider, M., 2013. France's great energy debate, Bulletin of the Atomic Scientists, Vol. 69, Issue 1, pp 27-35

Schreurs, M. A., 2012. The politics of phase-out, Bulletin of the Atomic Scientists, Vol. 68, Issue 6, pp 30–41

Schultz, I., 2012. Passive Nuclear Safety Technology, Introduction, Stanford University, California, USA
http://large.stanford.edu/courses/2012/ph241/schultz1/ [11 June 2014]

Shapiro, J., 2002. Radiation Protection - A Guide for Scientists, Regulators, and Physicians, Gamma Rays – A Major Class of Uncharged Ionizing Particles, 4th Edition, Harvard University Press, Massachusetts, USA.

Shokr A. M*., n.d*. Synergy between Nuclear Safety and Security for Research Reactors, Operating Principles, p.14-16, IAEA, Vienna, Austria
http://www-ns.iaea.org/downloads/ni/training/rr-presentations-pdf/synergy-between-safety-and-security-for-rr.pdf [14 June 2014]

Shultis, J.K and Faw, R.E., 2005. Radiation Shielding Technology, HPS, Vol. 88(4), pp.297-322
https://www.mne.ksu.edu/~jks/papers/HPreview.pdf [29 July 2014]

Sidhu, B., Singh, H and Chhabra, A., 2007. Emerging Wireless Standards - Wi-Fi, ZigBee and WiMAX, World Academy of Science, Engineering and Technology, International Journal of Electrical, Robotics, Electronics and Communications Engineering, Vol.1, No.1

Siegel, R.P., 2012. Clean Coal: Pros and Cons,
http://www.triplepundit.com/2012/04/clean-coal-pros-cons/ [12 May 2014]

Sienicki, J., 2011. Energy Engineering and Systems Analysis, Design Basis and Severe Accidents, Argonne National Laboratory, Lemont, Illinois, USA
http://www.ne.anl.gov/pdfs/nuclear/design_basis_and_severe_accidents_sienicki.pdf [19 June 2014]

SNETP, 2010. Implementation Plan 2010-12,
http://ec.europa.eu/energy/technology/initiatives/doc/implementation_plan_2010_2012_eii_nuclear.pdf [28 July 2014]

Southworth, F. H., 2011. Radiation Basics, Areva, March Review.
http://www.geos.vt.edu/events/uranium/pdf/1030-1100_Southworth_Radiation_Basics.pdf [17 July 2014]

Squassoni, S., 2013. The limited national security implications of civilian nuclear decline, Bulletin of the Atomic Scientists, Vol. 69, Issue 2, pp 22-33

Steele, R., 2010. Environmental Protection, Reorienting Teacher Education to Address Sustainable Development: Guidelines and Tools, UNESCO, Bangkok 10110, Thailand.

Stott, A.K., 2013.The current status of nuclear energy in South Africa, Eskom,
http://www.sanea.org.za/CalendarOfEvents/2013/SANEALecturesCT/Jun19/TonyStott-Eskom.pdf [15 July 2014]

Strand, P., Brown, J. E., Drozhko, E., Mokrov, Y., Salbu, B., Oughton, D., Christensen, G. C., and Amundsen, I. (1999). Biogeochemical behaviour of 137Cs and 90Sr in the artificial reservoirs of Mayak PA, Russia, Elsevier, Vol. 241, pp. 107-116

Streffer, C., 2010. Radiological Protection: Challenges and Fascination of Biological Research, Strengthening Radiation Protection Worldwide: Highlights-Global Perspective and Future Trends, 12th Congress of the International Radiation Protection Association (IRPA12), Buenos Aires, Argentina, 19–24 October 2008

SurvivalIQ, 2008. The Nuclear Environment,
http://www.survivaliq.com/survival/survival-in-man-made-hazards_s1.htm [10 July 2014]

