Reactor Dosimetry

Harry Farrar IV,
E. Parvin Lippincott,
John G. Williams,
and
David W. Vehar,
editors

STP 1228

STP 1228

Reactor Dosimetry

Harry Farrar IV, E. Parvin Lippincott, John G. Williams, and David W. Vehar, Editors

ASTM Publication Code Number (PCN):
04-012280-35

ASTM
1916 Race St.
Philadelphia, PA 19103
Printed in U.S.A.

Library of Congress Cataloging-in-Publication Data

Reactor dosimetry / Harry Farrar . . . [et al.], editors.
p. cm. — (STP ; 1228)
Proceedings of the 8th ASTM-Euratom Symposium on Reactor Dosimetry, held August 29 to Sept. 3, 1993, Vail, Colorado.
Includes bibliographical references and index.
ISBN 0-8031-1899-6
1. Nuclear reactors—Materials—Effect of radiation on—Congresses. 2. Radiation dosimetry—Congresses. I. Farrar, Harry. II. ASTM-Euratom Symposium on Reactor Dosimetry (8th : 1993 : Vail, Colo.) III. Series: ASTM special technical publication ; 1228.
TK9185.A1R42 1994
621.48'332—dc20 94-42668
CIP

Photocopy Rights

Peer Review Policy

Each paper published in this volume was evaluated by three peer reviewers. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

To make technical information available as quickly as possible, the peer-reviewed papers in this publication were printed "camera-ready" as submitted by the authors.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

Printed in Fredericksburg, VA
December 1994

Foreword

The Eighth ASTM-Euratom Symposium on Reactor Dosimetry was held in Vail, Colorado from 29 August to 3 September 1993. ASTM Committee E-10 on Nuclear Technology and Applications and The Commission of the European Communities served as sponsors. Co-sponsors were the U.S. Department of Energy, the U.S. Nuclear Regulatory Commission, the U.S. National Institute of Standards and Technology, the Institute of Electrical and Electronic Engineers, and the Electric Power Research Institute. The symposium was held in cooperation with the International Atomic Energy Agency and the American Society of Mechanical Engineers.

Appendix I lists the members of the ASTM Symposium Committee and the Euratom Programme Committee. Appendix II is a list of the symposium attendees and their addresses.

Contents

GAMMA-RAY DOSIMETRY TECHNIQUES

RADIATION FIELD CHARACTERIZATION

NUCLEAR DATA

Overview

Important advances have been made over the past three decades in neutron and gamma-ray physics and dosimetry, advances that have generated new analysis and measurement techniques, lessened uncertainties, and produced standards for international use. Most of this has been done in support of reactor development programs and the enhanced understanding of radiation damage to reactor fuels, materials, and components. An important contribution to these activities has been a series of successful symposia that have brought together leading experts from around the world, resulting in, among other things, a number of highly productive joint research projects.

This ASTM special technical publication (STP) is a compilation of peer-reviewed papers presented at the most recent of these symposia, held in Vail, Colorado from 29 August to 3 September 1993. Many of the authors were specifically invited to provide coverage of the range of topics identified by the ASTM and Euratom program committees. Therefore, this volume provides a particularly comprehensive state-of-the-art review of the subject by leading worldwide experts in the field.

The first ASTM-Euratom Symposium on Reactor Dosimetry, which took place in 1975 at the Joint Research Centre, Petten, The Netherlands, generally defined the status of reactor neutron metrology and damage-analysis programs and identified the needs of the nuclear power industry. The second symposium, hosted in 1977 by the Electric Power Research Institute, Palo Alto, California, emphasized data and techniques used to characterize neutron and gamma-ray environments, including the use of well-characterized benchmark fields. The third meeting, in 1979 at the Joint Research Centre, Ispra, Italy, focused on the interactions between materials experts and dosimetry metrologists. The thrust of the next two symposia, at the National Bureau of Standards, Washington, D.C. in 1982 and at the GKSS Research Centre, Geesthacht, Germany in 1984, was radiation metrology techniques, data bases, damage correlation analyses, and standardization. However, a growing number of papers were concerned with reactor pressure vessel surveillance techniques and correlation of the resulting data, reflecting a progression from test reactor research to applications in a maturing power reactor industry.

