

THE RADIOLOGICAL AND SAFETY CONSIDERATIONS FOR NUCLEAR
POWER PLANT SITING IN IRAQ

ISMAEL MOHAMMED MOHAMMED SAEED

UNIVERSITI TEKNOLOGI MALAYSIA

THE RADIOLOGICAL AND SAFETY CONSIDERATIONS FOR NUCLEAR
POWER PLANT SITING IN IRAQ

ISMAEL MOHAMMED MOHAMMED SAEED

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Physics)

Faculty of Science
Universiti Teknologi Malaysia

JANUARY 2018

Dedicated to:

My dearest father, my mother soul (be blessed), my dear wife for her patience and support, my Asma & Asia, the most dear daughters ever, for their never-ending love, and my dear friends who never stop supporting me during hard times of my study.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful.

First of all, a great praise and unlimited thanks to Allah S.W.T, my great lord who guided me through every step of this research and gave me enough support to continue and succeed.

I am pleased and honored to extend my acknowledgment and appreciation with gratitude to:

- My supervisor DR. Muneer Aziz Mohammed Saleh, for his non-stop support, expensive advises, and his patience during preparing this research.
- My Co-supervisor Assoc. Prof. Suhairul Hashim, for his support and valuable advises.
- My senior supervisor Prof Ahmad Termizi Bin Ramli who was a teacher more than my supervisor. Thanks for everything.
- My family, my dear wife fo her support and love.
- All of my friends who supported me financially or spiritually along this hard journey.

ABSTRACT

The consecutive shortages in electricity supply during the last 25 years in Iraq makes the review of the energy capabilities and policies extremely important. Long-range Energy Alternative and Planning (LEAP) model was used to estimate the demand for electricity and its corresponding environmental impact by 2040 setting 2011 as the base year. The demand for electricity is expected to increase more than twice that of the base year. Introducing 1 GW of electricity from nuclear power plant (NPP) starting from 2020 will reduce 8.1% of CO₂ emissions due to the demand on electricity. Atmospheric dispersion models of Hybrid Single Particle Lagrangian Integrated Trajectory model (HYSPLIT), Consequences of Releases to the Environment: Assessment Methodology (PC-CREAM) and Environmental Radiation Dosimetry Software System (GENII) were used to study the dispersion profile and its corresponding radiological impact for radioactive releases from NPP at four nominated sites; Abbasiyah, Abu Dalaf, Baii and Mahzam during the normal and accidental operation. The air concentration and the ground deposition of radionuclides at Baiji and Mahzam nominated sites were lower than other sites. The annual effective dose equivalent (AEDE) in Baiji site was lower than other sites during normal operation, but this does not pose any significant radiological impact for all sites. The air concentrations and their corresponding AEDE due to the accidental operation of the NPP at Baiji and Abu Dalaf sites based on source term (ST); ST1 and ST4 accident scenarios were lower at Baiji site. Based on time series of spatial distribution of the radionuclide releases, the emergency planning zones were determined. Baiji and Samarra cities were categorized as plume zone as the AEDE exceeded 100 mSv and instant evacuation is required, while Tikrit and Balad cities were categorized as ingestion zones and north areas from the NPP as support zone. Predetermined protective action plans were proposed to avoid and mitigate potential exposure to the radioactive releases.

ABSTRAK

Kekurangan bekalan elektrik selama 25 tahun berturut-turut di Iraq menjadikan kajian semula keupayaan dan dasar tenaga sangat mustahak. Model Tenaga Alternatif dan Perancangan Jangka Panjang (LEAP) digunakan untuk menganggarkan permintaan tenaga elektrik dan kesannya terhadap alam sekitar menjelang tahun 2040 dengan tahun 2011 ditetapkan sebagai tahun asas. Permintaan untuk tenaga elektrik dijangka meningkat lebih daripada dua kali ganda daripada tahun asas. Dengan penjana 1 GW tenaga elektrik daripada loji tenaga nuklear (NPP) bermula dari tahun 2020, didapati 8.1% pengeluaran CO₂ dapat dikurangkan kerana permintaan elektrik. Model penyebaran atmosfera seperti Model Trajektori Bersepadu Lagrangian Hibrid Zarah Tunggal (HYSPLIT), Kesan Pelepasan terhadap Alam Sekitar: Metodologi Penilaian: (PC-CREAM) dan Sistem Perisian Dosimetri Sinaran Alam Sekitar (GENII) digunakan untuk mengkaji profil penyebaran dan kesan radiologi melalui pelepasan bahan radioaktif daripada NPP semasa operasi biasa dan semasa kemalangan di empat tapak yang dicalonkan iaitu; Abbasiyah, Abu Dalaf, Baiji dan Mahzam. Kepekatan udara dan pendedahan tanah radionuklid di tapak yang dicalonkan di Baiji dan Mahzam adalah lebih rendah berbanding tapak yang lain. Dos setara berkesan tahunan (AEDE) di tapak Baiji adalah lebih rendah dari tapak yang lain semasa operasi biasa, tetapi tidak mempunyai impak ketara untuk kesemua tapak. Kepekatan udara dan dos setara berkesan tahunan (AEDE) yang sepadan semasa kemalangan di NPP Baiji dan Abu Dalaf berdasarkan senario kemalangan terma sumber (ST); ST1 dan ST4 adalah lebih rendah di Baiji. Berdasarkan siri masa pengagihan ruang pelepasan radionuklid, zon perancangan kecemasan telah ditentukan. Bandar Baiji dan Samarra dikategorikan sebagai zon plum dengan AEDE melebihi 100 mSv dan pemindahan segera perlu dilakukan, manakala bandar Tikrit dan Balad dikategorikan sebagai zon pengingesan dan kawasan utara dari NPP sebagai zon sokongan. Pelan tindakan perlindungan telah dicadangkan untuk mengelakkan dan mengurangkan kemungkinan pendedahan berlebihan akibat pelepasan bahan radioaktif.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xiv
	LIST OF FIGURES	xvii
	LIST OF SYMBOLS	xxiii
	LIST OF ABBREVIATIONS	xxv
	LIST OF APPENDICES	xxviii
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Overview of electricity in Iraq	2
	1.3 Problem statement	6
	1.4 Research objectives	8
	1.5 Scope of the study	8
	1.6 Significance of the research	10
	1.7 Thesis's organization	11
2	LITERATURE REVIEW	13
	2.1 Introduction	13
	2.2 Energy demand growing in Iraq	13
	2.2.1 Non-Renewable energy sources in Iraq	15

2.2.2	Renewable energy sources	16
	2.2.2.1 Hydro-electricity	17
	2.2.2.2 Solar energy	18
	2.2.2.3 Wind energy	20
2.2.3	Electricity crisis in Iraq	21
2.3	Energy, environment and climate change	23
2.4	Long-range Energy Alternatives Planning (LEAP)	24
2.5	Atmosphere dispersion modeling	26
	2.5.1 Structure of the atmosphere	26
	2.5.2 The planetary boundary layer	28
	2.5.3 Types of air dispersion modeling	30
	2.5.4 Gaussian plume models	30
	2.5.5 Stability classification scheme	33
	2.5.6 Turbulence parameterization	36
	2.5.7 Consequences of Releases to the Environment: Assessment Methodology (PC-CREAM) Model	37
	2.5.8 Gaussian puff models	38
	2.5.9 Stochastic Lagrangian particle models	39
	2.5.10 Eulerian advection and dispersion models	40
	2.5.11 Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model	41
	2.5.12 Ground deposition calculation using HYSPLIT model	43
2.6	Site selection survey	44
	2.6.1 Nuclear reactors	45
	2.6.2 Revolutionary generation of reactors	46
	2.6.3 Advanced pressurized water reactor (AP1000)	48
	2.6.4 Nuclear power plant siting criteria	49
	2.6.5 Site selection criteria and evaluation	50
	2.6.6 Site survey and evaluation for potential NPP in Iraq	53

	2.6.7	Nuclear facilities and fuel resources in Iraq	55
2.7		Nuclear safety principles	57
	2.7.1	Defense in depth principle	57
	2.7.2	Levels of defense in depth	58
	2.7.3	Nuclear accident scenario selection	59
		2.7.3.1 Accident scenario selection methodology	59
	2.7.4	Radiation exposure and risks	61
	2.7.5	Exposure pathways	62
	2.7.6	Radiological risk assessment	65
	2.7.7	GENII radiation dose and risk calculation model	65
3		METHODOLOGY	67
	3.1	Introduction	67
	3.2	Set up of LEAP	69
		3.2.1 Data collections and scenario selection	72
		3.2.2 Environmental impact calculation in LEAP	75
	3.3	Atmospheric dispersion	76
		3.3.1 Study area	76
		3.3.1.1 Seismotectonics of Iraq	78
		3.3.1.2 Seismic history of Iraq	79
	3.4	Configurations of HYSPLIT model	80
		3.4.1 Meteorological input data	82
		3.4.2 Radionuclides input data	84
		3.4.3 Particle dispersion and removal mechanisms	86
		3.4.4 Seasonal dispersion profile	89
		3.4.5 Air concentrations and deposition	90
		3.4.6 Exposure dose calculations	92
		3.4.7 Spatial presentation of radionuclides dispersion	96

3.4.8	Time Series analysis of atmospheric dispersion	97
3.4.9	Atmospheric dispersion of accidental release	98
3.4.10	Validation for results of atmospheric dispersion	99
3.5	Assessment of health impact for radioactive releases	99
3.5.1	Environmental Radiation Dosimetry Software System GENII	100
3.5.2	Constituents (GENII radionuclide database)	104
3.5.3	AFF air module	104
3.5.4	WFF surface water module	104
3.5.5	Chronic plume module	105
3.5.6	GENII V.2 chronic exposure module	105
3.5.7	GENII V.2 intake module	106
3.5.8	Health impact module	107
3.5.9	Report generator module	109
3.6	Siting procedure inquiries	109
3.6.1	Siting safety pre-requirements availability	110
4	RESULTS AND DISCUSSION	111
4.1	Introduction	111
4.2	Current and future demand on electricity	112
4.3	Environmental impact of energy technologies	117
4.4	Environmental impact of non-fossil energy utilization	119
4.5	Atmospheric dispersion in normal operation	122
4.5.1	Dispersion profile in normal operations	123
4.5.2	Atmospheric dispersion for ¹³¹ I radionuclide at Abbasiyah site	124
4.5.3	Atmospheric dispersion for ¹³¹ I radionuclide at Baiji site	127

