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Edward C. Morse

Analytical Methods for Nonproliferation

Springer

Edward C. Morse
Department of Nuclear Engineering
University of California, Berkeley
Berkeley, CA
USA

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To my father, Robert A. Morse

Preface

This book has its roots in a course that was taught at Lawrence Livermore National Laboratory in the summer of 2005 entitled "Analytic Methods for Nonproliferation." This course was an intensive two-week experience for 22 graduate students from around the United States, with two foreign nationals included. The instruction was shared among 36 people, with three Berkeley faculty (Michael Nacht, Stan Prussin, and me), and 33 LLNL scientists. It was an impressive tour de force of scientific knowledge and technical capability in the area of nonproliferation and arms control. The Berkeley students followed up with another week on the Berkeley campus (a required element for them to get course credit through the university), which allowed a more "hands-on" approach to detection experiments, but without large quantities of weapons-grade material available. While at first it was thought that we would hold this class at Livermore in subsequent summer sessions, the tremendous amount of time, effort, and money required resulted in this being a one-off experience. It became clear that there was a need for this type of education on the Berkeley campus in a regular semester-long course. This resulted in a course at Berkeley with the same title as this book, which has now been taught in each of the 10 years since the 2005 course at Livermore. It became clear that the course needed a textbook, and this book is the result.

The level of this book assumes knowledge of some concepts of basic nuclear engineering, such as the cross-section concept and alpha, beta, and gamma decay. While some background on gamma and neutron transport is provided here, it is done so only to show some of the simplified forms of these mathematically rich subjects, which can lead to approximations that can be used to evaluate detection schemes in applications relevant to nonproliferation, arms control, and treaty verification. Thus the book is not intended as a replacement for standard textbooks such as Lamarsh (for neutron transport and reactor theory) and Knoll (for detector physics). The exercises in the book are best carried out with a mathematical processing language such as Mathematica or Matlab.

This book should be accessible to advanced undergraduates as well as graduate students in nuclear engineering or applied physics. There is a good bit of material

outside the normal exposure that students in these disciplines have, such as seismology, chemical engineering, and materials processing techniques. Again, this book is not intended to be a substitute for stand-alone courses in these areas. Also, the chapter on public policy is not a replacement for a well-rounded education in this field, but rather to help a reader with an engineering or science background understand how the organizations responsible for global nuclear security fit together, and perhaps help potential job seekers understand what is out there.

I have many people to thank in the preparation of this manuscript. First, I would like to thank the 10 year's worth of graduate and undergraduate students who have helped shape the contents of this book through their input as students exposed to most of this material in the graduate and undergraduate courses in this area at Berkeley. I would also like to thank some experts in the fields covered in this book who have given certain chapters a critical review. These include Mike Moran "Nuclear Explosives" and "Nuclear Testing," Rhonda Righter "Detection Statistics," Joon-Hong Ahn "The Nuclear Fuel Cycle," and Dennis Slaughter "Active Interrogation." I am grateful for the conversation with Siegfried Hecker regarding the plutonium metallurgy material in "Nuclear Forensics". Also, I am grateful for the data and insight from Rick Norman and for the data from Ryan Pavlovsky.

I am grateful for careful editing of the manuscript by Lisa Zemelman and for encouragement and moral support from many friends, especially Wendy Reid.

Berkeley, CA, USA Edward C. Morse
December 2015

Contents

Acronyms

ARIX	(Russian) Radio-xenon measurement device
AUC	Area Under Curve: metric for ROC performance
AVLIS	Atomic Vapor Laser Isotope Separation
CANDU	CANada Deuterium Uranium: heavy water reactor
CEC	Center for Export Controls
CITS	Center for International Trade and Security
CLLB	$Cs_2LiLaBr_6:Ce^{3+}$: scintillator material
CLLC	$Cs_2LiLaCl_6:Ce^{3+}$: scintillator material
CLYC	$Cs_2LiYCl_6:Ce^{3+}$: scintillator material
CNS	Center for Nonproliferation Studies
CTBT(O)	Comprehensive Test Ban Treaty (Organization)
DHS	Department of Homeland Security
DNDO	Domestic Nuclear Detection Office
DoD	Department of Defense
FSU	Former Soviet Union
FWHM	Full Width at Half Maximum (probability distributions)
GYGGAG	$Gd_{1.5}\ Y_{1.5}Ga_{2.2}Al_{1.8}O_{12}$:Ce (scintillator material)
HEU	Highly Enriched Uranium
ICPMS	Inductively Coupled Plasma Mass Spectrometry
ICRP	International Commission on Radiological Protection
IMS	International Monitoring System
ISIS	Institute for Science and International Security (ISIS)
ITDB	Illicit Trafficking Database
MCNP	Monte Carlo N-Particle Transport Code
MIRV	Multiple Independent Re-entry Vehicle
MLIS	Molecular Laser Isotope Separation
MVRDS	Machine Vision Radiation Detection system
MWd/THM	Megawatt-days per Ton of Heavy Metal
NATO	North Atlantic Treaty Organization
NNSA	National Nuclear Security Administration
NNWS	Non-Nuclear Weapon States

NORM	Naturally Occurring Radioactive Material
NRF	Nuclear resonance Fluorescence
NTI	Nuclear Threat Initiative (NTI)
NWS	Nuclear Weapon States
Pu300/600/900	Tests to determine properties of plutonium (numbers are gamma energies in keV)
PUREX	Plutonium Uranium Redox EXtraction
REM	Radiation Equivalent Man
RF	Russian Federation
ROC	Receiver Operating Characteristic
SAUNA	(Swedish) Radio-xenon measurement system
SIPRI	Stockholm International Peace Research Institute
SNM	Special Nuclear Material
SOFAR	Sound Fixing and Ranging
SPALAX	(French) Radio-xenon measurement system
SWU	Separative Work Unit
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
TIMS	Thermal Ion Mass Spectrometry
UN	United Nations
USSR	Union of Soviet Socialist Republics