The sixth and seventh symposia, held in 1987 at Jackson Hole, Wyoming, and in 1990 in Strasbourg, France, again covered reactor dosimetry and dosimetry standardization. There was major input on light water reactor pressure surveillance work and on dosimetry in support of plant life extension. Progress was reported on multinational joint research projects designed to improve the accuracy of pressure vessel dosimetry and the accuracy of materials property trend curves by performing interrelated experiments in a number of well-characterized neutron fields. The technical community concerned with dosimetry for radiation effects in electronics was also strongly represented.

The eighth symposium, the proceedings of which are presented herein, provided an update of the field of reactor dosimetry. Experts were specifically invited to discuss their latest results under the broad theme of dosimetry for the correlation of radiation effects. The symposium format included oral and poster sessions and nine organized but informal round-table workshop meetings. The symposium started with a keynote session in which three papers reviewed the current status and future prospects of nuclear power, as well as historical perspectives on reactor dosimetry.

The papers in this volume have been organized by subject into nine separate sections, preceded by a summary of the three keynote presentations, and followed by summaries of the nine workshops. The first section contains 17 papers on the subject of pressure vessel surveillance dosimetry, including review papers on the current status of surveillance standards, several papers on the status of surveillance programs in central and eastern European countries, and a number of papers on handling uncertainties in surveillance data. This is followed by two sections containing papers on passive and active neutron dosimetry techniques, which describe some of the newest techniques in neutron metrology. The fourth section on benchmarks includes papers describing the analysis of benchmark neutron environments for verification and validation of measurement and calculational results. The following section on gamma-ray dosimetry techniques contains five papers describing some of the latest techniques for determining gamma-ray fluences in reactor environments.

The sixth section on radiation damage evaluation and measurements contains papers correlating various aspects of radiation damage with fluence. Eight papers in the following section on radiation field characterization describe analyses in a wide variety of neutron environments, ranging from neutron fields in light-water moderated research reactors to photoneutron fields produced by an electron accelerator. The eighth section on nuclear data contains papers on evaluations of specific cross sections important for dosimetry applications, as well as evaluation and testing of updated dosimetry cross-section libraries. In addition, this section includes two papers on the evaluation and testing of the most recent multigroup cross-section libraries used for neutron and gamma-ray transport calculations. The last section of the presented papers in this book contains five papers on high-energy neutron dosimetry used to support research in fusion energy.

The enthusiastic participation by a record number of attendees (127) for this symposium series, 48 of whom were from 16 overseas countries, is an indication of the worldwide importance that continues to be placed on the improvement and standardization of dosimetry techniques for reactor operations and for materials testing in reactors. Increased participation in the symposium by experts from central and eastern Europe was very much welcomed, and this has resulted in a decision to hold the ninth symposium in Prague, The Czech Republic, in September 1996.

The four editors of this volume would like to take this opportunity to thank the authors and the program committees of ASTM Subcommittee E10.05 and Euratom, all of whom made the symposium a success. We would also like to acknowledge the help of the ASTM staff for interacting with the authors and reviewers during the long paper-review process and for making this publication possible.

Harry Farrar IV
Symposium General Chairman
Consultant
Bell Canyon, California

E. Parvin Lippincott
Program Committee Chairman
Westinghouse
Pittsburgh, Pennsylvania

John G. Williams
Program Committee Vice Chairman
University of Arizona
Tucson, Arizona

David W. Vehar
Scientific Secretary
Sandia National Laboratories
Albuquerque, New Mexico

A Note on ASTM and Committee E-10

The international standards movement is playing an increasingly critical role in the advancement of technology and in the progress towards a higher standard of living. To assist in global prosperity in the coming years, the American Society for Testing and Materials (ASTM) recognizes that it must be fully involved in this dynamic movement.

