

Journal of ASTM International
Selected Technical Papers



STP 1513

A photograph of a nuclear power plant at night, with a large cooling tower emitting a plume of white steam. The plant is reflected in a body of water in the foreground. The entire image has a blue color cast.

Effects of Radiation on Nuclear Materials and the Nuclear Fuel Cycle

24th Volume

Guest Editors

Jeremy T. Busby
Brady Hanson

Journal of ASTM International
Selected Technical Papers STP1513
**Effects of Radiation on Nuclear Materials
and the Nuclear Fuel Cycle:
24th Volume**

JAI Guest Editors:

Jeremy T. Busby
Brady D. Hanson



INTERNATIONAL
Standards Worldwide

ASTM International
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA 19428-2959

Printed in the U.S.A.

ASTM Stock #: STP1513

Library of Congress Cataloging-in-Publication Data

ISBN: 978-0-8031-3425-6

ISSN: 1050 7515

Copyright © 2010 ASTM INTERNATIONAL, West Conshohocken, PA. All rights reserved. This material may not be reproduced or copied, in whole or in part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of the publisher.

Journal of ASTM International (JAI) Scope

The JAI is a multi-disciplinary forum to serve the international scientific and engineering community through the timely publication of the results of original research and critical review articles in the physical and life sciences and engineering technologies. These peer-reviewed papers cover diverse topics relevant to the science and research that establish the foundation for standards development within ASTM International.

Photocopy Rights

Authorization to photocopy items for internal, personal, or educational classroom use, or the internal, personal, or educational classroom use of specific clients, is granted by ASTM International provided that the appropriate fee is paid to ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9634; online: <http://www.astm.org/copyright>.

The Society is not responsible, as a body, for the statements and opinions expressed in this publication. ASTM International does not endorse any products represented in this publication.

Peer Review Policy

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

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 the peer reviewers. In keeping with long-standing publication practices, ASTM International maintains the anonymity of the peer reviewers. The ASTM International Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM International.

Citation of Papers

When citing papers from this publication, the appropriate citation includes the paper authors, "paper title", J. ASTM Intl., volume and number, Paper doi, ASTM International, West Conshohocken, PA, Paper, year listed in the footnote of the paper. A citation is provided as a footnote on page one of each paper.

Foreword

THIS COMPILATION OF THE *JOURNAL OF ASTM INTERNATIONAL (JAI)*, STP1513, on *Effects of Radiation on Nuclear Materials and the Nuclear Fuel Cycle: 24th Volume*, contains only the papers published in JAI that were presented at a symposium in Denver, CO from June 24–26, 2008 and sponsored by ASTM Committees E10 on Nuclear Technology and its Applications and C26 on the Nuclear Fuel Cycle.

The JAI Guest Editors are Jeremy T. Busby, Materials Science and Technology, Oak Ridge National Laboratory, Oak Ridge, TN, and Brady D. Hanson, Radiochemical Science and Engineering, Pacific Northwest National Laboratory, Richland, WA.

