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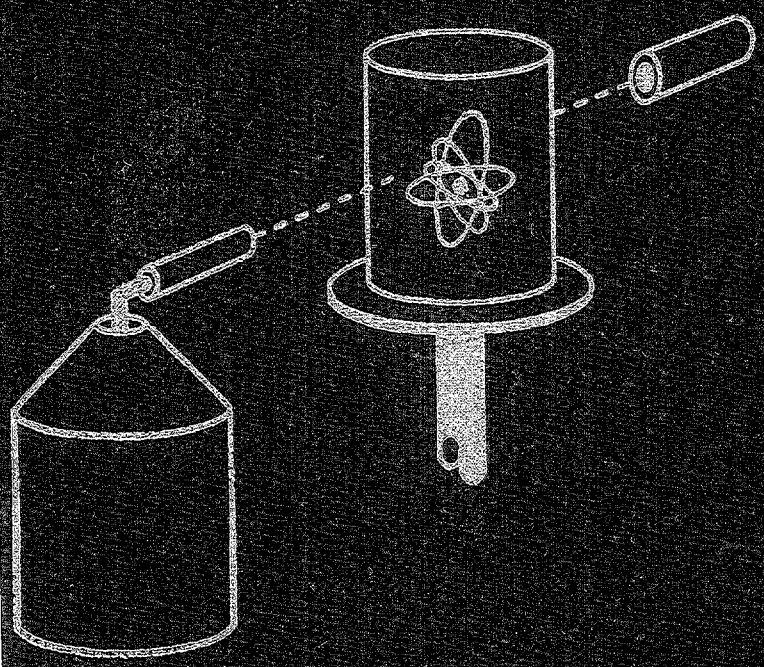
Passive Nondestructive Assay of Nuclear Materials

Doug Reilly, Norbert Ensslin, Hastings Smith, Jr.,
and Sarah Kreiner



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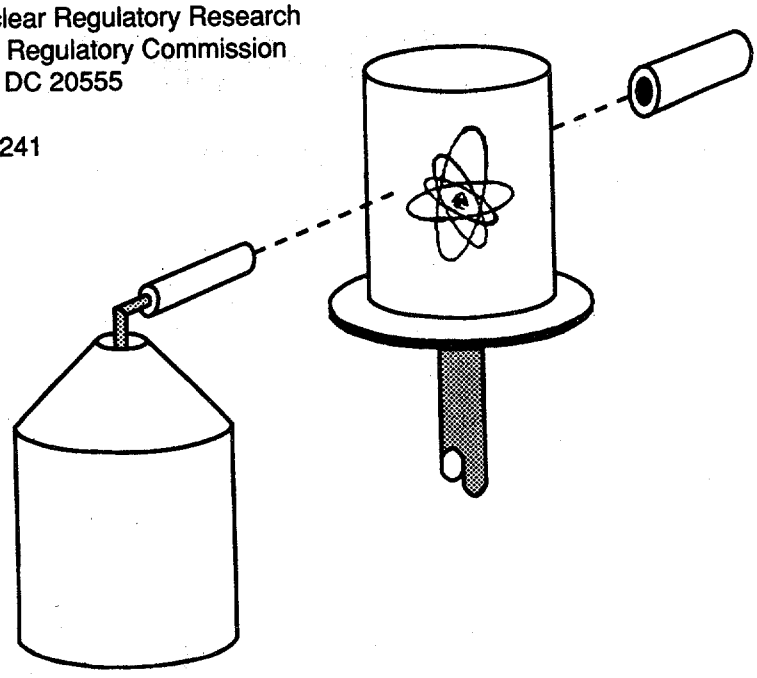

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PREFACE

This book is a general reference on the theory and application of passive nondestructive assay (NDA) techniques, or PANDA. It is part of a four-volume set on nuclear material measurement and accountability sponsored by the US Nuclear Regulatory Commission (NRC). Although we discuss a few active NDA techniques, they have been treated in detail in another book in the NRC series authored by T. Gozani.

The book's intended audience ranges from NDA neophytes to experienced practitioners. While the major motivation to write this book was provided by the NRC, there has long been a desire at Los Alamos to prepare a text of this kind. Many of the techniques and instruments described herein were developed at Los Alamos, and we welcome the opportunity to describe the techniques more completely than is possible in reports or papers.

We hope that you will find this text a useful and lasting reference to the interesting subject of passive NDA.

Doug Reilly, Norbert Ensslin, and Hastings Smith, Jr.