Organized in 1898, ASTM has grown today into one of the largest voluntary standards development systems in the world. ASTM is a not-for-profit organization that provides a forum for producers, users, ultimate consumers, and those having a general interest (representatives of government and academia) to meet on common ground and write standards for materials, products, systems, and services. From the work of 134 standards-writing committees, ASTM publishes standard test methods, specifications, practices, guides, classifications, and terminology. ASTM's standards development activities encompass metals, paints, plastics, textiles, petroleum, construction, energy, the environment, consumer products, medical services and devices, computerized systems, electronics, and many other areas. ASTM Headquarters has no technical research or testing facilities; such work is done voluntarily by the 33 000 technically qualified ASTM members located throughout the world. Because the society's activities are open to the entire international community, additional experts also contribute to the standards-writing process, resulting in an effective total participation of 100 000 individuals. More than 8 500 ASTM standards are published each year in the 68 volumes of the *Annual Book of ASTM Standards.* These standards and related information are distributed throughout the world.

ASTM also provides continuing education and training in the use and application of ASTM standards through standards technology training courses. ASTM members propose ideas for the courses, work with staff to establish course outlines, and serve as instructors. Attendees learn the practical application of standards and benefit from the instructors' technical expertise and knowledge of standards development.

ASTM Committee E-10 on Radioisotopes and Radiation Effects was founded in 1951 to provide an ASTM liaison function for the rapidly growing interests in the peaceful uses of atomic energy. Now named Committee E-10 on Nuclear Technology and Applications, its goal is to promote the advancement of nuclear science and technology and the safe application of nuclear energy in all its forms. Committee E-10 has published 100 standards covering a diverse range of nuclear procedures. Publication of standards follows a strict ASTM protocol that requires that the standard have the unanimous consensus of all concerned parties. Successive ballots are taken at the subcommittee, committee, and society levels, and any negative votes or comments must be satisfactorily resolved.

Committee E-10 sponsors scientific and technical symposia and generates publications in its fields of specialization. For the past 30 years, E-10 symposia have been held about once a year. Two symposia series that have attained international prominence are the ASTM-Euratom Symposia on Reactor Dosimetry and the ASTM Symposia on the Effects of Radiation on Materials. At these symposia, speakers present formal papers that are often published as ASTM special technical publications (STPs). All published papers are subject to a stringent peer-review process.

Standards and technological publications are serving as agents for change, with technology as a prime driver of the change. This is resulting in increased cooperation among nations, rapidly rising volume of world trade with emergent large new geographic markets,

increasing cooperation among organizations and nations, quality certifications and awards, such as ISO 9000, environmental and other regulatory issue resolutions, global product standards and communications, and rapidly changing geo-political and economic environments.

The greatest challenge to organizations and nations is to manage the changes taking place around them. Today's new reality for even the most challenging technical areas is that the market place is already demanding standards and technology baselines, regardless of how technically advanced the area seems to be. The point is that standards are at the heart of the changes taking place external to organizations and nations, and will certainly be drivers of the changes that must take place internally to them as well.

The ultimate goal of the series of ASTM-Euratom symposia on Reactor Dosimetry is to obtain international standardization of nuclear radiation physics and dosimetry methods with improved accuracy and well-quantified uncertainty limits. Physics and dosimetry in connection with the characterization of the effects of ionizing radiation continues to be a focus of interest to Committee E-10. Committee E-10 strongly encourages technical contributions in this area and invites all who are interested to become involved in the standards development process.

On behalf of ASTM Committee E-10, I wish all participants in this vital area of work continued success and a productive future.

Paul S. Olson, Chairman
ASTM Committee E-10 on Nuclear
Technology and Applications, Rockwell International

Summary of Keynote Session

At the Eighth ASTM-Euratom International Symposium on Reactor Dosimetry, a keynote session was held to review the current status and future prospects of nuclear power, as well as historical perspectives on reactor dosimetry. There were three keynote session speaker presentations to cover several points of view on the situation today in the nuclear power arena. The three presentations were:

- *Nuclear Power in an Age of Uncertainty,* by A. David Rossin, 1992–1993 President, American Nuclear Society (ANS)
- *Next Generation Reactors in the National Energy Strategy,* by D. J. McGoff, Acting Director, Office of Civilian Reactor Development, U.S. Department of Energy (DOE)
- *Impact of U.S. NRC Reactor Vessel Embrittlement Research on Regulation of Nuclear Power Plants,* by C. Z. Serpan, Branch Chief, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission (NRC)

