

EFFECTS OF RADIATION ON STRUCTURAL MATERIALS

*Proceedings of the
Ninth International
Symposium*

SPRAGUE/KRAMER, editors

 **STP 683**

**AMERICAN SOCIETY FOR
TESTING AND MATERIALS**

EFFECTS OF RADIATION ON STRUCTURAL MATERIALS

Proceedings of the
Ninth International
Symposium

A symposium
sponsored by ASTM
Committee E-10 on
Nuclear Technology
and Applications
AMERICAN SOCIETY FOR
TESTING AND MATERIALS
Richland, Wash., 11-13 July 1978

ASTM SPECIAL TECHNICAL PUBLICATION 683
J. A. Sprague, Naval Research Laboratory, and
David Kramer, Atomics International, editors

List price \$58.50
04-683000-35



AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race Street, Philadelphia, Pa. 19103

Copyright © by AMERICAN SOCIETY FOR TESTING AND MATERIALS 1979
Library of Congress Catalog Card Number: 79-50935

NOTE

The Society is not responsible, as a body,
for the statements and opinions
advanced in this publication.

Printed in Baltimore, Md.
October 1979

Foreword

The ninth International Symposium on Effects of Radiation on Structural Materials was held in Richland, Washington, 11-13 July 1978. The symposium was sponsored by the American Society for Testing and Materials through its Committee E-10 on Nuclear Technology and Applications. J. A. Sprague, Naval Research Laboratory, and David Kramer, Atomics International, presided as chairmen and editors of this publication.

Related ASTM Publications

Irradiation Effects on the Microstructure and Properties of Metals, STP 611 (1976), \$49.00, 04-611000-35

Effects of Radiation on Substructure and Mechanical Properties of Metals and Alloys, STP 529 (1973), \$49.50, 04-529000-35

Unified Numbering System for Metals and Alloys, DS 56A (1977), \$49.00, 05-056001-01

Radiation Effects Information Generated on the ASTM Reference Correlation—Monitor Steels, DS 54 (1974), \$9.75, 05-054000-35

A Note of Appreciation to Reviewers

This publication is made possible by the authors and, also, the unheralded efforts of the reviewers. This body of technical experts whose dedication, sacrifice of time and effort, and collective wisdom in reviewing the papers must be acknowledged. The quality level of ASTM publications is a direct function of their respected opinions. On behalf of ASTM we acknowledge with appreciation their contribution.

ASTM Committee on Publications

Editorial Staff

Jane B. Wheeler, *Managing Editor*
Helen M. Hoersch, *Associate Editor*
Ellen J. McGlinchey, *Senior Assistant Editor*
Helen Mahy, *Assistant Editor*

Contents

Introduction	1
MICROSTRUCTURE	
Determination of the Nature of Neutron Irradiation-Induced Dislocation Loops in Magnesium Using Electron Irradiation in the Transmission Electron Microscope—A. WOLFENDEN	5
Radiation Effects on Molybdenum Alloys Bombarded by Electrons in a High-Voltage Electron Microscope—N. IGATA, A. KOHYAMA, AND K. ITADANI	12
Microstructural Development During Low-Dose Irradiation—B. O. HALL AND D. I. POTTER	32
Neutron Irradiation-Induced Defect Structures in Zirconium—A. JOSTSONS, P. M. KELLY, R. G. BLAKE, AND K. FARRELL	46
Irradiation Growth in Zirconium and Its Alloys—D. O. NORTHWOOD	62
Dependence of Cavity Nucleation Density Upon Gas Implantation Rate and Its Importance in Dual-Beam Irradiation Conditions—M. R. HAYNS, M. H. WOOD, AND R. BULLOUGH	77
Response of Inconel 600 to Simulated Fusion Reactor Irradiation—F. W. WIFFEN	88
Effects of Neutron Irradiation on the Microstructure of Niobium and Niobium-Base Alloys—D. J. MICHEL AND H. H. SMITH	107
Effects of Bombarding Ions on the Void Swelling Profile in Nickel—J. B. WHITLEY, G. L. KULCINSKI, H. V. SMITH, JR., AND P. WILKES	125
Development of Physically Based Void Swelling Equations for Engineering and Design Use—M. R. HAYNS AND R. BULLOUGH	143
A Reassessment of the Role of Stress in Development of Radiation-Induced Microstructure—F. A. GARNER, W. G. WOLFER, AND H. R. BRAGER	160

Radiation-Induced Segregation in Nickel-Silicon Alloys—L. E. REHN, P. R. OKAMOTO, D. I. POTTER, AND H. WIEDERSICH	184
An Example of Precipitate Stability in Reactor-Irradiated Nimonic PE16—D. S. GELLES	194
Dependence of Void Formation on Phase Stability in Neutron-Irradiated Type 316 Stainless Steel—H. R. BRAGER AND F. A. GARNER	207

