



**Ain Shams University**  
**Faculty of Science**

# **DEVELOPMENT OF NUCLEAR TECHNIQUES FOR LANDMINE DETECTION AND ILLICIT MATERIALS**

**Thesis**

**In Partial Fulfillment of the Requirements of the  
Degree of Ph.D. in Physics**

**BY**

**AHMED MAHMOUD OSMAN ABDOH**

**Under Supervision of**

**Prof. Dr. Samir Usha El-Kameesy**  
**Faculty of Science, Ain Shams University**

**Prof. Dr. Riad Mostafa Megahid**  
**Nuclear Research Centre, Atomic Energy Authority**

**Dr. Salh Mohammed Metwally**  
**Faculty of Science, Ain Shams University**

**Dr. Wagdy Ahmed Kansouh**  
**Nuclear Research Centre, Atomic Energy Authority**

**Physics Department,**  
**Faculty of Science**  
**Ain Shams University**  
**Cairo, Egypt**

**2009**

## **APPROVAL SHEET**

**Title of the Ph.D. Thesis**

### **DEVELOPMENT OF NUCLEAR TECHNIQUES FOR LANDMINE DETECTION AND ILLICIT MATERIALS**

**Name of the candidate**

***AHMED MAHMOUD OSMAN ABDOH***

**Supervisors:**

**(signature)**

**Prof. Dr. Samir Usha El-Kameesy**  
Faculty of Science,  
Ain Shams University

**(.....)**

**Prof. Dr. Riad Mostafa Megahid**  
Nuclear Research Centre,  
Atomic Energy Authority

**(.....)**

**Dr. Salh Mohammed Metwally**  
Faculty of Science,  
Ain Shams University

**(.....)**

**Dr. Wagdy Ahmed Kansouh**  
Nuclear Research Centre,  
Atomic Energy Authority

**(.....)**



**Ain Shams University**  
**Faculty of Science**

***Name:*** Ahmed Mahmoud Osman Abdoh

***Degree:*** Ph.D.

***Department:*** Physics

***Faculty:*** Science

***University:*** Ain Shams

***Graduation Date:*** 2001-El-Azhar university

***Registration Date:*** 15/1/2007

***Grant Date:*** 2009

## *Dedication*

*This work is gratefully dedicated to*

*My Father*

*My Mother*

*My wife*

*My Son*

*My Daughter*

*Author*

*Ahmed Mahmoud Osman*

## **Table of Contents**

Acknowledgment	
Table of Contents.....	I
List of Figures.....	V
List of Tables.....	XIV
List of Publications.....	XV
List of Abbreviations.....	XVI
Abstract.....	XVII

### **Chapter One**

#### **General Introduction**

General Introduction.....	1
---------------------------	---

### **Chapter Two**

#### **Current Technologies for Demining and Detection of illicit materials**

2.1. Introduction .....	16
2.2. History of Landmines .....	16
2.3. Review of Technologies for Landmines/Illicit materials Detection.....	18
2.3.1. Conventional Techniques.....	19
A. Prodders and Probes.....	19
B. Metal Detectors (MDs).....	20
C. Mine Clearing Machines.....	21
2.3.1.1. Limitations of the Conventional Techniques.....	22
2.3.2. Innovative Techniques.....	22
2.3.2.1. Innovative Electromagnetic Detection Method.....	23
a. Ground Penetrating Radar (GPR).....	23
b. Magnetic Sensors.....	25
c. Electrical Impedance Tomography.....	26
2.3.2.2. Infrared/Hyperspectral Systems.....	28
2.3.2.3. Innovative Acoustic/Seismic Detection Methods.....	29
2.3.2.4. Innovative Vapor Detection Methods.....	31
A. Biological Methods.....	31
B. Chemical Methods.....	37
C.	