These three presentations provided U.S. industry, the Department of Energy (DOE), and the Nuclear Regulatory Commission (NRC) perspectives on various aspects of the acceptance, development, operation, surveillance, and regulation of existing and advanced light-water reactor (LWR) nuclear power plants (NPP). In addition, Rossin and McGoff each addressed a number of general issues associated with international and national energy strategies, which tie in with the international efforts for standardization fostered by this symposium series. A brief summary of the keynote papers is supplied here, based on the more detailed summary given in Ref *1*.

In the first keynote address, Rossin provided insight and observations that are essential for understanding national and international trends associated with energy and electricity usage. He connected the increasing usage with many benefits, including economic growth, and also with reduction in the population growth rate. Rossin started his talk by stating,

> "The future of nuclear power is not clear today. Issues involve waste management, plant operating economics, and license extension, plus many others. Despite its ability to contribute in a positive way to the solution of environmental problems, critical decisions will be hard to reach. 'Process' and 'public participation' will be seen as more important than reaching important decisions. A particularly important example is to be able to predict the material condition of reactor pressure vessels over the period of license extension, and to communicate the facts in a clear and understandable way. This will be even more challenging because technical uncertainties will exist in making projections of the degree of neutron embrittlement."

Rossin was critical of the attitudes of the Clinton-Gore administration regarding nuclear power. In particular, he took issue with the premise that, "It is energy production and use that causes pollution and environmental degradation, both local and global," which is a major theme in Vice President Gore's book *Earth in the Balance—Ecology and the Human Spirit* [*2*]. What Rossin observed is very different and he concluded that economic, demographic, and environmental data all show clearly that where there is enough energy, and particularly enough electricity, health care is better, food is more affordable, more children are educated, life spans are longer, the quality of life is better, and hopes for the future exist. Rossin expressed serious concern with Gore's statement in his book that, "We must all

become partners in a bold effort to change the very foundation of our civilization'' because Gore does not provide any specifics on what it should be changed to!

Rossin went on to address the ''downside risks'' of not having enough electricity to meet demand and what has happened since limits on energy resources became evident in the 1970s. In a section of his paper entitled Standards, Rossin stated:

> What has been missing is any requirement in our complex and institutionalized decision-making process to consider seriously another of the downside risks, the risk of failing to go ahead at all. I recently visited two departments at the U.S. Environmental Protection Agency (EPA), the Office of Air and Radiation Programs and the Office of Research. Both have roles in setting standards. Neither have ever considered the downside risks of failure to proceed with a technology. . . . So here we sit, a nation gridlocked by public participation in decision-making, holding public hearings on issues like how to set radiation standards for cleaning up former weapons production areas and contaminated sites, listening to emotional demands for zero everything, and never facing up to downside risks of losing the confidence of the people and not getting anything done at all.

In the second keynote address, David McGoff provided a commentary on current energy usage, Department of Energy (DOE) goals, and future reactor prospects. The Comprehensive National Energy Policy Act (NEPA) of 1992 was enacted with strong bipartisan support in the U.S. Congress and provides endorsement of nuclear power development, licensing reform, and waste management. In this regard, it provides strong policy on a more predictable licensing process that:

- combines construction and operating licenses;
- limits the scope of post-construction hearings;
- allows plants to operate during hearings, if safety is not at issue; and
- limits the scope of hearings to amend combined licenses.

The National Energy Strategy for the future, from DOE's perspective is:

- conservation and demand-side management programs will reduce future electrical generating capacity requirements;
- significant new capacity requirements remain after conservation; and
- it is anticipated that a mix of renewables: natural gas, nuclear power, and clean-coal technologies will be needed to support economic growth.

The electric generation in 1992 by different fuels in the United States was 56.3% by coal, 22.1% by nuclear, 9.4% by gas, 8.6% by hydroelectric, 3.2% by oil, and 0.4% by other sources. Electricity growth has been, and will continue to be, tied to economic growth, and additional capacity will be needed to meet improved economic growth targets. Meeting environmental goals will require that electricity continues to become an even larger share of our energy mix.