4.5.4	Atmospheric dispersion for ^{137}Cs radionuclide at Baiji site	131
4.5.5	Ground deposition for ^{137}Cs radionuclide at Baiji site	135
4.6	Time Series analysis of atmospheric dispersion	137
4.6.1	Time Series analysis of air concentration for ^{131}I radionuclide in Baiji site	137
4.6.2	Time Series analysis of air concentration for ^{131}I radionuclide in Abbasiyah site	142
4.6.3	Time Series analysis of ^{131}I radionuclide air Concentration for nominated sites	146
4.7	Annual average air concentration and ground deposition for atmospheric release at nominated sites	150
4.7.1	Annual average air concentration and ground deposition for atmospheric release using HYSPLIT	150
4.7.2	Annual average air concentration using GENII and PC-CREAM models	153
4.7.3	Results validation for air concentration of the radionuclides	154
4.8	Health impacts of NPP at nominated sites in routine operation	156
4.8.1	Assessment of radiological impact due to radiation exposure in the nominated sites	156
4.8.2	Assessment of radiological impact from ingestion exposure pathways in nominated sites	159
4.8.3	Assessment of radiological impact from inhalation exposure pathways in nominated sites	161
4.8.4	Assessment of radiological impact from external exposure pathways at nominated sites	163

4.9	Assessment of radiological impact of radionuclides in annual effective dose equivalent at the nominate sites	166
4.9.1	Contribution of radionuclides in exposure radiation pathways	168
4.9.2	Cancer incidences and fatalities estimated from normal operation of NPPs	172
4.10	Health impact of NPP at nominated sites due to contaminant discharges to aquatic medium	175
4.11	Total health impact from normal operation of nominated sites	178
5	ACCIDENT SCENARIOS AND EMERGENCY PLAN	181
5.1	Introduction	181
5.2	Nuclear accident management	181
5.2.1	Emergency response criteria	182
5.3	Atmospheric dispersion profile during hypothetical nuclear accident	184
5.3.1	The Time Series of ⁸⁵ Kr radionuclide air concentration in Abu Dalaf and Baiji nominated sites during ST4 scenario	190
5.4	Assessment of radiological impacts and risks of accidental releases in Abu Dalaf and Baiji nominated sites for ST1 and ST4 accident scenarios	195
5.4.1	Assessment of annual effective dose equivalent of accidental releases in Abu Dalaf and Baiji nominated sites for ST1 and ST4 accident scenario	195
5.4.2	Assessment of equivalent dose due to Thyroid gland in Abu Dalaf and Baiji nominated sites for ST1 and ST4 scenarios	197

5.4.3	Assessment of public health risk in Abu Dalaf and Baiji nominated sites for ST1 and ST4 scenarios	198
5.5	Spatial distribution of annual effective dose equivalent for ST4 scenario in Abu Dalaf and Baiji nominated sites	199
5.5.1	The Variation of annual effective dose equivalent for ST4 scenario in Abu Dalaf nominated site	200
5.5.2	The variation of annual effective dose equivalent for ST4 scenario in Baiji nominated site	204
5.6	Emergency planning zone (EPZ) and emergency preparedness (EP)	208
5.7	Implementation of emergency plan and protective actions for Baiji site	214
6	CONCLUSION AND RECOMMENDATIONS	218
6.1	Introduction	218
6.2	Conclusion	218
6.3	Recommendations and further study	221
	REFERENCES	223
	Appendices A – F	234 – 253

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.1	The growth rate of economic sectors from 1953-1963 (Alnasrawi, 2002)	2
2.1	Daily production, export and consumption of crude oil	16
2.2	Current hydroelectric plants with power capacity in Iraq (Uqaili, 2013; Kubba, 2004)	17
2.3	The under-construction dams of hydroelectric plants in Iraq and their expected power capacity (Uqaili, 2013)	18
2.4	Iraqi government's five years plan to expand the electricity capacity	23
2.5	Atmospheric stability classes (Smith and Simmonds, 2009)	33
2.6	Roughness length of some terrain surfaces (Smith and Simmonds, 2009)	34
2.7	Coefficients given by Hosker to derive the vertical standard deviation of the plume for the various stability categories (Smith and Simmonds, 2009)	35
2.8	Coefficients for the roughness correction factor $f(z_o, x)$ (Smith and Simmonds, 2009)	35
2.9	Parameters that affect turbulence patterns in the planetary boundary layer (De Visscher, 2013)	36
2.10	Suggested points by IAEC for evaluation by the contractor (Atomteploelektroproekt, 1985b)	54
2.11	Safety levels in Defense in Depth (IAEA, 1996)	58
2.12	Public and worker effective dose limits under normal operations (Wrixon, 2008; Lecomte, 2016)	63

3.1	Growth rate values in population and GDP for adopted scenarios and other configurations (CSO, 2011, 2014)	74
3.2	Location parameters of nominated sites	77
3.3	Meteorological parameters included in global reanalysis dataset	83
3.4	Releases to atmosphere during normal operation (NRC, 2013)	84
3.5	Parameters used for modeling radionuclides annual discharges to air in HYSPLIT	85
3.6	Time periods of the release based on seasons	90
3.7	Dose conversion factors for simulated radionuclides	95
3.8	Selected cities around the potential site of Baiji with distance and population density	97
3.9	Selected cities around the potential site of Abbasiyah with distance and population density	98
3.10	Releases to River During Normal Operation (Westinghouse, 2011)	104
3.11	The physical description of the releasing source facility to the atmosphere (UNEP, 2014)	105
3.12	Pathway parameters for exposure, inhalation and ingestion activity	106
4.1	Average annual air concentration of ^{131}I radionuclide at nominated sites for all seasons	147
4.2	Air concentration of radionuclides using HYSPLIT, GENII and PC-CREAM models in Baiji site	154
4.3	The radionuclides contribution to annual effective dose equivalent due to internal and external exposure pathways at nominated sites.	169
4.4	Annual effective dose equivalent and risk of cancer incidence and fatalities from aquatic discharge to Tigris River at normal operation of NPP	176
4.5	Radionuclide contribution to exposure doses from fish ingestion	177
4.6	Total and annual effective dose equivalent from atmospheric and aquatic discharges in nominated sites	179

5.1	High population cities around nominated sites for potential NPP with location and distance	190
5.2	Annual effective dose equivalent due to accidental release of hypothetical accident scenario ST1 and ST4 in Abu Dalaf and Baiji nominated sites	196
5.3	Total equivalent dose of thyroid gland for ST1 and ST4 scenarios in Abu Dalaf and Baiji nominated sites	197
5.4	Total cancer risk for ST1 and ST4 scenarios in Abu Dalaf and Baiji nominated sites	198
5.5	Total annual effective dose in different locations and directions from a NPP at Abu Dalaf nominated site for ST4	201
5.6	Total annual effective dose for different locations and directions from the NPP at Baiji nominated site for ST4	205
5.7	Protective action levels for evacuation, sheltering and thyroid blocking under US NRC regulations	209
5.8	Total annual effective dose equivalent at populated cities during three days for ST4 scenario at Baiji nominated site	215

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Electricity demand and production in Iraq from 1990 to 2010 (Kubba, 2013; CSO, 2014)	4
1.2	Electricity losses by type in selected countries at 2010 (IEA, 2012)	5
1.3	Electricity production share in Iraq from 2004 to 2011 (CSO, 2014)	6
2.1	Average monthly irradiance in Iraq (Reegle, 2014)	19
2.2	Annual wind speed of some Iraqi cities at 10 m height (Reegle, 2014; Darwish and Sayigh, 1988)	20
2.3	Iraq source and reliability of electricity supply by governorate at 2011 (IEA, 2012)	22
2.4	Structure of the atmosphere: based on the U.S. Standard Atmosphere (Lagzi <i>et al.</i> , 2014)	28
2.5	Layer levels of the atmosphere based on their turbulence parameters (Lagzi <i>et al.</i> , 2014)	29
2.6	Schematic of a Gaussian plume model (De Visscher, 2013)	31
2.7	Siting and evaluation process for nuclear installations	45
2.8	Prototype generation IV sodium cooled fast reactor (Ahn <i>et al.</i> , 2016)	48
2.9	Advanced pressurized water reactor (AP1000) design (Queral <i>et al.</i> , 2015)	49
2.10	INES classification for accident level (IAEA <i>et al.</i> , 2008; IAEA, 2008)	60
2.11	Components of an exposure pathway (EPA, 1997)	64

3.1	Summary of all the main methodologies used through the research	68
3.2	The structure of LEAP calculations (Heaps, 2012)	70
3.3	LEAP main window	71
3.4	Scenario manager in LEAP	72
3.5	Growth rate of economy in Iraq from 1969 to 2016 (CSO, 2011, 2016)	73
3.6	Growth rate of population in Iraq from 1970 to 2015 (CSO, 2011, 2014)	74
3.7	Iraqi plan to expand electricity generation capacity (Uqaili, 2013)	75
3.8	The four nominated sites by IAEC for NPP	77
3.9	Seismic isointensity of Iraq (Jassim and Goff, 2006)	79
3.10	Schematic diagram for modeling procedure of HYSPLIT for normal operation and hypothetical severe accidents	81
3.11	Main menu of HYSPLIT model	91
3.12	Setup of dispersion profile	91
3.13	Setup of simulating air concentration and ground deposition	92
3.14	Conversion utility in HYSPLIT	93
3.15	Conversion utility by pathways in HYSPLIT	94
3.16	Example of ASCII output file	96
3.17	Schematic diagram of GENII sequent procedures (Dispersion Process)	100
3.18	Schematic diagram of GENII sequent procedures (health impact and risk study)	101
3.19	GENII scenario of health impact due to release to atmosphere for normal operation of NPP	102
3.20	GENII scenario of health impact due to release to atmosphere for hypothetical accident	103
3.21	Setup of GENII scenario to simulate health impact of radioactive releases to river during normal operation at nominated sites	103
4.1	The energy demand for scenarios SC ₁ , SC ₂ and SC ₃ in Iraq	113