## **Chapter Three**

### **Nuclear Technologies for Detection of Landmine and Illicit materials**

3.1.	Introduction.....	40
3.2.	Explosive Materials.....	40
3.2.1.	Types of Explosives.....	42
3.3.	Nuclear Techniques for explosive and Illicit Materials Detection.....	44
3.3.1.	Nuclear Techniques Based on Density variation.....	45
3.3.1.1.	X-ray Imaging Technique.....	45
3.3.1.2.	Gamma-ray Imaging Technique.....	46
3.3.2.	Nuclear techniques based on nitrogen density variation.....	47
3.3.2.1.	Positron Emission Tomography (PET).....	47
3.3.2.2.	Thermal Neutron Activation Analysis (TNA).....	48
3.3.2.3.	Nuclear Quadruple Resonance (NQR).....	50
3.3.3.	Nuclear Techniques Based on Hydrogen Density Variation.....	53
3.3.3.1.	Thermal Neutron Backscattering Technique.....	53
3.3.3.2.	Fast Neutron Backscattering Technique.....	55
3.3.4.	Nuclear techniques based on analysis of material whole elements.....	55
3.3.4.1.	Fast Neutron Activation Analysis (FNA).....	56
3.3.4.2.	Fast Neutron Scattering Analysis (FNSA).....	56
3.3.4.3.	Pulsed F/T Neutron Activation analysis (PFTNA).....	58
3.3.4.4.	Pulsed fast neutron transmission spectroscopy (PFNTS).....	59
3.3.4.5.	Associated Particle Technique.....	61
3.3.4.6.	Fast Neutron Resonance Radiography (FNRR).....	62

## **Chapter Four**

### **Installed Combined Systems and Measuring Procedures**

4.1.	Introduction.....	66
4.2.	Egypt SCAnning LAndmine Detector ESCALAD.....	66
4.2.1.	Neutron Backscattering Device.....	66
A.	NBS Detectors.....	67
B.	Neutron sources.....	68
C.	Neutron Scatterers and Reflectors.....	69
D.	Measuring Electronics.....	70
E.	Trolley.....	72
4.2.1.1.	Measuring procedures.....	72
4.2.1.2.	Performance Measurements.....	75

A. Energy spectra.....	75
B. Position distribution.....	75
C. Gamma-Ray Discrimination.....	76
4.2.1.3. Optimization of Neutron Sources Geometry.....	79
4.2.1.4. ESCALAD Workability.....	81
4.2.1.5. Test Site.....	81
4.2.2. Elemental Analysis Device.....	83
4.2.2.1. Spectrometer Characterize.....	84
4.2.2.2. Experimental Arrangement.....	86
4.2.2.3. Measuring Procedures.....	86
4.2.3. Examined Landmines and other suspected objects.....	87
4.3. Inspection System for Explosives and Illicit Material.....	88
4.3.1. Mechanical system.....	88
4.3.2. Radiation sources.....	90
4.3.3. Measuring instruments.....	90
4.3.4. Data processing and analysis.....	91
4.3.5. Examined Explosive and other suspected objects.....	92

## Chapter Five

### Results and Discussion

5.1. Detection of Landmines.....	94
5.1.1. Neutron Backscattering by NBS Device.....	94
5.1.1.1. Effect of Neutron Sources Geometry.....	95
A. System Reliability.....	99
B. Dependence on side distance.....	101
C. Effect of sources separating distances.....	104
5.1.1.2. System Workability.....	108
I. Maximum Detection Depth.....	114
II. Maximum Stand-off Distance.....	117
III. Scanning Width.....	121
IV. Surface Roughness.....	125
V. Result Obtained by Combined Detection System.....	130
5.1.2. Results Obtained by Elemental Analysis device.....	132
5.1.2.1. Plain Soil.....	132
5.1.2.2. Gamma ray Spectra for APM.....	133
5.1.2.3. Gamma ray Spectra for ATM.....	136
5.1.2.4. Gamma-ray Spectra for Other Objects.....	138

5.2.	Detection of Illicit Materials.....	141
5.2.1.	Gamma-ray Scanner Technique.....	141
5.2.2.	Neutron Identifier Technique.....	143

## **Chapter Six**

### **Conclusions and Recommendations**

Conclusions and Recommendations.....	152
--------------------------------------	-----