Suzuki, M., Izumi, Y., Kimoto, T., Naoi, Y., Inoue, T and Hoffheins, B., 2010. Investigating 3S Synergies to Support Infrastructure Development and Risk-Informed Methodologies for 3S by Design, Nuclear Non-proliferation Science and Technology Centre, Japan, Atomic Energy Agency 2-4 Shirane, Shirakata, Tokai-mura, Naka-gun, pp. 319-1195, Japan http://www.iaea.org/safeguards/Symposium/2010/Documents/PapersRepository/0647160806199588803977.pdf [20 May 2014]

Tagare, D. M., 2011. Electric Power Generation – The Changing Dimensions, Nuclear Power Generation, IEEE, Wiley & Sons, Inc., Hoboken, New Jersey, USA

Takagi, T., Kimura, O and Minagoshi, A. Environmental Radiation Monitoring System, In Radiation Monitoring System, Vol. 50, Issue No. 207,Fuji Electric Group, Tokyo, Japan

Tape, J and Pilat, J., 2008. Nuclear Safeguards and the Security of Nuclear Materials.p.17, In Doyle, J. (ed), 2008. Nuclear Safeguards, Security, and Non-proliferation Achieving Security with Technology and Policy Elsevier Inc, Burlington, USA

Thomasnet, 2014. Materials Used in Radiation Shielding, Thomas Publishing Company, New York, USA
http://www.thomasnet.com/articles/custom-manufacturing-fabricating/radiation-shielding-materials [3 July 2014]

TR, 2011.Disease Briefing: Acute Radiation Syndrome, Facts about Acute Radiation Syndrome, Thomson Reuters
http://www.arsco.org/file/Get/6867e52a-f917-4497-8798-0435d416fcf2 [4 July 2014]

Tsoulfanidis, N., 1995. Measurement and Detection of Radiation, Atoms, 2nd Edition, Taylor & Francis, Washington, DC

UNCCD, 1996. About the Convention,
http://www.unccd.int/en/about-the-convention/Pages/About-the-Convention.aspx [02 April 2014]

UNEP, 1989. Objective, Basel Convention,
http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx [14 April 2014]

UNEP, 1998. Objectives of the Rotterdam Convention,
http://www.pic.int/TheConvention/Overview/tabid/1044/language/en-US/Default.aspx [18 April 2014]

UNEP, 2001. Introduction on Stockholm Convention,
http://chm.pops.int/TheConvention/Overview/tabid/3351/Default.aspx [17 April 2014]

UNEP, 2003. About United Nations Environmental Programme,
http://www.unep.org/About/ [22 April 2014]

UNESCO, 1992. The Rio Declaration on Environment and Development,
http://www.unesco.org/education/nfsunesco/pdf/RIO_E.PDF [19 April 2014]

UNESCO, 2012. Introducing UNESCO,
http://en.unesco.org/about-us/introducing-unesco [20 April 2014]

UNFCCC, 1994. First steps to a safer future: Introducing the United Nations Framework Convention on Climate Change,
http://unfccc.int/essential_background/convention/items/6036.php [09 April 2014]

United Nations, 1997. Earth Summit,
http://www.un.org/geninfo/bp/envirp2.html [11 April 2014]

UNSCEAR, 2000. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, Vol.1, pp 1-17 http://www.unscear.org/docs/reports/gareport.pdf [11 July 2014]

UOM, 2014.Environmental Safety, The inverse square law, p.1, College Park, USA http://www.des.umd.edu/rs/material/tmsg/rs6.html [26 July 2014]

USNRC, 2002. Radioactive Waste: Production, Storage, Disposal, USNRC, Washington, USA

Upton, C., 2010. Radiation In Frumkin, H. (ed.), 2010. Environmental health from global to Local, Wiley, Hoboken – NJ, USA.