4.2	The population electricity demand for each scenario (SC ₁ , SC ₂ and SC ₃) in Iraq	114
4.3	Energy demand for each consumption sector according to SC ₂ scenario in Iraq	115
4.4	Energy demand for each consumption sector according to SC ₃ scenario in Iraq	116
4.5	Energy demand for each consumption sector according to SC ₁ scenario in Iraq	117
4.6	The global warming potential based on energy generation technologies under third scenario (SC ₃) in Iraq.	118
4.7	Electricity demand based on energy technologies under SC ₃ scenario	120
4.8	Electricity demand based on energy technologies under SC ₄ scenario	121
4.9	The global warming potential and its mitigation based on energy production technologies for SC ₄ scenario in Iraq	122
4.10	Annual air concentration of ¹³¹ I radionuclide at Abbasiyah site in the summer time	125
4.11	Annual air concentration of ¹³¹ I radionuclide at Abbasiyah site in the winter time	125
4.12	Annual air concentration of ¹³¹ I radionuclide at Abbasiyah site in the autumn time	126
4.13	Annual air concentration of ¹³¹ I radionuclide at Abbasiyah site in the spring time	127
4.14	Annual air concentration of ¹³¹ I radionuclide at Baiji site in the summer time	128
4.15	Annual air concentration of ¹³¹ I radionuclide at Baiji site in the winter time	129
4.16	Annual air concentration of ¹³¹ I radionuclide at Baiji site in the autumn time	130
4.17	Annual air concentration of ¹³¹ I radionuclide at Baiji site in the spring time	131
4.18	Air concentration of ¹³⁷ Cs at Baiji site in the summer time	132
4.19	Air concentration of ¹³⁷ Cs at Baiji site in the winter time	133

4.20	Air concentration of ^{137}Cs at Baiji nominated site in the autumn time	134
4.21	Air concentration of ^{137}Cs at Baiji site in the spring time	135
4.22	Ground deposition of ^{137}Cs at Baiji site in winter time	136
4.23	Ground deposition of ^{137}Cs at Baiji site in spring time	137
4.24	The air concentration time series for ^{131}I radionuclide at Baiji nominated site in summer	139
4.25	Time Series of air concentration for ^{131}I radionuclide from Baiji site in winter	141
4.26	The time Series of air concentration for ^{131}I radionuclide from Abbasiya site in summer	143
4.27	Time series of air concentration for ^{131}I radionuclide from Abbasiyah site in winter	145
4.28	Time series of air concentration for ^{131}I radionuclide at nominated sites at the winter time	149
4.29	Annual average air concentration of the radionuclides using HYSPLIT	151
4.30	Annual average ground deposition in nominates sites using HYSPLIT	152
4.31	Annual average air concentration of radionuclides in nominates sites using GENII and PC-CREAM models	153
4.32	Comparison of radionuclides air concentrations calculated by HYSPLIT with GENII and PC-CREAM models for normal operation at Baiji nominated site	155
4.33	Annual effective dose equivalent by external and internal exposure pathways at nominated sites	157
4.34	The contribution of exposure pathways to annual effective dose equivalent at nominated sites	158
4.35	Annual effective dose equivalent from ingestion pathway by food ingestion at nominated sites	160
4.36	The contribution of ingestion exposure pathways to annual effective dose equivalent at nominated sites	161
4.37	Annual effective dose equivalent from inhalation pathways at nominated sites	162

4.38	The contribution of inhalation exposure pathways to annual effective dose equivalent at nominated sites	163
4.39	The annual effective dose equivalent due to external exposure pathways at nominated sites	164
4.40	The contribution of external exposure pathways to annual effective dose equivalent in nominated sites	165
4.41	Annual effective dose equivalent by radionuclides at nominated sites	167
4.42	Radionuclides contribution to annual effective dose equivalent at nominated sites	168
4.43	Contribution of radionuclides to annual effective dose equivalent due to internal exposure pathway at nominated sites	171
4.44	Contribution of radionuclides to annual effective dose equivalent due to external exposure pathways at nominated sites	172
4.45	Annual cancer incidence risk by radionuclides in nominated sites	173
4.46	Annual cancer fatalities risk by radionuclides in nominated sites	174
4.47	Annual effective dose equivalent and cancer risk from aquatic discharges by Radionuclides	178
5.1	Atmospheric dispersion of ^{131}I radionuclide for a hypothetical accident release scenario (ST1) at nominated sites	185
5.2	Atmospheric dispersion of ^{131}I radionuclide for hypothetical accident release scenario (ST4) at nominated sites	187
5.3	Atmospheric dispersion of ^{85}Kr radionuclide for hypothetical accident release scenario (ST4) at nominated sites	189
5.4	Time series of air concentration of ^{85}Kr radionuclide for ST4 scenario at Abu Dalaf nominated site	192
5.5	Time series of air concentration for ^{85}Kr radionuclide for ST4 scenario at Baiji nominated site	194
5.6	Cancer fatality risk along different distances east of Baiji nominated site for ST4 accident scenario	199

5.7	The variation of annual effective dose equivalent to the south of Abu Dalaf nominated site for ST4 accident scenario	202
5.8	The variation of annual effective dose equivalent for the northeast direction for ST4 scenario from Abu Dalaf nominated site	204
5.9	The variation of annual effective dose equivalent to the south of Baiji nominated site for ST4 scenario	206
5.10	The variation of annual effective dose equivalent at the northern direction for ST4 scenario from Baiji nominated site	207
5.11	Concept of emergency planning zones	208
5.12	Time series of spacial distribution of annual effective dose equivalent at Baiji nominated site during first day of ST4 scenario	210
5.13	Wind speed and direction frequency at Baiji potential site during 15 th to 19 th of Dec 2015	211
5.14	Time series of spatial distribution of annual effective dose equivalent in Baiji nominated site during second day of ST4	212
5.15	Time series of spacial distribution of annual effective dose equivalent at Baiji nominated site during third day of ST4 scenario	213
5.16	Wind direction and speed annual frequency at Baiji potential site	216

LIST OF SYMBOLS

σ	-	Diffusion coefficients
Q	-	Source emission rate (Bq h^{-1})
λ	-	Weighting coefficient
$C_{c,s}\{x_r, y_r, z_r\}$	-	Concentration contribution from the terrain-following plume state-convective and stable (g m^{-3})
$C_T\{x_r, y_r, z_r\}$	-	Total concentration (g m^{-3})
σ_y	-	Dispersion coefficient in crosswind direction
σ_z	-	Dispersion coefficient in vertical direction
u	-	Wind speed (m s^{-1})
f	-	Plume state weighting function
z_r	-	Height relative to elevation of stack base
z_p	-	Receptor height above local ground
z_t	-	Height of terrain at a receptor location
P_w	-	Probability density function of the instantaneous vertical velocities
P_y	-	Lateral probability density function
P_z	-	Vertical probability density function
σ_w	-	Vertical turbulence (m s^{-1})
d_a	-	Distance from the puff center to the receptor along-wind direction (m)
d_c	-	Distance from the puff center to the receptor in the cross-wind direction (m)
g	-	Vertical term of Gaussian equation
H	-	Effective height above the ground of the puff center (m)

x_{pi}	-	Particle position
u_{pi}	-	Lagrangian turbulent velocity fluctuation
\bar{u}_i	-	Eulerian mean velocity
d_W	-	Incremental Wiener process
m	-	Mass of the pollutant
$D_{wet+dry}$	-	Total deposition (wet and dry)
β	-	Deposition constant
V_d	-	Deposition velocity
Z_p	-	Depth of pollutant layer
P	-	Precipitation rate
F_b	-	The fraction of the pollutant layer that is above the cloud bottom
F_t	-	The fraction of the pollutant layer that is below the cloud bottom
\hat{H}	-	Henry's Law constant
\hat{R}	-	Universal gas constant
T	-	Absolute temperature
\hat{S}	-	Average scavenging ratio
E_c	-	Energy consumption
E_a	-	Energy activity
E_e	-	Energy intensity
$D_{b,s,t}$	-	Energy demand
$TA_{b,s,t}$	-	Total activity
$Emission_f\{t, v\}$	-	An environment measure of the energy technology
Sc	-	Scenario
l/l	-	Scavenging ratio
l/s	-	Explicit scavenging coefficient
$EID\{t, y - v\}$	-	A factor which represents the change in energy intensity as a technology ages

LIST OF ABBREVIATIONS

ADM	-	Atmospheric Dispersion Modelings
AEDE	-	Annual Effective Dose Equivalent
AMS	-	American Meteorological Society
amu	-	Atomic Mass Units
BMI	-	Business Monitor International
BP	-	British Petroleum
CEA	-	Atomic Energy Commission
DoE	-	Department of Energy USA
DRNS	-	Directorate of Radiological and Nuclear Safety
EIA	-	Energy Information Administration
FRAMES	-	Framework for Risk Analysis in Multimedia Environmental Systems
FSU	-	Former Soviet Union
GCR	-	Gas Cooled Reactor
GDAS	-	Global Data Assimilation System
GDP	-	Gross Domestic Product
GEOSURVIRAQ	-	Ministry of Industry-Iraqi Geology Survey-Iraq
GHG	-	Greenhouse Gas
GWP	-	Global warming potential
HOMER	-	Hybrid Optimization of Multiple Energy Resources
HWR	-	Heavy Water Reactor
HYSPLIT	-	Hybrid Single-Particle Lagrangian Integrated
IAEA	-	International Atomic Energy Agency
IAEC	-	Iraqi Atomic Energy Commission