FRACTURE OF THERMAL REACTOR MATERIALS

Evaluation of Commercial Production A533-B Steel Plates and Weld Deposits with Extra-Low Copper Content for Radiation Resistance—J. R. HAWTHORNE, J. J. KOZIOL, AND S. T. BYRNE	235
An Empirical Evaluation of the Irradiation Sensitivity of Reactor Pressure Vessel Materials—J. D. VARSIK AND S. T. BYRNE	252
Irradiation Behavior of Nickel-Chromium-Molybdenum Type Weld Metal—E. N. KLAUSNITZER, A. GERSCHA, AND C. LEITZ	267
Exploratory Investigations of Cyclic Irradiation and Annealing Effects on Notch Ductility of A533-B Weld Deposits— J. R. HAWTHORNE, H. E. WATSON, AND F. J. LOSS	278
Effect and Possibilities of Irradiation Results Error Correction (Demonstrated on the Results of the IAEA Coordinated Program)— G. NAGEL	295
Fracture Toughness of Irradiated Beryllium—J. M. BEESTON	309

PRIMARY DAMAGE PRODUCTION AND IRRADIATION CREEP SIMULATION

Irradiation Creep and Growth in Zirconium During Proton Bombardment—D. FAULKNER AND R. J. McELROY	329
Radiation Damage Effects in 16-MeV Proton and 14-MeV Neutron Irradiated Nickel and Niobium—R. H. JONES, D. L. STYRIS, AND E. R. BRADLEY	346

DOSIMETRY AND DAMAGE FUNCTION ANALYSIS

Helium Production in Fast Breeder Reactor Out-of-Core Structural Components—R. L. SIMONS	365
---	-----

- Radiation Damage Function Analysis**—R. GOLD, E. P. LIPPINCOTT,
W. N. McELROY, AND R. L. SIMONS 380
- Solid-State Track Recorder Materials for Use in Light-Water-
Reactor Pressure Vessel Surveillance Exposures**—R. GOLD,
J. H. ROBERTS, AND F. H. RUDDY 402

MECHANICAL PROPERTIES

- Microstructure and Tensile Properties of Heavily Irradiated 1100-0
Aluminum**—K. FARRELL AND A. E. RICHT 427
- Tensile Properties of Neutron-Irradiated 6061 Aluminum Alloy in
Annealed and Precipitation-Hardened Conditions**—K. FARRELL
AND R. T. KING 440
- Tensile Property Correlations for Highly Irradiated 20 Percent Cold-
Worked Type 316 Stainless Steel**—R. L. FISH, N. S. CANNON,
AND G. L. WIRE 450
- Low-Cycle Fatigue of Three Irradiated and Unirradiated Vanstar Al-
loys**—G. E. KORTH AND R. E. SCHMUNK 466
- Effects of Neutron Irradiation and Fatigue on Ductility of Stainless
Steel DIN 1.4948**—M. I. DE VRIES, B. VAN DER SCHAAF,
H. U. STAAL, AND J. D. ELEN 477
- Estimates of Time-Dependent Fatigue Behavior of Type 316
Stainless Steel Subject to Irradiation Damage in Fast Breeder
and Fusion Power Reactor Systems**—C. R. BRINKMAN, K. C. LIU,
AND M. L. GROSSBECK 490
- Fracture Toughness of Irradiated AISI 304 and 316L Stainless
Steels**—J. DUFRESNE, B. HENRY, AND H. LARSSON 511
- Fracture Toughness of Irradiated Nimonic PE16 at High Tempera-
tures**—R. D. NICHOLSON AND R. B. JONES 529
- Effects of Irradiation on the Mechanical Properties of Austenitic
Stainless Steels Under Dynamic Loading**—C. ALBERTINI,
A. DEL GRANDE, AND M. MONTAGNANI 546
- Effects of Irradiation Temperature, Fluence, and Heating Rate on
Postirradiation Flow Properties of Cladding Under Simulated**

Temperature Transient Heating and Deformation Conditions— N. S. CANNON AND D. R. DUNCAN	557
Effects of Irradiation Creep on Ex-Reactor Mechanical Properties— D. R. DUNCAN	567
CREEP	
Formulation of Constitutive Laws for Deformation During Irradia- tion— W. G. WOLFER	581
Irradiation Creep in Bending of Cold-Worked AISI 316 Stainless Steel at Low Neutron Fluence— A. J. McSHERRY, M. R. PATEL, J. MARSHALL, AND W. K. APPLEBY	598
A Comparison of Fuel Pin Deformations with Pressurized Tube Creep Tests— J. P. TAYLOR, E. R. GILBERT, AND A. J. LOVELL	608
Reduction of Irradiation-Induced Creep by Point-Defect Trapping— L. K. MANSUR AND W. G. WOLFER	624
Irradiation Creep Due to Stress-Induced Preferred Absorption of Point Defects in Zirconium Single Crystals— C. H. WOO	640
In-Reactor Deformation and Fracture of Austenitic Stainless Steels— E. E. BLOOM AND W. G. WOLFER	656
SUMMARY	
Summary	675
Index	681

