Ain Shams University
Faculty of science
Physics Department

Study on Neutronics of Minor Actinides Transmutation in Accelerator Driven System Reactor

A Thesis Submitted for the Degree of Ph.D of Science

In Nuclear Physics

To
Physics Department, Faculty of Science, Ain Shams University

By

Amer Ahmed Abdullah Al Qaaod

M. Sc. In Physics, Helwan University, 2012

2015

Ain Shams University
Faculty of science
Physics Department

Study on Neutronics of Minor Actinides Transmutation in Accelerator Driven System Reactor

A Thesis Submitted for the Degree of Ph.D of Science
In Nuclear Physics

To
Physics Department, Faculty of Science, Ain Shams University

By

Amer Ahmed Abdullah Al Qaaod
M. Sc. In Physics, Helwan University, 2012

Supervised by

Prof. Dr. Samir Yousha El-Khamisy
Professor of Nuclear Physics, Physics Department, Faculty of Science, Ain Shams University, Cairo

Prof. Dr. Esmat Hanem Amin
Professor of Reactor Safety Engineering, Nuclear safety and Radiological Authority

Dr. Hesham Ibrahim Shahbunder
Lecturer of Nuclear Engineering, Physics Department, Faculty of Science, Ain Shams University, Cairo

Dr. Ashraf Hamed Mohamed
Assistant Professor, Hot Laboratories Center, Egyptian Atomic Energy Authority

Dr. Riham Mahmoud Refeat Sherief
Lecturer of Nuclear Safety Engineering Dept.
Nuclear and Radiological Regulatory Authority

2015

To my mother and Soul of my father

Words cannot express how grateful I am to my mother and father. My Parents, whose has been a source of sympathy, and for their continuous encouragement and inspiration to me. This work is the result supplication

To my brothers who supported me at the beginning of Education

To my wife who stood long by my side until my success saw the light

To my beloved daughters Doa'a and Jana, the smiles and flowers that were born in my life.

To all who helped me and wished me good luck

ACKNOWLEDGEMENTS

First and foremost praising to my god, Allah who led me through this work sustains me with the power and will to do this work.

I would like to express my deep gratitude to ***Prof. Samir El-Khamisy*** *for his supervision, guidance and continuous support to me, during the study period and his handling upscale and humble, which had a major impact in the completion of this work.*

I am profoundly grateful to ***Prof. Esmat Amin*** *for suggesting this work, and for her help to overcome all the difficulties and obstacles that I faced during the work.*

I would like to express my deep gratitude to ***Dr. Hesham Shahbunder*** *for her supervision, great efforts, fruitful discussions, and continuous help during the preparation of this thesis*

My very deep gratitude goes to ***Prof.Dr. Salah Yaseen El-Bakry****, chairman of the physics department, for his interest, fruitful comments, support and encouragement.*