ICARDA	-	The International Center for Agricultural Research in the Dry Areas
ICRP	-	International Commission on Radiological Protection
IEA	-	International Energy Agency
IMOS	-	Iraqi Metreological Organization and Siesmology
INES	-	Integrated National Energy Strategy
INES	-	International Nuclear Events Scale
ISH	-	Integrated Surface Hourly
LEAP	-	Long-range Energy Alternative and Planning
LMCFR	-	Liquid Metal Cooled Fast Reactor
LWR	-	Light Water Reactor
MMBOE	-	Million Barrels of Oil Equivalents
MMtCO ₂	-	Million Metric Tonnes CO ₂ Equivalent
MoE	-	Ministry of Electricity - Iraq
MoO	-	Ministry of Oil - Iraq
NCAR	-	National Center for Atmospheric Research
NCEP	-	National Centers for Environmental Prediction
NCRP	-	National Council on Radiological Protection and Measurments
NESHAPS	-	National Emission Standards for Hazardous Air Pollutants Compliance Monitoring
NPP	-	Nuclear Power Plant
NWP	-	Numerical Weather Prediction
OBT	-	Organically Bound Tritium
OECD/NEA	-	Organisation for Economic Co-operation and Development/The Nuclear Energy Agency
OPEC	-	Organization of the Petroleum Exporting Countries
PBL	-	Planetary Boundary Layer
PC-CREAM	-	Consequences of Releases to the Environment:

		Assessment Methodology
pdf	-	Probability Density Function
PGSFR	-	Prototype Gen-IV Sodium Cooled Fast Reactor
PNNL	-	Pacific Northwest National Laboratory
PWR	-	Pressurized Water Reactor
REEEP	-	Renewable Energy & Efficiency Partnership
SiC _f	-	Silicon Carbide Fiber
SEI	-	Stockholm Environment Institute
SOARCA	-	State-of-the-Art Reactor Consequence Analyses
TED	-	Technology and Environmental Database
TSSD	-	Time Series of Spatial Distribution
USCEAR	-	United Nations Scientific Committee on the Effects of Atomic Radiation and Others
US EPA	-	U.S. Environmental Protection Agency
US-NRC	-	United State-Nuclear Regulatory Commission
UTM	-	Universiti Teknologi Malaysia

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	GENII Input & Output File Samples	234
B	Examples of HYSPLIT configuration requirement files	237
C	Example of PC-CREAM result output	240
D	Accident Scenarios	242
E	Additional Information about Iraq	248
F	List of Publications	253

CHAPTER 1

INTRODUCTION

1.1 Introduction

It is well known that energy is the source of life, and it has made great contribution to every aspect of human activity on earth. Electricity is considered to be the main engine in rotating the wheel of everyday life in all economic and social sectors. Electricity has become a measure to the welfare of people and a determinant on the lifestyle of human societies. People, represented by their governments, seriously and vigorously seek to ensure sustainable sources of energy, especially electrical energy for the sustainability of the lifestyle that governments seek to provide to the people (Hodgson, 2010).

Nuclear power technology is considered as the only energy source that provides a large scale of electricity with comparatively minimum environment impact. At the global level, there were 441 operating nuclear reactor at the end of 2002 providing 16% of global electricity generation (Lillington, 2004). However, any future expansion in nuclear power technology will acquiesce to the further innovations in reactor, fuel cycle and waste disposal technologies. Such innovations should provide and inherent the safety system, anti-proliferation characteristics and reduction of radioactive wastes (Lillington, 2004; Hodgson, 2010).

Nuclear power plant accidents were a main motivation the nuclear industry sector to improve the safety principles in nuclear reactors, especially after Chernobyl accident on 26th April 1986. The nuclear industry among the world shocked and it faced a considerable recession. Nuclear safety standards, from the basic design of

nuclear reactors to the emergency preparation have changed and thoroughly revised (Labib, 2014; Lillington, 2004). The independent systems of control and shutdown was the most considerable improvements that have been invented in the design of next generations of reactors (Generation III) after Chernobyl accident in terms of safety considerations. Many generic lessons have been learnt in terms of safety measures and emergency preparednesses during accidents, which lead specialists to seek for urgent improvement in all fields related to nuclear power plants (Beresford *et al.*, 2016).

1.2 Overview of electricity in Iraq

The first electricity generation machine in Iraq was commercial and it was used by the English-Persian Oil company in 1911 (Kubba, 2004). The discovery and extraction of oil in Iraq helped Iraqi government to build more service institutions and industrial facilities across the country, including electrical facilities (World Bank, 1952). Table 1.1 shows the extent of change in the growth rate of the industrial sector (including oil production industry) and national income during the last time period from 1953-1963 (Alnasrawi, 2002).

Table 1.1: The growth rate of economic sectors from 1953-1963 (Alnasrawi, 2002)

Sectors	Growth Rate (%)
Industry	11
Electricity Production	16.7
Banking and Insurance	11.3
Transport	6
Civil Administration	10.5
Defense	10.5
Wholesale and singular trade	5.7
Housing and construction	2.4
Imports	67
Non-oil funds	19
Gross Domestic Product (GDP)	6.4

Industrial sector witnessed a growth rate of 11% over ten years, while the growth rate in electricity production sector was 16.7% during the same period. This indicates that a rapid development within the industry and energy sectors were achieved during that period as a result of the government orientation towards the adoption of industry as a major income source in the structure of the Gross Domestic Product (GDP) (Alnasrawi, 2002).

Iraqi government has planned to become an industrial country by the adoption of a five-year plan in development of the industrial sectors within the country, including the industry for extraction and export of oil (Dawisha, 2009; World Bank, 1952). Accordingly, the need for electricity increased, and the need for new power plants became inevitable.

Many new power plants were built, and the process of electrification of cities and villages continued after the 1958 revolution, with a new distribution grid system joining together all the country regions. The capacity for electricity production in Iraq could match the slowly increasing demand through continuous projects being carried out around the country (Kubba, 2004).

The production capacity of electricity was twice of that required by the domestic demand since the beginning of the year 1990, when the Iraqi government was aspiring to export electricity to both Turkey and Syria through a huge distribution network. Some parts of the project have been completed before the occupation of Kuwait by Iraq, but did not become operational (Yee, 2010; Al-Khalisi, 2014). After the invasion of Kuwait and the second Gulf War, the destruction included 80% of the productive capacity in the electricity sector in Iraq, and the subsequent Iraqi governments from 1991-2013 have not been able to execute a successful plan to make electricity production capacity match the domestic demand (Al-Khalisi, 2014).

Since 1991, after the second gulf war, Iraq has suffered from the lack of electricity power supply. The military operations and the bombing of infrastructure facilities in Iraq from 1991 to 2003 resulted in the destruction of Iraq's administrative potentials for reconstruction of electricity production sector (Istepanian, 2014;

Al Qaisi, 2013). Figure 1.1 shows the increase in the gap between electricity production and demand in Iraq, especially after 2003 when the demand has increased rapidly due to the new market policy adopted by the new government and high increase in GDP per capita (Kubba, 2013).

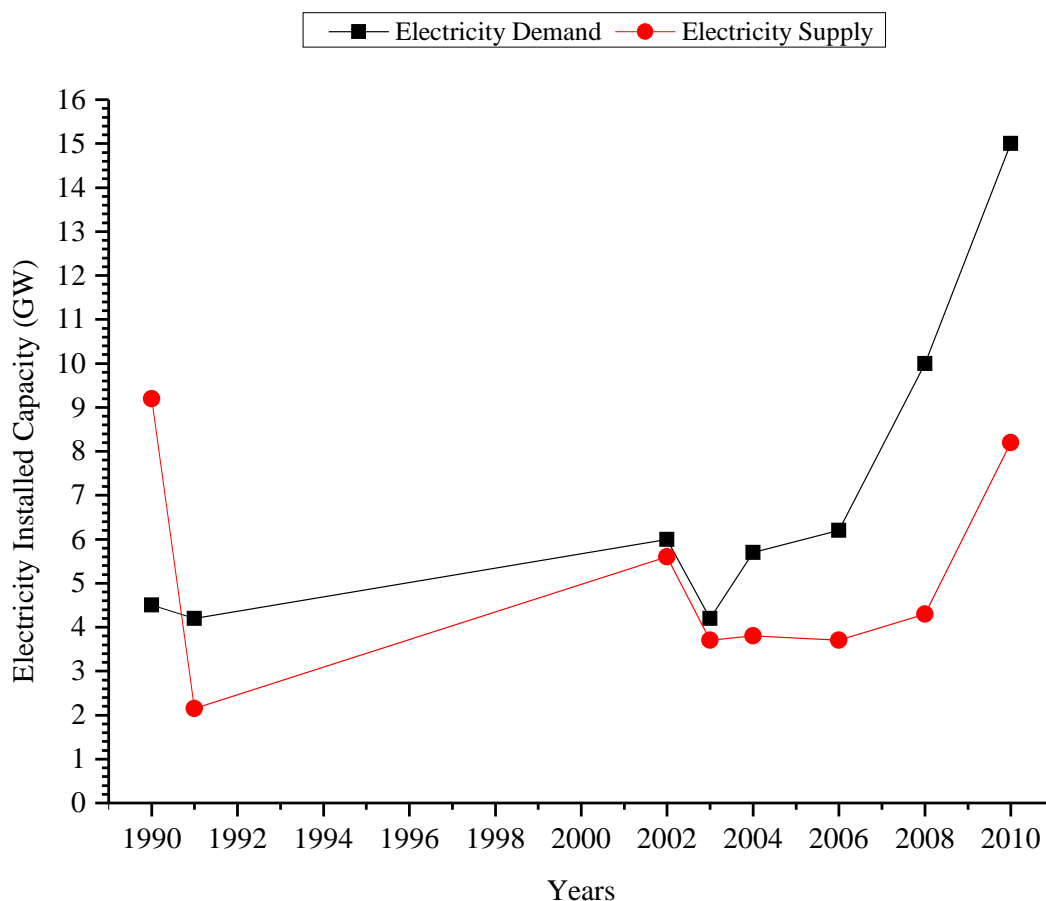


Figure 1.1: Electricity demand and production in Iraq from 1990 to 2010 (Kubba, 2013; CSO, 2014)

Beside the lack of electric power supply, high percentages of loss in electricity power is also due to the deterioration of transmission and distribution in the networks in electricity sector in Iraq. The loss rate in the electricity energy sector has continued to grow rapidly, and has been ranked number one among the surrounding countries. As shown in Figure 1.2, Iraq has the highest rate of lose in electricity power (IEA, 2012).