## **Appendices**

Appendix - 1.....	159
Appendix - 2 .....	162
Appendix - 3.....	197
Appendix - 4.....	210
Appendix - 5.....	213

References.....	214
-----------------	-----

Arabic Summery

## **List of Figures**

<b>2.1.</b>	Sectioned diagram of a PMN mine	18
<b>2.2.</b>	Section of an anti-tank mine	18
<b>2.3.</b>	Fully man point stick method for detection of landmine	19
<b>2.4.</b>	Typical construction of metal detector	20
<b>2.5.</b>	Panther armoured mine clearing vehicle	21
<b>2.6.</b>	Ground Penetrating Radar at work	24
<b>2.7.</b>	The Electrical Impedance Tomography EIT detector prototype	27
<b>2.8.</b>	Infrared Imaging in action	28
<b>2.9.</b>	A conceptual design of a robotic acoustic land-mine detection system	30
<b>2.10.</b>	Mine Detecting Dog and Rat in use	31
<b>2.11.</b>	Illustration of a tagged bee.	34
<b>2.12.</b>	Bacterial biosensors for mine detection.	36
<b>2.13.</b>	Fluorescent polymer sensors.	37
<b>3.1.</b>	Over-view of some common explosive structures.	42
<b>3.2.</b>	Decay scheme and branching ratios for thermal radiative capture for $^{15}\text{N}$ .	49
<b>3.3.</b>	Schematic diagram shows the principle of the NQR system.	50
<b>3.4.</b>	Neutron scattering angle for various elements.	57
<b>3.5.</b>	Schematic illustration of the FNSA detection setup.	58
<b>3.6.</b>	DT Pulsed neutron generator and its time sequence.	59
<b>3.7a)</b>	Schematic description of the PFNTS method.	60

<b>3.7b)</b>	The total cross sections of C, N, O, and H.	60
<b>3.8.</b>	Neutron yield spectrum at different deuteron energies for the Be(d,n) reaction.	60
<b>3.9.</b>	Schematic diagram of the tagged neutron production and the nuclear reaction initiated by fast neutrons.	61
<b>3.10.</b>	Schematic diagram of Associated Particle Technique using salad tube neutron generator.	62
<b>3.11.</b>	Total neutron cross-section for Carbon.	63
<b>3.12.</b>	D-D Neutron energy emission angle.	64
<b>3.13.</b>	Rotational Geometry.	64
<b>4.1.</b>	Schematic diagram for NBS detector array while scanning over a landmine.	67
<b>4.2.</b>	Measured neutron spectrum from $^{252}\text{Cf}$ source.	69
<b>4.3.</b>	Measured neutron spectrum from Pu- $\alpha$ -Be source.	69
<b>4.4.</b>	Overview of two different types fast neutron scatterers.	70
<b>4.5.</b>	Overview of neutron reflector.	70
<b>4.6.</b>	Schematic diagram for the ESCALAD system.	71
<b>4.7.</b>	Photographs of ESCALAD system arrangement.	72
<b>4.8.a)</b>	Pulse height spectra from all neutron detectors (16- $^3\text{He}$ -tubes) in ESCALAD system.	75
<b>4.8.b)</b>	Expected pulse height spectrum from a $^3\text{He}$ tube.	75
<b>4.9.</b>	Position distribution of the measured backscattered thermal neutrons from Pu- $\alpha$ -Be neutron source placed at the center.	76
<b>4.10.</b>	Position distribution of the measured backscattered thermal neutrons from two Pu- $\alpha$ -Be neutron sources placed at the center.	76
<b>4.11.</b>	Counting curves for ESCALAD detectors generated by	77

varying electronic threshold under constant source conditions.