CONTENTS

CONTENTS ..... **III**

LIST OF FIGURES ..... **VI**

LIST OF TABLES ..... **IX**

ABSTRACT ..... **X**

SUMMARY ..... **XII**

CHAPTER 1. INTRODUCTION AND OVERVIEW **1**

1.1 Background 1

1.2 Different Transmutation of Waste Strategies 6

1.3 The ADS Concept 11

1.4 The Spallation Target 13

1.5 Electron ADS Preliminary Design 15

1.5.1 Bremsstrahlung physics 15

1.5.2 Electron-based ADS concept 18

1.6 Literature Survey 20

1.6.1 General review of ADS projects 20

1.6.2 ADS related target properties 22

1.6.3 ADS related accelerator beam type 23

1.6.4 Review of ADS applications 24

1.7 Aim of the Present Work 25

CHAPTER 2. NEUTRON TRANSPORT THEORY **27**

2.1 Introdution 27

2.2 Criticality 29

2.3 Theoretical Basis of Subcritical Multiplication Parameters 29

2.3.1 Effective multiplication factor 31

2.3.2 Subcritical multiplication factor 32

2.3.3 Relation between k_s and k_{eff} in subcritical system 34

2.3.4 Neutron multiplication and external source efficiency 37

2.4 The Depletion Equation 38

CHAPTER 3. CALCULATION METHOD AND MODEL 42

3.1 Introduction 42

3.2 Monte Carlo Method 42

3.2.1 Monte Carlo N-particle Transport Code (MCNP) 44

3.2.2 MCNPX 44

3.2.3 Monte carlo continuous energy burnup code (MCB) 47

3.2.4 Nuclear Data Libraries 48

3.3 Core Descriptions and Modeling 49

3.3.1 TRIGA Mark II reactor 49

3.3.2 Linear electron accelerator (Linac) installation 54

3.3.3 Operation of an electron linac 54

3.3.4 MCNP parameter optimization 56

CHAPTER 4. RESULTS AND DISCUSSIONS 58

4.1 Introduction 58

4.2 Target Optimization and Investigation of Subcritical Multiplication Parameters 59

4.2.1 Model validation 59

4.2.2 Target optimization 59

4.2.3 Numerical calculations of k_s and φ^* 62

4.3 Multiplication and Beam Type Characteristics With Pu and MA in Heterogeneous and Homogenous Distribution 68

4.3.1. Neutron flux distribution and spectrum 70

4.3.2 Beam type and energy 74

4.4 Plutonium and Minor Actinides Transmutation 78

CHAPTER 5. CONCLUSION AND FUTURE WORK 88

REFERENCES 92

APPENDIX: MCNPX INPUT FILE i

LIST OF PUBLICATIONS I

LIST OF FIGURES

LIST OF FIGURES

Fig. 1.1: Composition of spent nuclear fuel……... 2
Fig. 1.2: Estimated inventory of minor actinides worldwide……. 3
Fig. 1.3: Heat generation rate in LWR spent fuel irradiated to 50 GW•d/t……. 5
Fig. 1.4: The impact of removing transuranic on ingestion radiotoxicity of spent fuel…… 6
Fig. 1.5: Different fuel cycle strategies. Percentage in parentheses indicates the fraction of a nuclear power park corresponding to ADS……. 9
Fig. 1.6: Concept of an accelerator-driven system……. 12
Fig. 1.7: The different stages of the spallation process…… 14
Fig. 1.8: Electromagnetic Cascade……. 16
Fig. 1.9: Layout of High-Energy Electron Induced Neutron Fission by PNNL…….. 19
Fig. 3.1: A flow sheet of nuclear data treatment, finally applied by a simulation tool such as MCNP……. 43
Fig. 3.2: UT- TRIGA reactor under operation and cross sectional core layout……... 50
Fig. 3.3: A schematic view of the fuel rod in TRIGA core…… 51
Fig. 3.4: MCNPX model of UT-TRIGA Mark II configuration…… 53
Fig. 3.5: 3-D view of UT-RACE linac……... 55
Fig. 3.6: View of the design MCNP geometry for target with cooling jacket……... 57
Fig. 4.1: Effective multiplication factor versus control rod position.. 60
Fig. 4.2: Source neutrons versus target radius for W, Pb, and W-Cu materials……... 60
Fig. 4.3: Source neutrons versus electron beam energy for W, Pb, and W-Cu targets……. 61
Fig. 4.4: Comparison between calculated neutron spectra for W, Pb, and W-Cu targets……... 62
Fig. 4.5: Top view of the MCNPX model of TRIGA reactor with accelerator source target at the center……. 63
Fig. 4.6: Top view of the MCNPX model of TRIGA reactor with accelerator source target in beam port #5…… 64
Fig. 4.7: Top view of the MCNPX model of TRIGA reactor with accelerator source target in beam port #3…… 64
Fig. 4.8: Schematic view of the horizontal cross section of the TRIGA MARK II core in heterogeneous configurations… 69
Fig. 4.9: Schematic view of the horizontal cross section of the TRIGA MARK II core in homogenous configurations… 69