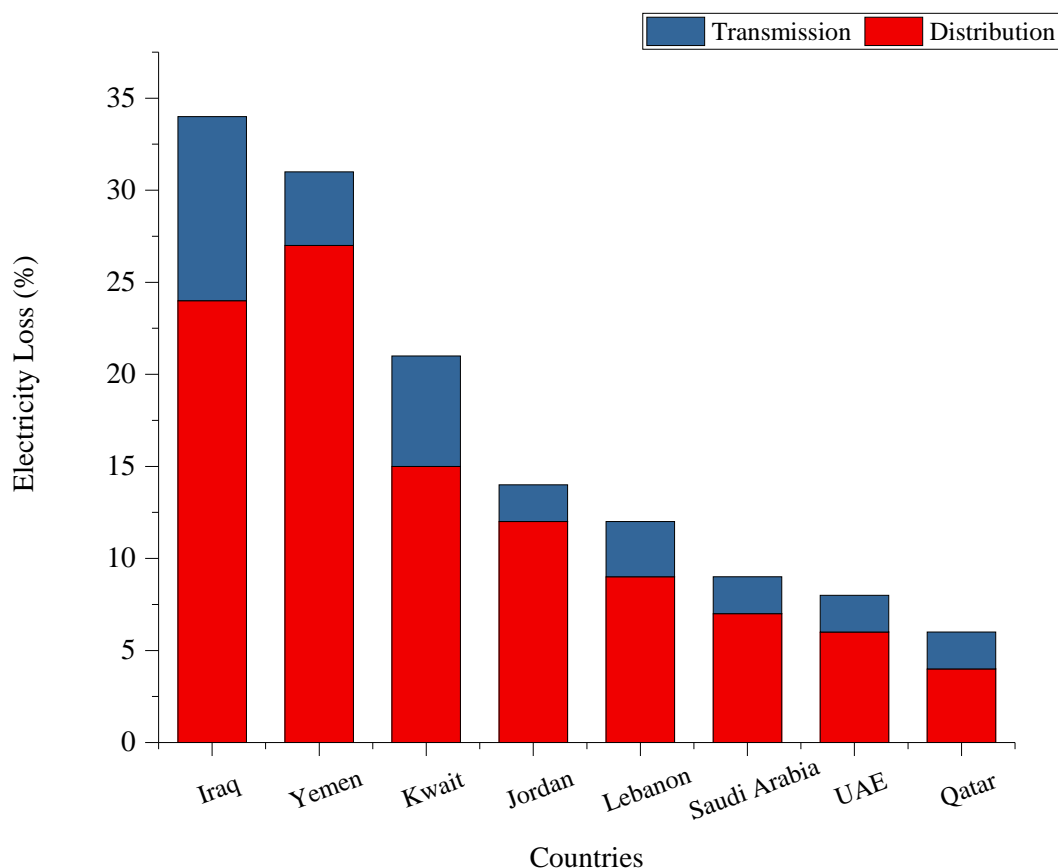


Figure 1.2: Electricity losses by type in selected countries at 2010 (IEA, 2012)

Iraq has good potential of non-renewable and renewable energy sources that could be utilized in energy production sectors, including the electricity (Hamdan, 2014; Chaichan, 2012). Iraq is ranked fourth in oil reserve. It has a proven oil reserve of 140-150 billion barrels according to latest surveys in 2013. Iraq's natural gas reserve accounts for around 1.5% of total world reserve, ranking thirteenth among global reserve countries (IEA, 2012; BMI, 2014), even though most areas of Western, North Western, North, and some areas in the South of Iraq have not been subjected to a thorough advanced geological survey (Kubba, 2004). Other potential sources of energy are available in Iraq such as nuclear, hydroelectric, wind, and solar energy. Exploitation of these energy sources should be included in current or future plans of Iraqi government for electricity generation, and they need to be adopted seriously (Hamdan, 2014). In addition, Iraqi government did not have a clear and elaborate master plan to rebuild the electricity generation infrastructure in spite of her huge investments in electricity sector from 2003 until now (Al-Majid, 2013). Hence,

The electricity generation technologies restricted to the fossil fuel consumers which were more easier for Iraqi government to put more investment and development through, while other technologies of electricity generation became too far from official ambitions during last 30 years, as shown in Figure 1.3.

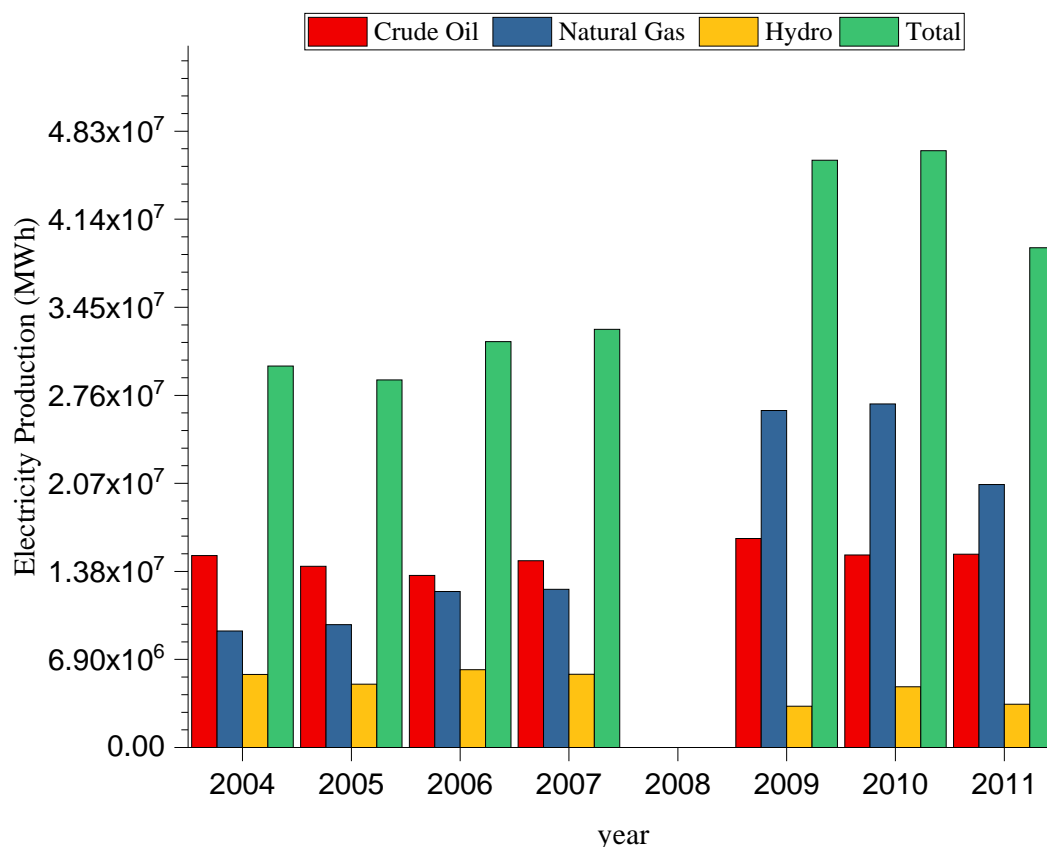


Figure 1.3: Electricity production share in Iraq from 2004 to 2011 (CSO, 2014)

1.3 Problem statement

Iraq has faced consecutive shortages in electricity supply during the last 25 years. This requires a review of the current and previous plans in energy sector, especially electricity supply system. This study aims to determine the potential energy sources available in Iraq besides fossil fuels, which can be in the form of renewable energy and nuclear facilities. The possibility of their exploitation as well as their impact on mitigation of greenhouse-gas emissions are also discussed (Kubba, 2013).

Electricity generation in Iraq relies completely on oil and gas products as the main source of fuel, due to its abundance. Hence, the security and diversity in energy supply are not assured due to the depletion of oil and gas resources. Also, the environment will continue to be affected negatively by greenhouse gas (GHG) emission from fossil energy sources. Iraq owns good potential sources of non-fossil energy such as renewable energy. Renewable energy sources are considered as desired alternative sources due to their low impact on environmental (Hodgson, 2010), but the limitation of their production capacity which is dominant by the weather conditions make them undesired based on the huge demand on energy in Iraq.

Thus, reliable sources of energy is required to provide sustain and huge amounts of energy in Iraq to ensure the required energy for country developments. Therefore, nuclear energy could be the desired alternative of reliable energy source in terms of its provision rate of energy and its low environmental impact.

Within the context of the above investigation this study will also focus on the site selection for nuclear power plants in accordance with IAEA safety requirements. This study will also concentrate on such factors as possible radioactive radiation and contamination of the environment in both normal operations and those due to accidents (IAEA, 2006b; Farmer, 1967). Preliminary radiological assessment of public health impact due to atmospheric release of radionuclides during normal operation for two selected potential sites; Al-Mahzam and Baiji, was conducted previously for the (VVER-440) reactor using (AIRDOS-EPA) computer code (Marouf *et al.*, 1991a, 1992). The assessment was interrupted by the invasion of Kuwait in 1991, and hence the estimation of radiological impact for nominated sites were not completed.

