NUCLEAR ENERGY

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PRINCIPLES, PRACTICES, AND PROSPECTS

SECOND EDITION

David Bodansky

With 47 Figures

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Preface to the Second Edition

This second edition represents an extensive revision of the first edition, although the motivation for the book and the intended audiences, as described in the previous preface, remain the same. The overall length has been increased substantially, with revised or expanded discussions of a number of topics, including Yucca Mountain repository plans, new reactor designs, health effects of radiation, costs of electricity, and dangers from terrorism and weapons proliferation.

The overall status of nuclear power has changed rather little over the past eight years. Nuclear reactor construction remains at a very low ebb in much of the world, with the exception of Asia, while nuclear power's share of the electricity supply continues to be about 75% in France and 20% in the United States. However, there are signs of a heightened interest in considering possible nuclear growth. In the late 1990s, the U.S. Department of Energy began new programs to stimulate research and planning for future reactors, and many candidate designs are now contending—at least on paper—to be the next generation leaders. Outside the United States, the commercial development of the Pebble Bed Modular Reactor is being pursued in South Africa, a French-German consortium has won an order from Finland for the long-planned EPR (European Pressurized Water Reactor), and new reactors have been built or planned in Asia.

In an unanticipated positive development for nuclear energy, the capacity factor of U.S. reactors has increased dramatically in recent years, and most operating reactors now appear headed for 20-year license renewals. In a negative development, the German and Dutch governments have announced plans to phase out nuclear power and Sweden continues its earlier, but considerably delayed, program to do the same. Further, it remains unlikely that private U.S. companies will find it financially prudent to order new reactors without incentives from the federal government.

Significant uncertainties remain in important areas, including the fate of the Yucca Mountain nuclear waste repository project, the degree to which

the U.S. government will act to further the construction new reactors, the outcome of on-going debates on the effects of low doses of ionizing radiation, and the extent to which nuclear weapons proliferation and nuclear terrorism can be restrained. In the broader energy picture, concern about climate change caused by fossil fuel combustion has intensified, with increased interest in the potential of sequestering carbon dioxide after it is produced and in finding alternatives to fossil fuels.

Given the uncertainties facing nuclear energy, including the overriding uncertainty as to the extent that it may expand or contract, a new look at its current status seems warranted. This book seeks to provide background for considering the role that nuclear energy might play in addressing the overall energy dilemmas facing the United States and other countries throughout the world. It also briefly discusses alternatives to nuclear energy, without attempting a comparative evaluation of the competing, or complementary, possibilities.

The preface to the first edition stated the hope that "the book will be useful to readers with a wide variety of backgrounds who have an interest in nuclear energy matters." This was meant to include readers with technical backgrounds and those without such backgrounds. With the latter readership in mind, the somewhat mathematically oriented material has been slightly reduced for this edition. I hope that where uncongenial equations are found (now mostly confined to Chapter 7), readers will be able to skip over them without too much loss of basic content.

Again, I am indebted to many individuals, at the University of Washington and elsewhere, for much appreciated help. The debts that were acknowledged in the first edition remain. For this edition, assistance from a number of additional individuals calls for special mention. Robert Albrecht, at the University of Washington, has read and discussed many parts of the book with me, and has given me the benefit of his deep understanding of nuclear matters. Robert and Susan Vandenbosch, also in Seattle, have reviewed virtually the entire manuscript and have made numerous helpful suggestions. Edwin Kolbe, the Project Manager for Radioactive Materials at the Swiss National Cooperative for the Disposal of Radioactive Waste (NAGRA) and a 2002 visitor at the Institute for Nuclear Theory at the University of Washington, kindly offered to carry out ORIGEN calculations that give the yield of radionuclides in "typical" spent fuel. Abraham Van Luik, with the Yucca Mountain Project, has provided valuable help in elucidating the DOE's planning and analyses for the project.

Many other colleagues have read drafts of one or more chapters and I am grateful to them for their comments on those chapters, and in many cases, on other aspects of the book. I here thank: Chaim Braun, Bernard Cohen, Stanley Curtis, J. Gregory Dash, David Hafemeister, Isaac Halpern, Robert Halvorsen, William Sailor, Luther Smith, and Gene Woodruff. I also am grateful to Edward Gerjuoy, Phillip Malte, Jeffrey Schneble, and Donald Umstadter for comments on the first edition.

