EFFECTS OF RADIATION ON MATERIALS: 21st International Symposium

TECHNICAL EDITORS: Martin L. Grossbeck, Todd R. Allen, Randy G. Lott, Arvind S. Kumar



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Effects of Radiation on Materials

Martin L. Grossbeck, Todd R. Allen, Randy G. Lott, and Arvind S. Kumar, editors

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Foreword

The Symposium on *Effects of Radiation on Materials* was held in Tucson, Arizona on 18–20 June 2002. ASTM International Committee E10 on Nuclear Technology and Applications served as sponsor. Symposium chairmen and co-editors of this publication were Martin L. Grossbeck, University of Tennessee, formerly at Oak Ridge National Laboratory; Todd R. Allen, University of Wisconsin, formerly at Argonne National Laboratory-West; Randy G. Lott, Westinghouse Electric Company; and Arvind S. Kumar, University of Missouri, Rolla.

Dedication



Wolfgang Schüle 1930–2000

The nuclear materials community lost one of its most active and dedicated scientists with the death of Wolfgang Schule. Dr. Schule contributed to the ASTM Radiation Effects on Materials Symposia for over 20 years. His research on radiation effects in metals covered many areas including mechanical properties, precipitation, phase stability, and radiation-produced defects. He served as a faculty member at Johann Wolfgang Goethe-University, as a scientist at both the Max-Planck-Institut fur Metallforschung and at the Joint Research Centre, Ispra. Additionally, he was a visiting scientist at the Oak Ridge National Laboratory. His keen interest in students led to advising 25 Ph.D. theses over thirty years. Wolfgang had an intense passion for science and enjoyed the controversy involved with the exchange of differing points of view. Approaching his hobbies with the same enthusiasm that he applied to his work, Wolfgang enjoyed art and mechanical devices; he was comfortable as both an engineer and a scientist. For all of us who knew him, he was always dynamic and personable. Many of us will remember him not only as a scientist but also as a friend. Indeed, he will be missed.



Participants in the E10 21st Symposium on the Effects of Radiation on Materials

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Overview

Selected papers from the 21st Symposium on the Effects of Radiation on Materials are published in this volume. That symposium, sponsored by ASTM Committee E-10 on Nuclear Technology and Applications, was held in Tucson, Arizona, on June 18–20, 2002. Martin L. Grossbeck, then at the Oak Ridge National Laboratory and now at the University of Tennessee, chaired the meeting. Cochairmen were Todd R. Allen, then at Argonne National Laboratory-West and now at the University of Wisconsin; Randy G. Lott, Westinghouse Electric Company; and Arvind S. Kumar, University of Missouri-Rolla.

This symposium series began in 1956 with a meeting sponsored jointly by E-10, then the Committee on Radioisotopes and Radiation Effects, and the Atomic Industrial Forum. The symposia in the present form, sponsored by Committee E-10, began in 1960 and became international in 1963 with the presentation of 5 papers of the total of 18 from laboratories outside the United States. At the current meeting, of the 96 papers presented (59 are published in this volume), 25 came from sources outside the United States. The editors are proud that is symposium was a truly international meeting which presented state of the art research in nuclear materials from around the world.

The symposium began with an invited plenary lecture given by Theodore U. Marston, Vice President of the Nuclear Power Sector of the Electric Power Research Institute. Dr. Marston presented an overview of the current and future reactors and their materials requirements. Renewed emphasis in austhenitic stainless steels was reflected in the strength of papers presented in this area. This class of alloys is again being considered for fuel cladding in advanced reactors. In addition, stainless steels are studied as model alloys for radiation effects on diffusion, elemental segregation and formation of radiation-induced phases. Reduced neutron activation for fusion reactor structural materials has spurred interest in vanadium alloys and ferritic steels designed for reduced neutron activation. Of special interest is the discovery that such steels can be made without sacrifice of properties. On the contrary, new research has led to the development of reduced activation steels with enhanced irradiation properties over previously used alloys. Research efforts continue in the area of ceramic and composite materials for advanced structural applications and for waste encapsulation.

Even though very significant and interesting progress was reported on a myriad of materials, the primary focus of the symposium remains pressure vessel steels, with a total of 35 presentations, 21 of which are included in these proceedings. In addition to dedicated sessions on the mechanical properties, fracture toughness, and microstructure of irradiated reactor pressure steels, numerous papers on related subjects were integrated into the remaining conference sessions on fundamental mechanisms. A related session on studies in model alloys also contained valuable information about radiation effects in a variety of Fe-Cu alloys. The increasing sophistication of microstructural examination techniques such as positron annihilation and atom probe temography has revealed much detail about the radiation induced features that cause embrittlement in these steels. New embrittlement prediction curves based on the knowledge gained from the microstructural studies have been developed and are being refined for eventual use in reactor pressure vessel integrity analysis. Increased understanding of the primary irradiation effects in these steels has made it possible to look more closely at the secondary effects, such as pre-irradiation stress relief, thermal neutron embrittlement, and dose rate effects. The recent adop-

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tion of the ASTM E1921, Standard Test Method for Determination of Reference Temperature, T_0 , for Ferritic Steels in the Transition Range, has provided a valuable new tool for the characterization of reactor pressure vessel materials.

The international participation in this symposium is indicative of the established benefit of this symposium series to the radiation effects community. This series of symposia will continue to evolve to best support the needs of the community. In keeping with this evolution, this volume will be the last Special Technical Publication for this symposium series. The proceedings of the twenty-second symposium will be part of a new journal published by ASTM, the *Journal of ASTM International*. In this way, the quality of the extensive peer review process can be maintained with timely publication of symposium papers as they are ready.

The editors wish to express our gratitude to all of the reviewers, without whom maintaining the quality of this publication would not be possible, and to all symposium participants.

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