The use of electricity in the United States increased by a factor of about 1.9 during the period 1970 to 1990. During this period, the electricity and gross national product (GNP) relative increases were parallel with the electricity being ~25% higher than the GNP. At the same time, total energy use increased only ~20% from 1970 to 1990, with hardly any change between 1972 and 1986. The projection of the electricity growth factor (compared with 1970) is ~2.5 by the year 2000 and ~4.5 by the year 2030. The corresponding factors for the GNP are ~2.5 and ~3.5, respectively.

The new, more predictable, licensing process will make significant reductions in the risk of nuclear power projects. The current U.S. DOE nuclear power strategy is to:

- cooperate with industry to develop advanced light-water reactors (ALWRs);
- eliminate overly-restrictive regulatory barriers to the use of nuclear power;

- defer long-range technologies, except for actinide recycle; and
- complete the evaluation for a geologic high-level waste repository at Yucca Mountain, Nevada.

It is noted that the United States remains committed to geologic disposal. Progress is being made in exploratory drilling at the Yucca Mountain site and studies are underway on means for the government to assist utilities in spent fuel management by 1998.

McGoff's DOE estimated time path leading to the availability of new orders for ALWRs is:

- complete design certification (first-of-a-kind engineering) and obtain the first order(s) by 1995/1996;
- start construction by about 1997, with a five-year completion period;
- initial operation by about 2003; and
- follow-on orders by 2003, with construction completed and initial operation by about 2008.

He further stated that "lessons learned" from operating experience are leading to improvements in the performance of existing NPPs. For the time period 1980 to 1992 he graphically showed that:

- The unit capability factor (median value) was up from 62.7 to 76.5%;
- The unplanned capability loss factor (median value) was down from 12.8 to 6.8%;
- The unplanned automatic scrams (median value) per 7 000 h critical were down from 7.3 to 1.1;
- The thermal performance (gross heat rate in btu/kWh) changed from 10.504 to 10.193;
- The collective radiation exposure (man-rem/unit; median value) for boiling-water reactors (BWR) and pressurized water reactors (PWR) plants decreased from 988 to 368 and from 528 to 193, respectively;
- The industrial safety accident rate (accidents per 200 000 manhours worked) decreased from 2.10 to 0.77; and
- The volume of low-level solid radioactive waste (m^3vs/unit, median value) for BWR and PWR plants decreased from 950 to 219 and 500 to 87, respectively.

The foregoing commentary provides an updated perspective on U.S. energy and technology trends, nuclear power generation, and the current and future direction for the development of ALWRs, licensing and regulatory reform, spent fuel storage, and the time frame for the availability of a high-level waste repository. This background information should be of benefit to those engaged in ASTM standards work associated with the licensing, regulation, operation, maintenance, surveillance, decontamination, and decommissioning of NPPs.

In the third keynote paper (presented by A. Taboada), C. Z. Serpan stated that, "The embrittlement of nuclear reactor pressure vessels by neutron radiation is the chief aging mechanism of these critical components." He went on to outline the extensive past and present programs sponsored by the U.S. NRC to determine the embrittlement effects. Because of its technical relevance to the broad theme of physics-dosimetry for the correlation of materials radiation effects, Serpan's full paper is provided in this book.

The keynote session successfully provided an introduction to a number of issues as discussed in this summary and set the stage for the other symposium papers that relate to standards and regulations. However, the keynote session primarily discussed the topics from a U.S. point of view, and to obtain a more international perspective on standards and regulations, the reader is encouraged to read the discussion in Ref *1* and the papers in this book, particularly in the section, Standards and Regulations.

References

[1] McElroy, W. N., *8th ASTM-Euratom International Symposium on Reactor Dosimetry Keynote Session and Consensus Standards: Trends in Energy and Nuclear Policy,* CTS-RP-94-1, Consultants and Technology Services, 113 Thayer Drive, Richland, WA, 1994.
[2] Gore, A., *Earth in the Balance—Ecology and the Human Spirit,* Plume-Penguin Books, 1993.

ISBN 0-8031-1899-6