Therefore, a complete system of safety analysis, which considers the human health and the environmental impact for normal operation and accidental situation, is required for new nuclear facility. The hypothetical accident scenarios and the emergency plan are needed to mitigate the radiological impact of any accident. This research conducted extensive radiological assessment for nominated sites for normal and different nuclear accident scenarios and verified the suitable site for NPP using atmospheric dispersion analysis.

1.4 Research objectives

This research aims to achieve certain objectives, which can be summarized as follows:

1. To assess the current and future electricity demand in Iraq and their corresponding environmental impact for each electricity generation technologies using Long-range Energy Alternatives Planning (LEAP) model.
2. To measure and compare the annual air concentration and ground deposition due to the atmospheric release using Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT), Radiation Dose and Risk Calculation (GENII) and Consequences of Releases to the Environment: Assessment Methodology (PC-CREAM) models from NPP at Abbasiyah, Abu Dalaf, Baiji and Mahzam nominated sites during normal operation.
3. To estimate the annual effective dose resulting from atmospheric and aquatic releases of radionuclides at nominated sites during normal operation, using GENII model.
4. To predict the human health impact and risks for different scenarios of hypothetical nuclear accidents at nominated sites using GENII and HYSPLIT models.
5. To create an appropriate emergency plan that ensures the mitigation of radiological impact from nuclear accidents, including preparednesses based on the prediction of atmospheric dispersion of radionuclides release during the accident using atmospheric dispersion models.

1.5 Scope of the study

This research studies the energy status of Iraq, particularly the electricity sector, and performs an estimation for future increment in demand for electricity by using LEAP model, including the environmental impact of current government plan for expanding the electricity production capacity. Study of different scenarios for growth

rate in both population and gross domestic product (GDP) is another scope of this study, including their impacts on the increase in the total energy demand in Iraq. Investigation and evaluation of availability and capability of other energy resources in Iraq and their potential on electricity generation are also the discussed in this research. This thesis will focus on the environmental impact of current energy technologies that are adopted by Iraqi government for electricity generation, including the future plan of Iraqi government for the extension of electricity generation capacity.

The mitigation impact of non-fossil fuel resources in electricity generation is one of the concern of this research. In order to avoid the disastrous effects of greenhouse-gas emission, which accompanies the consumption of fossil fuel, the use of nuclear power or renewable energy inclusion in any future extension plan for electricity generation sector have been examined in detail.

This research focus on the radiological and safety considerations for new power plant at four nominated sites in Iraq. Other factors and considerations that affect the site selection procedure for new nuclear power such as economic, social, political factors is excluded in the scope of this research.

Atmospheric dispersion of radioactive discharges from normal operation of potential nuclear power plants in terms of air concentration and ground deposition is another interest of this work. Different tools and models such as HYSPLIT, GENII and PC-CREAM have been utilized in order to obtain an accurate picture of atmospheric dispersion of radioactive discharges in terms of spatial distribution and quantitative values. This provides information on the health impact of these radioactive discharges to the population living around the nuclear power plants. This also provide information on the impact on atmospheric and aquatic environment.

This research is also involved in estimating the quantitative human health impact that is due to the normal operation of NPP at nominated sites. GENII model, which is certified and adopted by international institutions that are concerned with nuclear safety, has been used as a main tool to assess the health impacts of radioactive discharges to the atmosphere and aquatic environment.

Hypothetical scenarios of nuclear accident and their radiological impact are another concern of this research. Atmospheric dispersion models have been utilized to measure and indicate the spatial distribution of radioactive discharges to atmospheric environment. Assessment of radiological impact of hypothetical accident has been examined by this research, especially the region that are most susceptible to high levels of exposure doses. Emergency plan preparednesses have been proposed by this research to mitigate the radiological impacts. This was based on the atmospheric dispersion of radioactive discharges.

1.6 Significance of the research

The sharp increase in the demand for energy, especially electricity, makes the study and search for sustainable energy sources an urgent issue. This is to ensure sustainability, economic feasibility, as well as environmental sustainability. This research tries to obtain a clear picture of the energy situation, especially the electricity sector. It investigates the available potential from non-fossil and nuclear energy sources. The environmental impact of current energy policy in terms of GHG emission in ambient environment is studied. The future demand for energy has been predicted for next 30 years. The resultant impact of global warming potential was also investigated for Iraqi situation.

This research examined four nominated sites suggested by Iraqi Atomic Energy Council IAEC; Abu Daalaf, Abbasiyah, Baiji and Mahzam. Investigation were done in terms of atmospheric dispersion of radioactive discharges of NPP during normal operation. Suitable site for nuclear power plant construction has been chosen, to be more compatible with safety measures and regulations stipulated by ICRP recommendation and IAEA safety regulations.

This study also examines the impact of any hypothetical severe accident scenarios for nuclear power plant at two of the nominated sites, Abu Dalaf and Baiji. This is to figure out the expected radiological health impact upon human living around the nuclear power plant and surrounding areas. The atmospheric dispersion

models were used. Based on the estimated radiological impact, an emergency plan has been proposed to mitigate the accident impact upon population. The mitigation of an accident is depending on a proper emergency plan to handle the accident. This work provides the base line information that could be used for possible implementation and to scrutinize decisions by the Iraqi Atomic Energy Commission (IAEC) and Iraq government.

1.7 Thesis's organization

Chapter 1, gives detailed presentation of the electricity sector situation in Iraq. it also represents the electricity supply situation. The main objectives of this work are addressed in brief, followed by its signification and structure.

Chapter 2 represents the enormous natural sources of energy that are available in Iraq, including the possibility of exploiting this in diversification of energy sources. It also presents background and literature review about energy, nuclear energy, site selection for NPP according to international regularities, atmospheric dispersion models and health impact estimation of radioactive releases.

Chapter 3 presents the methodologies that were used to achieve the research objectives. A brief description of the tools that have been used to perform the tasks of this research, their configuration is also given.

Chapter 4 presents the results that were obtained for energy demand estimation and its environmental implications. Results of atmospheric dispersion for normal operation of nuclear power plants releases and its health impact were presented. Relevant discussions and analysis were presented.

Chapter 5 illustrates the results of atmospheric dispersion of accidental release at nominated sites. The results of radiological impact of hypothetical accident scenarios at two of the nominated sites were been presented in terms of annual effective

dose and cancer risks. Emergency planning zone has been determined based on the results of time series of spatial presentation of dispersed radioactive contaminants.

Finally, Chapter 6 draws the conclusions from the results, provides the the recommendations and future research suggestions.

REFERENCES

- Adalja, A. A., Sell, T. K., Ravi, S. J., Minton, K. and Morhard, R. (2015). Emergency preparedness in the 10-mile emergency planning zone surrounding nuclear power plants. *Journal of Homeland Security and Emergency Management*. 12(1), 81–100.
- Ahn, S. J., Ha, K.-S., Chang, W.-P., Kang, S. H., Lee, K. L., Choi, C.-W., Lee, S. W., Yoo, J., Jeong, J.-H. and Jeong, T. (2016). Evaluation of a Sodium–Water Reaction Event Caused by Steam Generator Tubes Break in the Prototype Generation IV Sodium-cooled Fast Reactor. *Nuclear Engineering and Technology*. 48(4), 952–964.
- Al-Chalaby, E. (2005). *Reading in: Iraq's oil industry and oil policy*. Technical Report 40. Iraq future. Retrievable at <http://www.iraqsnuclearmirage.com/articles/oil.html>.
- Al Hakeem, A. N. (2015). *Study in the Iraqi agriculture*. Adan Publisher, Baghdad.
- Al-Khalisi, E. (2014). *Manipulation and deception in management of Energy in Iraq*. Retrievable at <http://iraqieconomists.net/ar/2014/04/24/>.
- Al-Majid, A. (2013). *Laboratories and factories in Iraq waiting for rehabilitation*. Retrievable at http://www.gfiw.org/2013/08/blog-post_2893.htm.
- Al Qaisi, E. (2013). *(Az-Zaman) open the file of destruction of local industries after 11 years of change*. Retrievable at <http://www.azzaman.com/?p=6286>.
- Almomani, B., Lee, S., Jang, D. and Kang, H. G. (2017). Probabilistic risk assessment of aircraft impact on a spent nuclear fuel dry storage. *Nuclear Engineering and Design*. 311, 104–119.
- Alnasrawi, A. (2002). *Iraq's burdens: oil, sanctions, and underdevelopment*. Greenwood Pub Group, London.
- Alonso, A. (2012). *Infrastructure and methodologies for the justification of nuclear power programmes*. Elsevier, Cornwall.

- Andreeva, M., Pavlova, M. and Groudev, P. (2008). Overview of plant specific severe accident management strategies for Kozloduy nuclear power plant, WWER-1000/320. *Annals of Nuclear Energy*. 35(4), 555–564.
- Atomteploelekthroproekt (1985a). *Feasibility Study of Site Selection for Nuclear Power Plant Location in Iraq- Aerology Report*. All-Union State Institute an Research, Leningrad.
- Atomteploelekthroproekt (1985b). *Feasibility Study of Site Selection for Nuclear Power Plant Location in Iraq, Stage 1, Selection of Points*. All-Union State Institute an Research, Leningrad.
- Beresford, N., Fesenko, S., Konoplev, A., Skuterud, L., Smith, J. and Voigt, G. (2016). Thirty years after the Chernobyl accident: What lessons have we learnt? *Journal of Environmental Radioactivity*. 157, 77–89.
- BMI (2014). *Iraq Oil and Gas Report*. Business Monitor International, London.
- Bodansky, D. (2004). *Nuclear energy : principles, practices, and prospects*. Springer, Berlin.
- Bostan, G. A. V. D. V. S. I. B. V. S. A., I. (2012). *Resilient Energy Systems: Renewables: Wind, Solar, Hydro*. Springer, London.
- BP (2014). *Bp statistical review of world energy*. Retrievable at <http://www.bp.com/statisticalreview>.
- Chaichan, A. K. I., Miqdam Tariq (2012). Practical investigation for improving concentrating solar power stations efficiency in Iraqi weathers. *Anbar Journal for Engineering Sciences*. 5, 76–87.
- Chen, B., Stein, A. F., Maldonado, P. G., de la Campa, A. M. S., Gonzalez-Castanedo, Y., Castell, N. and Jesus, D. (2013). Size distribution and concentrations of heavy metals in atmospheric aerosols originating from industrial emissions as predicted by the HYSPLIT model. *Atmospheric Environment*. 71, 234–244.
- Chen, P.-Y., Chen, S.-T., Hsu, C.-S. and Chen, C.-C. (2016). Modeling the global relationships among economic growth, energy consumption and CO₂ emissions. *Renewable and Sustainable Energy Reviews*. 65, 420–431.
- Cimorelli, A., Perry, S., Venkatram, A., Weil, J., Paine, R., Wilson, R., Lee, R. and Peters, W. (2004). *AERMOD description of model formulation*. US Environmental

Protection Agency Rep.