It is not possible to give a full listing of all the other individuals who have assisted me with information, advice, and documents. In this regard, in addition to those acknowledged above and in the first edition, I want at least to thank Joseph Beamon, James Beard, Mario Carelli, Yoon Chang, Raymond Clark, Paul Craig, George Davis, Herbert Ellison, Rodney Ewing, Tom Ferriera, Steve Fetter, Brittain Hill, Mark Jacobson, John Kessler, Kristian Kunert, Edward Miles, Thomas Murley, Richard Poeton, Jerome Puskin, Lowell Ralston, Stanley Ritterbusch, Finis Southworth, John Taylor, Ronald Vijuk, David Wade, Kevan Weaver, Ruth Weiner, Bruce Whitehead, Bertram Wolfe, and Joseph Ziegler.

Again, as in the first edition, my thanks and apologies are extended to the many others, not named above, who have generously given me their help. I appreciate the willingness of the University of Washington and the Department of Physics to provide space, facilities, and a congenial working environment. Finally, again, I wish to thank my wife, Beverly, for her patience and support during the long continuation of an effort that seemed at times to belie the concept of retirement.

Seattle, Washington *David Bodansky*
May 2004

Preface to the First Edition

This book has evolved from notes prepared for students in a physics course designed to cover the major aspects of energy production and consumption. About one-third of the course dealt with nuclear energy, and the notes for that segment were revised and expanded for the present book.

The course assumed that the students had at least one year of college-level physics, thus permitting the inclusion of some technical discussions. The present book, in its occasional use of equations and technical terminology, somewhat reflects the nature of that original audience. Readers with relatively little background in physics and engineering may find it useful to refer to the Appendix on "Elementary Aspects of Nuclear Physics," and to the Glossary.

I have sometimes been asked: "For whom is the book written?" One difficulty in addressing this question has already been touched on. Some of the technical discussions include equations, which is not customary in a book for a "lay audience." Other parts are more elementary than would be the case were this a textbook on nuclear engineering. Nonetheless, most of the key issues can be constructively discussed using little or no mathematical terminology, and I therefore hope that the book will be useful to readers with a wide variety of backgrounds who have an interest in nuclear energy matters.

A more fundamental difficulty lies in the fact that such interest is now at a low ebb. In fact, it is often believed that the era of nuclear fission energy has passed, or is passing. While most informed people are aware that France is highly dependent on nuclear energy, this is ignored as an aberration, holding little broader significance. It is not widely realized that nuclear energy, despite its stagnancy in the United States and most of Europe, is expanding rapidly in Asia. Further, many people who are otherwise well-informed on issues of public policy are surprised to learn that the United States now obtains more than 20% of its electricity from nuclear power.

This book has been written in the belief that it is premature and probably incorrect to assume that there is to be only one era of nuclear power and that this era has passed. The future pattern of nuclear energy use will depend on developments in a variety of energy technologies and on public attitudes

in differing countries. There can be little certainly as to how these developments will unfold. However, the demands of a growing world economy and the pressures of declining availability of oil will inevitably force a realignment and reassessment of energy options. The goal of this book is to provide basic information to those who want to gain, or refresh, an introductory familiarity with nuclear power, even before broad new reassessments of energy policy are made in the United States and elsewhere.

The preparation of the book has been aided by contributions from many individuals. Among these, I would like especially to acknowledge three. Since I first became interested in energy issues some twenty years ago and continuing until his death in 1991, my understanding of these issues and of nuclear energy in particular benefited greatly from discussions and collaborative writing with my colleague Fred Schmidt. Over the years, I have also gained much from the wisdom of Alvin Weinberg, who has made unique contributions to nuclear energy and its literature and, most recently, has very kindly read and commented on much of this manuscript. I am also grateful to Peter Zimmerman who served the publisher as an anonymous reviewer of a preliminary draft of this book and who subsequently, anonymity discarded, has been a very constructive critic of a revised draft.

In addition, I am heavily indebted to many other individuals at the University of Washington, in government agencies, in industry, and elsewhere. Some have been generous in aiding with information and insights, some have commented on various chapters as the book has evolved, and some have done both. Without attempting to distinguish among these varied contributions, I particularly wish to thank Mark Abhold, Thomas Bjerdstedt, Robert Budnitz, Thomas Buscheck, J. Gregory Dash, Kermit Garlid, Ronald Geballe, Marc Gervais, Emil Glueckler, Lawrence Goldmuntz, Isaac Halpern, Charles Hyde-Wright, William Kreuter, Jerrold Leitch, Norman McCormick, Thomas Murley, James Quinn, Maurice Robkin, Margaret Royan, Mark Savage, Jean Savy, Fred Silady, Bernard Spinrad, Ronald Vijuk, and Gene Woodruff.

This list is far from exhaustive and I extend my thanks and apologies to the many others whom I have failed to mention. I am also grateful to the University of Washington and the Department of Physics for making it possible for me to teach the courses and devote the time necessary for the development of this book. Finally, I must express my appreciation to my wife, Beverly, for her support and encouragement as the book progressed.

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