SAFETY AND SECURITY
OF
COMMERCIAL
SPENT NUCLEAR FUEL STORAGE

Public Report

Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage
Board on Radioactive Waste Management
Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

PRE-PUBLICATION DRAFT: SUBJECT TO EDITORIAL CORRECTIONS
The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Wm. A. Wulf are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org
COMMITTEE ON THE SAFETY AND SECURITY OF
COMMERCIAL SPENT NUCLEAR FUEL STORAGE

LOUIS J. LANZEROTTI, Chair, New Jersey Institute of Technology, Newark, and Lucent Technologies, Murray Hill
CARL A. ALEXANDER, Battelle Memorial Institute, Columbus, Ohio
ROBERT M. BERNEIRO, U.S. Nuclear Regulatory Commission (retired), Gaithersburg, Maryland
M. QUINN BREWSTER, University of Illinois, Urbana-Champaign
GREGORY R. CHOPPIN, Florida State University, Tallahassee
NANCY J. COOKE, Arizona State University, Mesa
LOUIS ANTHONY COX, Jr., Cox Associates, Inc., Denver, Colorado
GORDON R. JOHNSON, Network Computing Services, Minneapolis, Minnesota
ROBERT P. KENNEDY, RPK Structural Mechanics Consulting, Escondido, California
KENNETH K. KUO, Pennsylvania State University, University Park
RICHARD T. LAHEY, Jr., Rensselaer Polytechnic Institute, Troy, New York
KATHLEEN R. MEYER, Keystone Scientific, Inc., Fort Collins, Colorado
FREDERICK J. MOODY, GE Nuclear Energy (retired), Murphys, California
TIMOTHY R. NEAL, Los Alamos National Laboratory, Los Alamos, New Mexico
JOHN WREATHALL, Jr., John Wreathall & Company, Inc., Dublin, Ohio
LORING A. WYLLIE, Jr., Degenkolb Engineers, San Francisco, California
PETER D. ZIMMERMAN, King’s College London, England

Staff
KEVIN D. CROWLEY, Study Director
BARBARA PASTINA, Senior Program Officer
MICAH D. LOWENTHAL, Senior Program Officer
ELISABETH A. REESE, Program Officer
DARLA THOMPSON, Research Associate
TONI G. GREENLEAF, Administrative Associate

1 Drs. Cox and Wreathall resigned from the committee on February 26 and March 17, 2004, respectively.
BOARD ON RADIOACTIVE WASTE MANAGEMENT

RICHARD A. MESERVE, Chair, Carnegie Institution, Washington, D.C.
ROBERT M. BERNERCO, U.S. Nuclear Regulatory Commission (retired), Gaithersburg, Maryland
SUE B. CLARK, Washington State University, Pullman
ALLEN G. CROFF, Oak Ridge National Laboratory (retired), Tennessee
DAVID E. DANIEL, University of Illinois, Urbana
RODNEY C. EWIN, University of Michigan, Ann Arbor
ROGER L. HAGENGRUBER, University of New Mexico, Albuquerque
KLAUS KÜHN, Technische Universität Clausthal, Germany
HOWARD C. KUNREUTHER, University of Pennsylvania, Philadelphia
SUSAN M. LANGHORST, Washington University, St. Louis, Missouri
NIKOLAI P. LAVEROV, Russian Academy of Sciences, Moscow
MILTON LEVENSON, Bechtel International (retired), Menlo Park, California
PAUL A. LOCKE, Johns Hopkins University, Baltimore, Maryland
NORINE E. NOONAN, College of Charleston, South Carolina
EUGENE A. ROSA, Washington State University, Pullman
ATSUYUKI SUZUKI, Nuclear Safety Commission of Japan, Tokyo

Staff

KEVIN D. CROWLEY, Director
MICAH D. LOWENTHAL, Senior Program Officer
BARBARA PASTINA, Senior Program Officer
JOHN R. WILEY, Senior Program Officer
TONI GREENLEAF, Administrative Associate
DARLA J. THOMPSON, Research Associate
LAURA D. LLANOS, Senior Program Assistant
MARII ULOA, Senior Program Assistant
JAMES YATES, JR., Office Assistant

1 Dr. Meserve did not participate in the oversight of this study.
ACKNOWLEDGMENTS

This study would not have been possible without the help of several organizations and individuals who were called upon for information and advice. The committee would like to acknowledge especially the following organizations and individuals for their help:

- Congressional staff members Kevin Cook, Terry Tyborowski, and Jeanne Wilson (retired) for their guidance on the study task.
- Nuclear Regulatory Commission staff Farouk Eltawila, who served as the primary liaison for this study, and Charles Tinkler and Francis (Skip) Young for their support of the committee’s information-gathering activities.
- Department of Homeland Security staff member Jon MacLaron, who also served as a liaison to the committee.
- Steve Kraft and John Vincent (deceased) of the Nuclear Energy Institute and staff of Energy Resources International for providing information about spent fuel storage practices in industry.
- ENTERGY Corp., Exelon Corp, and Arizona Public Service Corp. staff for organizing tours of the Braidwood, Dresden, Indian Point, and Palo Verde nuclear generating stations.
- German organizations and individuals who helped organize a tour of spent fuel storage facilities in Germany. These organizations and individuals are explicitly acknowledged in Appendix C.
- Speakers (see Appendix A) and participants at committee meetings as well as those who sent written comments for providing their knowledge and perspectives on this important matter.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council’s Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

John F. Ahearn, Sigma Xi and Duke University
Romesh C. Batra, Virginia Polytechnic Institute and State University
Robert J. Buchatz, Lawrence Livermore National Laboratory
Philip R. Clark, GPU Nuclear Corporation (retired)
Richard L. Garwin, IBM Thomas J. Watson Research Center
Roger L. Hagengruber, The University of New Mexico
Darleane C. Hoffman, E.O. Lawrence Berkeley National Laboratory
Melvin F. Kanninen, MFK Consulting Services
Milton Leveson, Bechtel International (retired)
Allison Macfarlane, Massachusetts Institute of Technology
Richard A. Meserve, Carnegie Institution of Washington
Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Chris G. Whipple, ENVIRON International Corporation, and R. Stephen Berry, University of Chicago. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.
CONTENTS

Note to Readers, 1
Summary for Congress, 2
Executive Summary, 3

1. Introduction and Background, 11
   Context for this study, 11
   Strategy to address the study charges, 12
   Report roadmap, 15
   Background on spent nuclear fuel and its storage, 15

2. Terrorist Attacks on Spent Fuel Storage, 25
   Background on risk, 25
   Terrorist attack scenarios, 28
   Risks of terrorist attacks on spent fuel storage facilities, 34
   Findings and recommendations, 36

3. Spent Fuel Pool Storage, 38
   Background on spent fuel pool storage, 40
   Previous studies on safety and security of pool storage, 44
   Evaluation of the potential risks of pool storage, 47
   Findings and recommendations, 57

4. Dry Cask Storage and Comparative Risks, 60
   Background on dry cask storage, 61
   Evaluation of potential risks of dry cask storage, 64
   Potential advantages of dry storage over wet storage, 68
   Findings and recommendations, 69

5. Implementation Issues, 75
   Timing issues, 75
   Communication issues, 75
   Finding and recommendation, 77

References, 79

Appendixes

A. Information-gathering sessions, 83
B. Biographical sketches of committee members, 87
C. Tour of selected spent fuel storage-related installations in Germany, 92
D. Historical development of current commercial power reactor fuel operations, 100
E. Glossary, 108
F. Acronyms, 114