Urban Earth, 2012. South African Carbon Snapshot, Future Works, http://urbanearth.co.za/system/files/private/Urban%20Earth_SA%20Carbon%20Snapshot_0.pdf [21 May 2014]

USNRC, 2012a. Location of Yucca Mountain, http://www.nrc.gov/waste/hlw-disposal/photo-loc.html [01 April 2014]

USNRC, 2012b. Location of Yucca Mountain, http://www.nrc.gov/waste/hlw-disposal/design.html [13 May 2014]

USNRC, 2013. Physical Protection, US.gov, Washington, U.S.A http://www.nrc.gov/security/domestic/phys-protect.html [16 May 2014]

USNRC, 2013. Quality Assurance for New Reactors, US.gov, Washington, U.S.A http://www.nrc.gov/reactors/new-reactors/oversight/quality-assurance.html [05 June 2014]

USNRC, 2014. Design basis accident, US.gov, Washington, U.S.A http://www.nrc.gov/reading-rm/basic-ref/glossary/design-basis-accident.html [09 June 2014]

USNRC. 2013. Nuclear Reactors http://www.nrc.gov/reading-rm/basic-ref/students/reactors.html [7 July 2014]

USNRC, 2011. Fact Sheet, Biological Effects of Radiation, USNRC, p.1-4 http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.pdf [14 July 2014]

USNRC, 2013. Natural Background Sources, http://www.nrc.gov/about-nrc/radiation/around-us/sources/nat-bg-sources.html [18 July 2014]

USNRC, *n.d.* Reactor Concepts Manual, Biological Effects of Radiation, USNRC Technical Training Centre, Vol. 0603, p. 9-23 http://www.nrc.gov/reading-rm/basic-ref/teachers/09.pdf [20 July 2014]

UWEHS, 2006. Principles of Radiation Protection Section 2– Biological Effects of Ionizing Radiation, HEW Publication (FDA), Vol.77-8004, p.1-26 https://www.ehs.washington.edu/rsotrain/radprotectionprinciples/biological_effects.pdf [20 July 2014]

Valentin, J., 2002. ICRP Principles for the Radiological Protection of Workers, Occupational Radiation Protection: Protecting Workers against Exposure to Ionizing Radiation, Proceedings of an International Conference, Geneva, 26–30 August

Vanhatupa, T., Hännikäinen, M and Hämäläinen T. D., 2008. Performance model for IEEE 802.11s wireless mesh network deployment design, Elsevier – Journal of Parallel and Distributed Computing, Vol. 68, pp. 291 – 305

Wahl, L. E and Berkeley, L., 2010. Environmental Radiation, Health Effects of Background Radiation, pp 1-6, McLean HPS, McLean VA, USA

Wang, T.W and Gone, J. K., 1999. Environmental radiation monitoring program of the institute of nuclear energy research in Taiwan http://www.irpa.net/irpa10/cdrom/00433.pdf [03 August 2014]

WCA, 2014. Coal & Electricity, http://www.worldcoal.org/coal/uses-of-coal/coal-electricity/ [16 May 2014]

Westinghouse, *n.d*. Westinghouse Technology Systems Manual – Radiation Monitoring System, http://pbadupws.nrc.gov/docs/ML1122/ML11223A335.pdf [10 August 2014]

WHO, 2012. Ionizing radiation, health effects and protective measures, WHO, http://www.who.int/mediacentre/factsheets/fs371/en/ [10 July 2014]

Wikipedia, 2014. Brundtland Commission, Wikipedia Foundation, San Francisco, USA http://en.wikipedia.org/wiki/Brundtland_Commission [09 April 2014]

Wikipedia, 2014. Environmental degradation, Wikimedia Foundation, Inc http://en.wikipedia.org/wiki/Environmental_degradation [03 August 2014]

WNA, 2012, Fast Neutron Reactors. World Nuclear Association, England http://www.world-nuclear.org/info/Current-and-Future-Generation/Fast-Neutron-Reactors/#.UTsT22faB1g [11 May 2014]

WNA, 2012. Radioactive Wastes - Myths and Realities, www.world-nuclear.org/info/nuclear-fuel-cycle/nuclear-wastes/radioactive-wastes---myths-and-realities/ [16 April 2014]

WNA, 2012. Fast Neutron Reactors, http://www.world-nuclear.org/info/Current-and-Future-Generation/Fast-Neutron-Reactors/#.UTsT22faB1g [09 May 2012]