- CSO (2007). *Water statistics in Iraq - Report submitted to the ESCWA Conference which was held in Cairo*. Retrievable at <http://www.cosit.gov.iq/ar/>.
- CSO (2011). *Population Status of Iraq-2010*. Retrievable at <http://www.cosit.gov.iq/en/>.
- CSO (2014). *Industry Sector Status in Iraq-2014*. Retrievable at <http://www.cosit.gov.iq/en/>.
- CSO (2016). *Economic Statistics of Iraq-2016*. Retrievable at <http://www.cosit.gov.iq/en/>.
- Darwish, A. and Sayigh, A. (1988). Wind energy potential in Iraq. *Journal of Wind Engineering and Industrial Aerodynamics*. 27(1-3), 179–189.
- Davis, P., Leclerc, E., Galeriu, D., Melintescu, A., Kashparov, V., Peterson, S., Ravi, P., Siclet, F. and Tamponnet, C. (2009). Specific activity models and parameter values for tritium, ¹⁴C and ³⁶Cl. *Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments*, 549.
- Dawisha, A. (2009). *Iraq, a political history from independent to occupation*. Princeton University Press, New Jersey.
- De Visscher, A. (2013). *Air dispersion modeling: foundations and applications*. John Wiley & Sons, Singapore.
- Delacroix, D., Guerre, J., Leblanc, P. and Hickman, C. (2002). Radionuclide and radiation protection data handbook 2002. *Radiation Protection Dosimetry*. 98(1), 1–168.
- Dessens, O., Anandarajah, G. and Gambhir, A. (2016). Limiting global warming to 2 C: What do the latest mitigation studies tell us about costs, technologies and other impacts? *Energy Strategy Reviews*. 13, 67–76.
- DeVaull, G. E., King, J. A., Lantzy, R. J. and Fontaine, D. J. (2010). *Understanding atmospheric dispersion of accidental releases*. vol. 14. John Wiley & Sons, Singapore.
- DoE (2011). *National Nuclear Regular Act, 1999 (ACT NO. 47 OF 1999)*. Retrievable at www.energy.gov.za/files/policies/act_nuclear_

47_1999.pdf.

- Draxler, R. R., Gillette, D. A., Kirkpatrick, J. S. and Heller, J. (2001). Estimating PM 10 air concentrations from dust storms in Iraq, Kuwait and Saudi Arabia. *Atmospheric Environment*. 35(25), 4315–4330.
- Draxler, R. R. and Hess, G. (1998). An overview of the HYSPLIT_4 modelling system for trajectories. *Australian Meteorological Magazine*. 47(4), 295–308.
- Draxler, R. R. and Hess, G. (2004). Description of the HYSPLIT 4 Modeling System. *NOAA Technical Memorandum ERL*.
- Duman, T., Katul, G. G., Siqueira, M. B. and Cassiani, M. (2014). A Velocity–Dissipation Lagrangian Stochastic Model for Turbulent Dispersion in Atmospheric Boundary-Layer and Canopy Flows. *Boundary-Layer Meteorology*. 152(1), 1–18.
- Elkmann, P. (2017). *Emergency Planning for Nuclear Power Plants*. CRC Press, New York.
- Elliott, D. (2007). *Nuclear or Not?* Palgrave Macmillan, London.
- EPA (1997). *EXPOSURE FACTORS HANDBOOK Update to Exposure Factors Handbook EPA/600/8-89/043 - May 1989*. Office of Research and Development National Center for Environmental Assessment U.S. Environmental Protection Agency Washington, DC.
- EPA, D., Washington (1989). *Risk Assessment Methodology - Environmental Impact Statement for NESHAPS Radionuclides*. EPA.
- Farmer, F. (1967). *Siting Criteria: A new approach*. Technical report. United Kingdom Atomic Energy Authority, Risley.
- GEOSURVIRAQ (2014). *Report about Floods in Iraq*. Retrievable at www.industry.gov.iq.
- Hamdan, S. S. (2014). Climatic elements available in Iraq and its potential in the production of alternative energy. *AL-Mostansiriyah Journal for Arab and International Studies*. 42, 147–176.
- Heaps, C. G. (2012). *Long-range Energy Alternatives Planning (LEAP) system*. Retrievable at www.energycommunity.org, [Software version 2014.0.1.14].

- Hodgson, P. E. (1999). *Nuclear power, energy and the environment*. World Scientific, London.
- Hodgson, P. E. (2010). *Energy, the environment and climate change*. World Scientific, London.
- Huang, Y., Bor, Y. J. and Peng, C.-Y. (2011). The long-term forecast of Taiwans energy supply and demand: LEAP model application. *Energy Policy*. 39(11), 6790–6803.
- Humam, A. and Alhijaj, A. (2009). *The strategy of the nuclear program in Iraq within the context of science and technology policies*. Center for Arab Studies, Beirut.
- Huo, H., Wang, M., Johnson, L. and He, D. (2007). Projection of Chinese motor vehicle growth, oil demand, and CO2 emissions through 2050. *Transportation Research Record: Journal of the Transportation Research Board*. (2038), 69–77.
- IAEA (1996). *Defence in Depth in Nuclear Safety, INSAG-10*. Retrievable at <http://www.iaea.org/books>.
- IAEA (1999). *Basic Safety Principles for Nuclear Power Plants, INSAG-12*. Retrievable at <http://www.iaea.org/books>.
- IAEA (2002). Accident analysis for nuclear power plants, Safety Reports Series No. 23.
- IAEA (2003). *Site evaluation for nuclear installations : safety requirements*. International Atomic Energy Agency, Vienna.
- IAEA (2006a). *Fundamental safety principles - IAEA Safety Standard Series No. SF-1*. International Atomic Energy Agency, Vienna.
- IAEA (2006b). *Fundamental Safety Principles, safety standards series No. SF-1*. Retrievable at <http://www.iaea.org/books>.
- IAEA (2007a). *IAEA Safety glossary terminology used in nuclear safety and radiation protection*. International Atomic Energy Agency, Vienna.
- IAEA (2007b). *Milestones in the Development of a National Infrastructure for Nuclear Power, Nuclear Energy Series No. NG-G-3.1*. Retrievable at <http://www.iaea.org/books>.
- IAEA (2008). Approaches and tools for severe accident analysis for nuclear power plants, Safety Reports Series No. 6.

- IAEA (2010). *Licensing Process for Nuclear Installations, Specific Safety Guide, No. SSG-12*. International Atomic Energy Agency, Vienna.
- IAEA (2011). *Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency No. GSG-2*. Retrievable at <http://www.iaea.org/books>.
- IAEA (2014). *Preparation of a feasibility study for new nuclear power projects, Nuclear Energy Series No. NG-T-3.3*. Retrievable at <http://www.iaea.org/books>.
- IAEA (2015). *Site Survey and Site Selection for Nuclear Installations*. International Atomic Energy Agency, Vienna.
- IAEA, INES and NEA (2008). *The international nuclear and radiological event scale user's manual*. Technical report.
- IAEC (1981). *Annual report 1981*. Retrievable at http://www.iraqwatch.org/government/Index_Iraq.htm.
- IAEC (1985). *Annual report 1985*. Retrievable at http://www.iraqwatch.org/government/Index_Iraq.htm.
- IAEC (1990). *Annual report 1990*. Retrievable at http://www.iraqwatch.org/government/Index_Iraq.htm.
- ICARDA (2010). *Meteorological map of Iraq*. Retrievable at <http://www.icarda.org/>.
- ICRP (1991). *ICRP Publication 60: 1990 Recommendations of the International Commission on Radiological Protection*. 60. Elsevier Health Sciences.
- ICRP (2007). Annals of the ICRP publication 103 -The 2007 Recommendations of the International Commission on Radiological Protection. *Ann. ICRP*. 37(2.4), 2.
- IEA (2012). *Iraq Energy Outlook*. International Energy Agency, Paris.
- Istepanian, H. H. (2014). Iraq's electricity crisis. *The Electricity Journal*. 27, 51–69.
- Jafar, D. J. and Al-Naemi, N. (2005). *Alaietiraf Alakhyr: Hqyqt albarnamaj alnnawawi aleiraqi*. Center for Arab Studies, Beirut.
- Jassim, S. Z. and Goff, J. C. (2006). *Geology of Iraq*. DOLIN, London.
- Kabanov, L. (1997). *The International Atomic Energy Agency's activities related to*