Contents

Overview	vii
International Atomic Energy Agency Coordinated Research Projects on Structural Integrity of Reactor Pressure Vessels	
W. L. Server and R. K. Nanstad	1
Analysis of the Belgian Surveillance Fracture Toughness Database Using Conventional and Advanced Master Curve Approaches	
E. Lucon, M. Scibetta, and R. Gérard	26
Final Results from the Crack Initiation and Arrest of Irradiated Steel Materials Project on Fracture Mechanical Assessments of Pre-Irradiated RPV Steels Used in German PWR	
H. Hein, E. Keim, H. Schnabel, T. Seibert, and A. Gundermann	40
Embrittlement Correlation Method for the Japanese Reactor Pressure Vessel Materials	
N. Soneda, K. Dohi, A. Nomoto, K. Nishida, and S. Ishino	64
Magnox Steel Reactor Pressure Vessel Monitoring Schemes—An Overview	
M. R. Wootton, R. Moskvic, C. J. Bolton, and P. E. J. Flewitt	93
Investigation of Beltline Welding Seam of the Greifswald WWER-440 Unit 1 Reactor Pressure Vessel	
H. W. Viehrig, J. Schuhknecht, U. Rindelhardt, and F. P. Weiss	114
Microstructural Characterization of RPV Materials Irradiated to High Fluences at High Flux	
N. Soneda, K. Dohi, K. Nishida, A. Nomoto, M. Tomimatsu, and H. Matsuzawa	128
Irradiation-Induced Grain-Boundary Solute Segregation and Its Effect on Ductile-to-Brittle Transition Temperature in Reactor Pressure Vessel Steels	
Y. Nishiyama, M. Yamaguchi, K. Onizawa, A. Iwase, and H. Matsuzawa	152
Irradiation-Induced Hardening and Embrittlement of High-Cr ODS Ferritic Steels	
J. H. Lee, R. Kasada, H. S. Cho, and A. Kimura	163
Kinetic Monte Carlo Simulation of Helium-Bubble Evolution in ODS Steels	
A. Takahashi, S. Sharafat, K. Nagasawa, and N. Ghoniem	175
Study of Microstructure and Property Changes in Irradiated SS316 Wrapper of Fast Breeder Test Reactor	
C. N. Venkiteswaran, V. Karthik, P. Parameswaran, N. G. Muralidharan, V. A. Raj, S. Saroja, V. Venugopal, M. Vijayalakshmi, K. V. K. Viswanathan, and B. Raj	195
Unusual Enhancement of Ductility Observed During Evolution of a “Deformation Wave” in 12Cr18Ni10Ti Stainless Steel Irradiated in BN-350	
M. N. Gusev, O. P. Maksimkin, I. S. Osipov, N. S. Silniagina, and F. A. Garner	209
Interrelationship between True Stress–True Strain Behavior and Deformation Microstructure in the Plastic Deformation of Neutron-Irradiated or Work-Hardened Austenitic Stainless Steel	
K. Kondo, Y. Miwa, T. Tsukada, S. Yamashita, and K. Nishinoiri	219
Influence of Neutron Irradiation on Energy Accumulation and Dissipation during Plastic Flow and Hardening of Metallic Polycrystals	
D. A. Toktogulova, M. N. Gusev, O. P. Maksimkin, and F. A. Garner	237

Comparison of CANDU Fuel Bundle Finite Element Model with Unirradiated Mechanical Load Experiments

T. J. Lampman, A. Popescu, and J. Freire-Canosa	251
Author Index	275
Subject Index	277

Overview

The Effects of Radiation on Materials series began in 1956 with a meeting jointly sponsored by the E-10 Committee (called the Committee on Radioisotopes and Radiation Effects at the time) and the Atomic Industrial Forum. In 1960, this symposium transitioned to its current format under the E-10 Committee and, for the past 44 years, this symposium has been an international forum. In this most recent meeting, over half of the presentations originated outside the United States with lead authors from eleven different countries. These proceedings reflect that international scope.

The 24th Symposium on the Effects of Radiation on Materials marked the first joint sponsorship between the E-10 and C-26 Committees. The expanded meeting scope was well received as the broader view provided an opportunity to examine radiation damage for the entire fuel cycle.

These proceedings continue the long-established strength and depth of the Effects of Radiation on Materials series. Papers on radiation effects in reactor pressure vessel steels are again an integral component with specific topics ranging from surveillance programs around the world to detailed characterization of irradiated microstructures. Radiation effects in oxide-dispersion strengthened alloys and austenitic stainless steels are also included with several papers highlighting renewed interest in non-uniform deformation in these steels. The balance of the papers covers a diverse set of radiation-effects topics, ranging from modeling helium bubbles to finite-element modeling of fuel bundles.

The editors wish to express our gratitude to all of the reviewers, who are a vital component in a publication of this quality. The ASTM staff also played a key role in the production of these proceedings. Finally, and most importantly, we would like to thank the symposium presenters and authors for their participation and dedication to this series.

Jeremy T. Busby
Oak Ridge National Laboratory

Brady D. Hanson
Pacific Northwest National Laboratory



www.astm.org

ISBN: 978-0-8031-5523-7

Stock #: STP1513