WNA, 2013. Safeguards to Prevent Nuclear Proliferation, World Nuclear Association, London, UK http://www.world-nuclear.org/info/Safety-and-Security/Non-Proliferation/Safeguards-to-Prevent-Nuclear-Proliferation/ [06 May 2014]

WNA, 2013. Sustainable Energy, http://www.world-nuclear.org/info/Energy-and-Environment/Sustainable-Energy/

WNA, 2014. What is Uranium? How Does it Work? http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Introduction/What-is-Uranium--How-Does-it-Work-/ [6 July 2014]

WNA, 2014. Nuclear Radiation and Health Effects, WNA, England, UK. http://www.world-nuclear.org/info/Safety-and-Security/Radiation-and-Health/Nuclear-Radiation-and-Health-Effects/ [17 July 2014]

Wordpress, 2005. Environmental Degradation Pdf, Automatic Inc., 2005 http://environmentaldegradationpdfeau.wordpress.com/ [03 August 2013]

WorldCoal, 2014. Underground Coal Gasification, http://www.worldcoal.org/coal/uses-of-coal/underground-coal-gasification/ [11 May 2014]

WSDOH, 2002. Background Radiation Natural versus Man-Made, Fact Sheet, Division of Environmental Health Office of Radiation Protection, Vol. 320-063, p. 1-7 http://www.doh.wa.gov/portals/1/Documents/Pubs/320-063_bkvsman_fs.pdf [2 July 2014]

WTO, 2014. The “Precautionary Principle”, chapter 8, 8.2, WTO publications (online bookshop) http://www.wto.org/english/tratop_e/sps_e/sps_agreement_cbt_e/c8s2p1_e.htm [21 April 2014]

Xu, P., Deng, Y., Su, X., Chen, X and Mahadevan, S., 2014. An evidential approach to physical protection system design, Elsevier, Science Direct Vol. 65, p.125-137

Yadav, S.C and Singh, S. K., 2009. An Introduction to Client/Server Computing, New Age International (P) Ltd. Publishers, New Delhi

ZERO, 2012. South Africa Energy & Climate Change - Policy and Progress, http://www.zeroco2.no/projects/south-africa [06 May 2014]

Zhang, W., Wang, Z., Das, S. K and Hassan, M., 2008. Security Issues in Wireless Mesh Networks, In Hossain, E and Leung, K (eds.), 2008, Wireless Mesh Networks – Architectures and Protocols, Springer, New York, USA

APPENDIX A

DISTANCE MODEL

```
%Effect of distance on Radiation dosage
clear
clc
d0=input ('Enter the  distance of the initial point from radiation source in meters:      ');
R1 = input('Enter the radiation intensity at initial point in mSv:    ');
d2 = input('Enter the  distance betwen initial and final points in meters:    ');
Limit=input('Enter acceptable dosage limit:    ');
d=d0 + d2;
md=1:d;
n=numel(md);
mLimit=1:n;
d3=d/n:d/n:n;
a=R1*d0^2;
for i= 1:d;
          b(i)=(d3(i))^2;
        in(i)= a/b(i);
  mLimit(i)=Limit;
  end
  plot(d3,in,'g-', d3,mLimit,'r-')
  xlabel('distance in meters')
  ylabel('Dose in mSv')
  title ('Effect of distance on dosage')
  legend('dosage received','acceptable dosage limit')
```

APPENDIX B

TIME MODEL

```
%Effect of Time on Radiation dosage
clear
clc
Time = input('Enter the total exposure time to radiation in minutes :    ');
mTime = [1:Time];
DR=input ('enter the dosage rate in microSv/min:     ');
Limit =input ('Enter radiation acceptable limit:      ');
n = numel(mTime);
mLimit= 1:n;
for i= 1:Time
    mTime(i)= i;
    Dose(i)=DR .* mTime(i);
    mLimit(i)= Limit;
    end
  plot(mTime,Dose,'g-', mTime,mLimit,'r-')
  xlabel('Exposure time in minutes')
  ylabel('Dose in microSv')
  title ('Effect of exposure time on dosage')
  legend('cumulative dosage','acceptable dosage limit')
```