<b>4.12.</b>	The pulse height spectra for Pu- $\alpha$ -Be neutron source measured by ESCALAD detectors with different electronic threshold for gamma ray discrimination.	78
<b>4.13.</b>	The geometry of the selected section on the detector tray with one Pu- $\alpha$ -Be source fixed at the center.	80
<b>4.14.</b>	The geometry of the selected section on the detector tray with two Pu- $\alpha$ -Be sources fixed at different apart distances.	80
<b>4.15.</b>	Impressions from (a) Our test area and the soil surface. (b) Ground structure in Alamein area.	82
<b>4.16.</b>	Overview of detection system: NaI(Tl) detector, pulse processing, and measuring PC.	84
<b>4.17.</b>	An example of a linear-scale spectrum for $^{137}\text{Cs}$ and $^{60}\text{Co}$ gamma sources.	85
<b>4.18.</b>	Energy calibration curve of the gamma ray spectrometer.	85
<b>4.19.</b>	Experimental arrangement for (n, $\gamma$ ) technique.	86
<b>4.20.</b>	Photographs of the combined systems.	88
<b>4.21.</b>	Schematic diagram of the gamma scanner and associated radiation measuring systems.	89
<b>5.1.</b>	Constructed 2D-image of fast neutrons flux distribution along the tube axis from a single Pu- $\alpha$ -Be source.	96
<b>5.2.</b>	Spatial distributions and reconstructed 2D-images of backscattered thermal neutron flux from one Pu- $\alpha$ -Be source placed at the center.	96
<b>5.3.</b>	Spatial distributions and reconstructed 2D-images of backscattered thermal neutron flux from one Pu- $\alpha$ -Be source placed at the center with cylindrical scatterer placed underneath the source.	97

<b>5.4.</b>	Spatial distributions and reconstructed 2D-images of backscattered thermal neutron flux from one Pu- $\alpha$ -Be source placed at the center with pyramid-like shape scatterer placed underneath the source.	97
<b>5.5.</b>	Constructed 2D-image of fast neutron flux distributions along the tube axis from two Pu- $\alpha$ -Be neutron sources.	98
<b>5.6.</b>	Spatial distributions and reconstructed 2D-images of backscattered thermal neutron flux from two Pu- $\alpha$ -Be sources placed at the center.	98
<b>5.7.</b>	Spatial distributions and reconstructed 2D-images of backscattered thermal neutron flux from two Pu- $\alpha$ -Be sources placed at the center with cylindrical scatterer placed underneath the source.	99
<b>5.8.</b>	Spatial distributions and reconstructed 2D-images of backscattered thermal neutron flux from two Pu- $\alpha$ -Be sources placed at the center with pyramid-like shape scatterer placed underneath the source.	99
<b>5.9.</b>	Object with 166.7 hydrogen content/g.	100
<b>5.10.</b>	Object with 111.13 hydrogen content/g.	100
<b>5.11.</b>	Object with 59.28 hydrogen content/g.	101
<b>5.12.</b>	The mine was buried at side distance = zero cm.	102
<b>5.13.</b>	The mine was buried at side distance = 10 cm.	102
<b>5.14.</b>	The mine was buried at side distance = 15 cm.	103
<b>5.15.</b>	The mine was buried at side distance = 20 cm.	103
<b>5.16.</b>	Constructed 2D-image of fast neutron fluxes distributions along the tube axis with two neutron sources placed at 40 cm.	104

<b>5.17.</b>	Spatial distribution and reconstructed 2D-images of backscattered thermal neutrons with two neutron sources placed at 40 cm apart with pyramid-like shape scatterer placed underneath the source.	105
<b>5.18.</b>	Constructed 2D-image of fast neutron fluxes distributions along the tube axis from two neutron sources placed at 50 cm apart.	106
<b>5.19.</b>	Spatial distributions and reconstructed 2D-images of backscattered thermal neutrons from two sources placed at 50 cm apart with pyramid like shape scatterer placed underneath the source.	106
<b>5.20.</b>	Constructed 2D-image of fast neutron fluxes distributions along the tube axis from two sources placed at 60 cm apart.	107
<b>5.21.</b>	Spatial distribution and reconstructed 2D-images of backscattered thermal neutron fluxes from sources placed at 60 cm apart with pyramid like shape scatterer placed underneath the source.	107
<b>5.22.</b>	Reconstructed 2D-images of backscattered thermal neutron fluxes from sources placed at 60 cm apart with pyramid-like shape scatterer and with neutron reflector.	108
<b>5.23.</b>	Scanning speed = 30 mm/s. The measured mine position was approximately 200 cm.	109
<b>5.24.</b>	Scanning speed = 60 mm/s. The measured mine position was approximately 200 cm.	109
<b>5.25.</b>	Scanning speed = 130 mm/s. The measured mine position was approximately 200 cm.	110
<b>5.26.</b>	Scanning speed = 200 mm/s. The measured mine position was approximately 200 cm.	110