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Many people have been involved in the production of this book. It was truly a team effort in which every participant played a vital role. The majority of the participants belong to the Safeguards Assay Group at Los Alamos National Laboratory; however, significant contributions were also made by members of the Advanced Nuclear Technology Group of the Laboratory, the University of Arizona, and Fort Lewis College. The contributing authors are listed at the beginning of the book and on the individual chapters. We would like to acknowledge the help of William B. Wilson (Applied Nuclear Science Group) on Chapter 11 and Stanley Simmonds on Chapter 14. Walt Strohm of Mound Laboratory and Ron Perry of Argonne National Laboratory provided essential information to Chapters 21 and 22 on calorimetry.

This book has benefited greatly from the peer reviewers who provided the contributing authors with corrections and suggestions for improvement. We would like to thank the following reviewers: James Cadieux (Westinghouse Savannah River Corp.), Paul Cloessner (WSRC), Raymond Dewberry (WSRC), John Fleissner (Rocky Flats Plant), Willy Higinbotham (Brookhaven National Laboratory), William Laing (Oak Ridge National Laboratory), and Samuel Untermeyer (Private Consultant).

Douglas Reilly, Norbert Ensslin, and Hastings Smith served as project leaders and principal technical reviewers as well as writers of several chapters. Sarah Kreiner was the technical editor throughout the long course of producing the volume. Much of the credit for the readability of the text goes to Sarah's careful and meticulous editing. Any volume of this size demands a great deal of work from word processors. We were ably served by Sophia Howard and Celina Ortiz who graciously put up with the many changes to the text. The photocomposition and final editing were done by Joyce A. Martinez of the Systems Technology Support Group and Martha Lee DeLanoy of the Writing and Editing Group at Los Alamos.

To all of these people we wish to express our heartfelt thanks.

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Introduction

The term nondestructive assay (NDA) is applied to a series of measurement techniques for nuclear fuel materials. The techniques measure radiation induced or emitted spontaneously from the nuclear material; the measurements are nondestructive in that they do not alter the physical or chemical state of the nuclear material. In some cases, the emitted radiation is unique to the isotope(s) of interest and the radiation intensity can often be related to the mass of the isotopes. Other techniques to measure nuclear material involve sampling the material and analyzing the sample with destructive chemical procedures. NDA obviates the need for sampling, reduces operator exposure, and is much faster than chemical assay; unfortunately NDA is usually less accurate than chemical assay. The development of NDA reflects a trend toward automation and workforce reduction that is occurring throughout our society. NDA measurements are applied in all fuel-cycle facilities for material accounting, process control, criticality control, and perimeter monitoring.

The original impetus for NDA development was the need for increased nuclear material safeguards. As safeguards agencies throughout the world needed more nuclear material measurements, it became clear that rapid measurement methods were required that would not alter the state of nuclear material items. Development efforts to address these needs were supported by the US Nuclear Regulatory Commission, the Department of Energy, and the International Atomic Energy Agency. Rapid nondestructive measurement techniques are required by the safeguards inspectors who must verify the inventories of nuclear material held throughout the world.

NDA techniques are characterized as passive or active depending on whether they measure radiation from the spontaneous decay of the nuclear material or radiation induced by an external source. This book emphasizes passive NDA techniques, although certain active techniques like gamma-ray absorption densitometry and x-ray fluorescence are discussed here because of their intimate relation to passive assay techniques.

The principal NDA techniques are classified as gamma-ray assay, neutron assay, and calorimetry. Gamma-ray assay techniques are treated in Chapters 1–10. Chapters 1–6 deal with basic subjects including the origin of gamma rays, gamma-ray interactions, detectors, instrumentation, and general measurement principles. Chapters 7–10 cover applications to uranium enrichment, plutonium isotopic composition, absorption densitometry, and x-ray fluorescence.

Neutron assay techniques are the subject of Chapters 11–17. Chapters 11–13 cover the origin of neutrons, neutron interactions, and neutron detectors. Chapters 14–17 cover the theory and applications of total and coincidence neutron counting.

Chapter 18 deals with the assay of irradiated nuclear fuel, which uses both gamma-ray and neutron assay techniques. Chapter 19 covers perimeter monitoring, which uses gamma-ray and neutron detectors of high sensitivity to check that no unauthorized nuclear material crosses a facility boundary. The subject of Chapter 20 is attribute and semiquantitative measurements. The goal of these measurements is a rapid verification of the contents of nuclear material containers to assist physical inventory verifications. Waste and holdup measurements are also treated in this chapter. Chapters 21 and 22 cover calorimetry theory and application, and Chapter 23 is a brief application guide to illustrate which techniques can be used to solve certain measurement problems. Appendices A–C contain information on statistical treatment of assay data, radiation safety, and on criticality safety.

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