APPENDIX C

SHIELDING MODELS

```
% half value layer Shielding
clc
clear
 Type= input('Enter the type of radiation source: Type 1 for Irridium-192; 2 for Cobalt-60:   ') ;
switch Type
    case 1
     Type = input('Enter  a number for shielding material: Choose 1 for concrete; 2 for steel; 3 
for lead; 4 for Tungsten; 5 for Uranium:   ');
        switch Type
            case 1
        th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=44.5;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of concrete shielding on Irridium-192')
 legend('change in radiation intensity','acceptable radiation limit')
            case 2

          th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=12.7;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
  plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of steel shielding on Irridium-192')
 legend('change in radiation intensity','acceptable radiation limit')
            case 3
                th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
       hlt=4.8;
```

```
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of lead shielding on Irridium-192')
 legend('change in radiation intensity','acceptable radiation limit')
            case 4
                th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=3.3;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of Tungsten shielding on Irridium-192')
 legend('change in radiation intensity','acceptable radiation limit')
            case 5
                th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=2.8;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of Uranium shielding on Irridium-192')
 legend('change in radiation intensity','acceptable radiation limit')
        end
    case 2
        Type = input('Enter  a number for shielding material: Choose 1 for concrete; 2 for steel;
3 for lead; 4 for Tungsten; 5 for Uranium:   ');
        switch Type
            case 1
        th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
```

```
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=60.5;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of concrete shielding on Cobalt-60')
 legend('change in radiation intensity','acceptable radiation limit')
            case 2

          th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=21.6;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
  plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of steel shielding on Cobalt-60')
 legend('change in radiation intensity','acceptable radiation limit')
            case 3
                th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
       hlt=12.5;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of lead shielding on Cobalt-60')
 legend('change in radiation intensity','acceptable radiation limit')
            case 4
                th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=7.9;
```

```
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of Tungsten shielding on Cobalt-60')
 legend('change in radiation intensity','acceptable radiation limit')
            case 5
                th= input('Enter thickness of shield in millimeters:    ');
        ri = input ('Enter radiation intensity at source in mSv:     ');
        al=input ('Enter acceptable radiation limit in mSv:       ') ;
        hlt=6.9;
        mth=0:hlt:th;
        n=numel(mth);
        mri=1:n;
         mal=1:n;
for i=1:n
        mri(i)=ri/(2^(i-1));
        mal(i)=al;
      end
 plot(mth,mri,'b-',mth,al,'r-')
 xlabel('shield thickness in mm')
 ylabel('intensity of radiation in mSv')
 title('Effect of Uranium shielding on Cobalt-60')
 legend('change in radiation intensity','acceptable radiation limit')
        end
end
```

APPENDIX D

RADIATION MONITORING SYSTEM MODEL

```
% radiation monitoring system program that allows you to choose a network
% topology before advising on detection possibility
clc
clear
Type = input('choose the  topology type, 1 or 2 :   ');
switch Type
   case 1
      st = input('Enter radiation strength at first receptor:   ');
      node = input ('Enter  the total number of nodes:   ');
     nodes = 1:node;
      faulty = input ('enter the faulty node number     ');
      faulty1=faulty-1;
      for m= 1:faulty1;
         strength(m)=st;
      end
      for j=faulty:node;
         strength(j)=0;
      end
      plot(nodes,strength,'-')
      xlabel('node')
      ylabel('radiation signal')
      title('radiation strength as it travels through the netwrok')
   case 2
       st = input('Enter radiation strength at first receptor:   ');
      node = input ('Enter  the total number of nodes:   ');
     nodes = 1:node;
      faulty = input ('enter the faulty node number     ');
      faulty1=faulty-1;
      for m= 1:faulty1;
         strength(m)=st;
      end
      for j=faulty:node;
         strength(j)=st;
      end
      plot(nodes,strength,'-')
      xlabel('node')
      ylabel('radiation signal')
      title('radiation strength as it travels through the netwrok')
end
```