<b>5.26.</b>	Scanning speed = 290 mm/s. The measured mine position was approximately 220 cm.	111
<b>5.28.</b>	Scanning speed = 30 mm/s. The measured mine position was approximately 140 cm.	112
<b>5.29.</b>	Scanning speed = 60 mm/s. The measured mine position was approximately 200 cm.	112
<b>5.30.</b>	Scanning speed = 130 mm/s. The measured mine position was approximately 220 cm.	113
<b>5.31.</b>	Scanning speed = 200 mm/s. The measured mine position was approximately 230 cm.	113
<b>5.31.</b>	The measured mines signals buried at 2 cm depth at different scanning speed.	114
<b>5.33.</b>	APM type-VS50 with 50 g explosive buried at 10 cm depth.	115
<b>5.34.</b>	APM type-PMN with 150 g explosive buried at 20 cm depth.	115
<b>5.35.</b>	ATM type- T-80 with 2.5 kg buried at 30 cm depth.	116
<b>5.36.</b>	ATM type- T-71 with 6 kg buried at 30 cm depth.	116
<b>5.37.</b>	APMR scanned at stand-off = 5 cm.	117
<b>5.38.</b>	APMR scanned at stand-off = 10 cm.	118
<b>5.39.</b>	APMR scanned at stand-off = 20 cm.	118
<b>5.40.</b>	ATM type T-80 scanned at stand-off = 5 cm.	119
<b>5.41.</b>	ATM type T-80 scanned at stand-off = 10 cm.	120
<b>5.42.</b>	ATM type T-80 scanned at stand-off = 22 cm.	120
<b>5.43.</b>	The mine was buried at zero side distance. The measured mine position was approximately 200 cm.	121

<b>5.44.</b>	The mine was buried at 20 cm side distance. The measured mine position was approximately 200 cm.	122
<b>5.45.</b>	The mine was buried at 35 cm side distance. The measured mine position was approximately 200 cm.	122
<b>5.46.</b>	The mine was buried at 50 cm side distance. The measured mine position was approximately 200 cm.	123
<b>5.47.</b>	Side distance 15 cm and platform at the center. The measured mine position was approximately 130 cm.	124
<b>5.48.</b>	Side distance 15 cm with the platform shifted by 10 cm. The measured mine position was approximately 200 cm.	124
<b>5.49.</b>	Scan over normal background with a scan speed = 100 mm/s.	125
<b>5.50.</b>	Scan over 10 cm deep hollow with a scan speed = 100 mm/s.	126
<b>5.51.</b>	Scan over APM buried at the bottom of 10 cm deep hollow with a scan speed = 100 mm/s.	126
<b>5.52.</b>	Scan over APM buried at 10 cm below the bottom of 10 cm deep hollow with a scan speed = 100 mm/s.	127
<b>5.53.</b>	Scan over APM buried at 15 cm below the bottom of 10 cm deep hollow with a scan speed = 100 mm/s.	127
<b>5.54.</b>	Scan over 5 cm high sand heap with a scan speed = 100 mm/s.	128
<b>5.55.</b>	Scan over 10 cm high sand heap with a scan speed = 100 mm/s.	129
<b>5.56.</b>	Scan over 15 cm high sand heap with a scan speed = 100 mm/s.	129
<b>5.57.</b>	Scan over APM buried at the bottom of 15 cm high sand heap with a scan speed = 100 mm/s.	130
<b>5.58.</b>	Two ATMs buried at 20 cm depth. The measured mine positions were approximately 150 and 260 cm.	131