- safety approaches for the new generation of nuclear power plants*. Technical report. American Nuclear Society, Inc., La Grange Park, IL (United States).
- Karam, R. A. and Morgan, K. Z. (2013). *Environmental Impact of Nuclear Power Plants: Proceedings of a Conference Held November 26-30, 1974, Sponsored by the School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332 USA*. Elsevier, Berlin.
- Khadduri, I. Y. (2003). *Iraq's Nuclear Mirage: Memoirs and Delusions*. Arab Scientific Publishers, Beirut.
- Kok, K. D. (2009). *Nuclear engineering handbook*. CRC Press, New York.
- Kröger, W. (2006). Reflections on current and future nuclear safety. *ATW-International Journal for Nuclear Power*. 51, 331–337.
- Kubba, S. (2004). *Electric power in Iraq of the twentieth century*. Retrievable at <http://www.ahewar.org>.
- Kubba, S. I. (2007). *Sustainable development in modern Iraq*. Retrievable at <http://www.ahewar.org>.
- Kubba, S. I. (2013). *Electricity in Iraq between comprehensive national strategy and the white terrorism*. Retrievable at <http://www.ahewar.org>.
- Labib, A. (2014). *Learning from failures: decision analysis of major disasters*. Elsevier, Berlin.
- Lagzi, I., Meszaros, R., Gelybo, G. and Leelossy, A. (2014). Atmospheric chemistry.
- Lamarsh, B. A. J., J. R. (2001). *Introduction to nuclear engineering*. Prentice Hall, New Jersey.
- Lecomte, J. (2016). Understanding existing exposure situations. *Annals of the ICRP*. 45(1 suppl), 54–63.
- Lillington, J. N. (2004). *The future of nuclear power*. Elsevier, Paris.
- Lindell, M. K. (2000). An overview of protective action decision-making for a nuclear power plant emergency. *Journal of Hazardous Materials*. 75(2), 113–129.
- Marouf, B. (1992). Environmental radioactivity monitoring program in Iraq: Outlook and results. *International journal of environmental studies*. 41(1-2), 169–172.
- Marouf, B., Al-Kateeb, G. and Al-Ani, D. (1991a). Ranking of four potential nuclear

- power plant sites in Iraq according to the collective dose criterion. *Nuclear Safety*. 32(3).
- Marouf, B., Al-Kateeb, G., Al-Ani, D., Mohamad, A., Taha, J. and Mahmood, J. (1991b). Radiological studies of the Baije nuclear power plant potential site. *International Journal of Environmental Studies*. 39(1-2), 79–84.
- Marouf, B., Al-Khateeb, G., Al-Ani, D., Mohamad, A., Taha, J. and Mahmood, J. (1992). Radiological evaluation of Al-Mahzam nuclear power plant potential site. *International Journal of Environmental Studies*. 42(1), 11–16.
- Marouf, B., Mohamad, A. and Taha, J. (1993). Assessment of exposure rate and collective effective dose equivalent in the city of Baghdad due to natural gamma radiation. *Science of the Total Environment*. 133(1), 133–137.
- Marquina, A. (2010). Global warming and climate change. Prospects and policies in Asia and Europe.
- McMahon, C., Kelleher, K., McGinnity, P., Organo, C., Smith, K., Currivan, L. and Ryan, T. (2013). *Proposed nuclear power plants in the UK-potential radiological implications for Ireland*. Technical report.
- McPherson, M. and Karney, B. (2014). Long-term scenario alternatives and their implications: LEAP model application of Panama s electricity sector. *Energy Policy*. 68, 146–157.
- MoO (2014). *Annual Oil Report*. Retrievable at www.oil.gov.iq.
- Napier, B. A. (1999). GENII version 2 users guide.
- Napier, B. A. (2006). GENII version 2 users guide. *Pacific Northwest National Laboratory report PNNL-14583, Rev. 3*.
- Napier, B. A. (2011). GENII Version 2 Users Guide.
- NCRP (2009). *Ionizing Radiation Exposure of the Population of the United States: An Update*. NCRP Report No. 160. NCRP, New York.
- NRC, U. (2013). *State-of-the-Art Reactor Consequence Analyses Project Volume 2: Surry Integrated Analysis*. Technical report.
- Pan, L. J., Xie, Y. B. and Li, W. (2013). An analysis of emission reduction of chief air pollutants and greenhouse gases in Beijing based on the LEAP model. *Procedia*

Environmental Sciences. 18, 347–352.

- Peterson, J., MacDonell, M., Haroun, L., Monette, F., Hildebrand, R. D. and Taboas, A. (2007). Radiological and chemical fact sheets to support health risk analyses for contaminated areas. *Argonne National Laboratory Environmental Science Division*. 133.
- Qeral, C., Montero-Mayorga, J., Gonzalez-Cadelo, J. and Jimenez, G. (2015). AP1000® Large-Break LOCA BEPU analysis with TRACE code. *Annals of Nuclear Energy*. 85, 576–589.
- Reegle (2014). *Energy profile Iraq*. Retrievable at <http://www.reegle.info/countries/iraq-energy-profile/IQ>.
- Rogelj, J., McCollum, D. L., O'Neill, B. C. and Riahi, K. (2013). 2020 emissions levels required to limit warming to below 2 °C. *Nature Climate Change*. 3(4), 405–412.
- Roshan, A., Shylamoni, P. and Acharya, S. (2005). *Monograph on Siting of Nuclear Power Plants*. Atomic Agency Regulatory Board, India.
- Sadeghi, N. and Sadrnia, M. (2011). Cancer risk assessment for Tehran research reactor and radioisotope laboratory with CAP88-PC code (Gaussian plume model). *Nuclear Engineering and Design*. 241(5), 1795–1798.
- Sadri, A., Ardehali, M. and Amirnekooei, K. (2014). General procedure for long-term energy-environmental planning for transportation sector of developing countries with limited data based on LEAP (long-range energy alternative planning) and EnergyPLAN. *Energy*. 77, 831–843.
- Scholz, H. and Zucchetti, M. (1995). Comparative radiological assessment of SiCf/SiC composites as structural materials in nuclear fusion technology. *Fusion Engineering and Design*. 29, 219–224.
- Seitz, R., Rittmann, P., Cook, J. and Wood, M. (1994). *Benchmarking of computer codes and approaches for modeling exposure scenarios*. Technical report. DOE/LLW-188, Idaho National Engineering Laboratory, Idaho.
- Selbi, A.-C. Z. K. I. Y., D. (2011). *Untold Milestones in the Iraqi National Nuclear Program 1981-1991*. Arab Scientific Publishers, Beirut.
- Serp, J., Allibert, M., Beneš, O., Delpech, S., Feynberg, O., Ghetta, V., Heuer, D., Holcomb, D., Ignatiev, V., Kloosterman, J. L. *et al.* (2014). The molten salt reactor

- (MSR) in generation IV: overview and perspectives. *Progress in Nuclear Energy*. 77, 308–319.
- Shan, W., Yin, Y., Lu, H. and Liang, S. (2009). A meteorological analysis of ozone episodes using HYSPLIT model and surface data. *Atmospheric Research*. 93(4), 767–776.
- Shin, H.-C., Park, J.-W., Kim, H.-S. and Shin, E.-S. (2005). Environmental and economic assessment of landfill gas electricity generation in Korea using LEAP model. *Energy Policy*. 33(10), 1261–1270.
- Smith, J. and Simmonds, J. (2009). *The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the the Environment Used in PC-CREAM 08*. Health Protection Agency, London.
- Sohrabi, M., Parsouzi, Z., Amrollahi, R., Khamooshy, C. and Ghasemi, M. (2013). Public exposure from environmental release of radioactive material under normal operation of unit-1 Bushehr nuclear power plant. *Annals Of Nuclear Energy*. 55, 351–358.
- Song, H.-J., Lee, S., Maken, S., Ahn, S.-W., Park, J.-W., Min, B. and Koh, W. (2007). Environmental and economic assessment of the chemical absorption process in Korea using the LEAP model. *Energy Policy*. 35(10), 5109–5116.
- Su, L., Yuan, Z., Fung, J. C. and Lau, A. K. (2015). A comparison of HYSPLIT backward trajectories generated from two GDAS datasets. *Science of The Total Environment*. 506, 527–537.
- Till, J. E. and Grogan, H. A. (2008). *Radiological risk assessment and environmental analysis*. Oxford University Press, Oxford.
- Turner, D. B. (1994). *Workbook of atmospheric dispersion estimates: an introduction to dispersion modeling*. CRC press, New York.
- UNEP (2014). *UNEP Year Book 2014: Emerging Issues in Our Global Environment*. UNEP, Nairobi.
- UNSCEAR (2014). Sources, effects and risks of ionizing radiation.
- Uqaili, T. (2013). *The integrated national energy strategy of Iraq (2010-2030), analysis of the executive summary*. Retrieval at <http://iraqieconomists.net/eng/>.

- Valentin, J. *et al.* (2007). *The 2007 recommendations of the international commission on radiological protection*. Elsevier Oxford, UK.
- Vierow, K., Hogan, K., Metzroth, K. and Aldemir, T. (2014). Application of dynamic probabilistic risk assessment techniques for uncertainty quantification in generation IV reactors. *Progress in Nuclear Energy*. 77, 320–328.
- Wang, Y., Stein, A. F., Draxler, R. R., Jesús, D. and Zhang, X. (2011). Global sand and dust storms in 2008: Observation and HYSPLIT model verification. *Atmospheric Environment*. 45(35), 6368–6381.
- Westinghouse (2011). *AP1000 Overview*.
- World Bank (1952). *The economic developments in Iraq economy*. World Bank, Washington.
- World Bank (1963). *Current economic position prospects of Iraq*. World Bank, Washington.
- World Bank (1971). *Current economic position and prospects of Iraq*. World Bank, Washington.
- Wrixon, A. D. (2008). New ICRP recommendations. *Journal of Radiological Protection*. 28(2), 161. Retrievable at <http://stacks.iop.org/0952-4746/28/i=2/a=R02>.
- Xu, X. G. and Eckerman, K. F. (2009). *Handbook of anatomical models for radiation dosimetry*. Taylor & Francis, London.
- Yee, A. (2010). *Iraq to build four power plants*. Retrievable at <http://www.thenational.ae/business/energy/iraq-to-build-four-power-plants>.
- Zaini, M. A. (2011). *Economic road map*. Retrievable at <http://iraqieconomists.net/arabic/>.
- Zali, A., Zafarghandi, M. S., Feghhi, S. and Taherian, A. (2017). Public member dose assessment of Bushehr Nuclear Power Plant under normal operation by modeling the fallout from stack using the HYSPLIT atmospheric dispersion model. *Journal of Environmental Radioactivity*. 171, 1–8.