EFFECTS OF RADIATION ON MATERIALS

Proceedings of the Tenth International Symposium

Kramer/Brager/Perrin, editors

ASTM STP 725

AMERICAN SOCIETY FOR TESTING AND MATERIALS
EFFECTS OF RADIATION ON MATERIALS

Proceedings of the Tenth International Symposium

A symposium sponsored by ASTM Committee E-10 on Nuclear Technology and Applications

AMERICAN SOCIETY FOR TESTING AND MATERIALS
Savannah, Ga., 3-5 June 1980

ASTM SPECIAL TECHNICAL PUBLICATION 725
David Kramer, Rockwell International, H. R. Brager, Westinghouse Hanford Co., and J. S. Perrin, Battelle Columbus Laboratories, editors

ASTM Publication Code Number (PCN)
04-725000-35

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

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

The Tenth International Symposium on Effects of Radiation on Materials was held in Savannah, Georgia, 3-5 June 1980. The symposium was sponsored by the American Society for Testing and Materials through its Committee E-10 on Nuclear Technology and Applications. David Kramer, Rockwell International, presided as chairman of the symposium with H. R. Brager, Westinghouse Hanford Company, and J. S. Perrin, Battelle Columbus Laboratories, as cochairmen. David Kramer, H. R. Brager, and J. S. Perrin are editors of this publication.
Related
ASTM Publications

Effects of Radiation on Structural Materials, STP 683 (1979), $58.50, 04-683000-35

Irradiation Effects on the Microstructural and Properties of Metals, STP 611 (1978), $49.00, 04-611000-35

Properties of Reactor Structural Alloys After Neutron or Particle Irradiation, STP 570 (1976), $59.50, 04-570000-35

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

Irradiation Effects on Structural Alloys for Nuclear Reactor Applications, STP 484 (1971), $49.25, 04-484000-35

Analysis of Reactor Vessel Radiation Effects Surveillance Programs, STP 481 (1970), $26.00, 04-481000-35


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, Senior Associate Editor
Helen P. Mahy, Senior Assistant Editor
Allan S. Kleinberg, Assistant Editor
# Contents

## Introduction

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal Reactor Vessels</strong></td>
<td></td>
</tr>
<tr>
<td>Apparent Embrittlement Saturation and Radiation Mechanisms of Reactor Pressure Vessel Steels—D. Pachur</td>
<td>5</td>
</tr>
<tr>
<td>Correlation Between Microhardness, Tensile Properties, and Notch Ductility of Irradiated Ferritic Steels—J. F. Mancuso, J. A. Spitznagel, R. P. Shogan, and J. R. Holland</td>
<td>38</td>
</tr>
<tr>
<td>Irradiation Surveillance Program as Applied in Switzerland—D. H. Njo and T. Varga</td>
<td>49</td>
</tr>
<tr>
<td>Experimental Investigation of Multicycle Irradiation and Annealing Effects on Notch Ductility of A533-B Weld Deposits—J. R. Hawthorne, H. E. Watson, and F. J. Loss</td>
<td>63</td>
</tr>
<tr>
<td>Influence of Neutron Irradiation on Mechanical Properties of Steels Under Impulsive Loading—J. Buchar and Z. Bílek</td>
<td>92</td>
</tr>
<tr>
<td>Fatigue Crack Growth Rates of Irradiated Pressure Vessel Steels in Simulated Nuclear Coolant Environment—W. H. Cullen, H. E. Watson, R. E. Taylor, and K. Torronen</td>
<td>102</td>
</tr>
</tbody>
</table>

## Solid Radioactive Waste

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
</table>
FUNDAMENTAL STUDIES

An Internally Consistent Model for Radiation-Induced Void Swelling—F. A. Nichols and Y. Y. Liu 145

Radiation-Enhanced Diffusion in Face-Centered Cubic Materials—Wolfgang Schüle 166

Positron Lifetime Studies of Electron-Irradiated Copper—T. D. Hadnagy, J. G. Byrne, and G. R. Miller 178

Simulation of Short-Term Annealing of Displacement Cascades in Face-Centered Cubic Metals—H. L. Heinisch, D. G. Doran, and D. M. Schwartz 191

High-Density Equation of State for Helium and Its Application to Bubbles in Solids—W. G. Wolfer 201

Applications of the Theory of Cavity Growth to Dual-Ion Swelling Experiments—M. R. Hayns and L. K. Mansur 213

MECHANICAL PROPERTIES


Fracture Resistance of HT-9 After Irradiation at Elevated Temperature—F. A. Smidt, Jr., J. R. Hawthorne, and V. Provenzano 269


Mechanical and Physical Properties of Irradiated Type 348 Stainless Steel—J. M. Beeston 303

Tensile Properties of Neutron-Irradiated Nimonic PE16—R. Bajaj, R. P. Shogan, C. Deflitch, R. L. Fish, M. M. Paxton, and M. L. Bleiberg 326
Effects of Neutron Irradiation on Fatigue and Creep-Fatigue Crack Propagation in Type 316 Stainless Steel at 649°C—D. J. MICHEL AND H. H. SMITH 352

State Variable Description of 316 Stainless Steel Postirradiation Mechanical Properties—G. L. WIRE 375


Coarse Slip Processes and Crack Propagation in Irradiated Stainless Steel—J. A. HORTON AND W. A. JESSER 413

Dynamic Mechanical Properties of AISI 304L Irradiated to 2.2 dpa—C. ALBERTINI, A. DEL GRANDE, AND M. MONTAGNANI 431

Postirradiation Cladding Strength Under Biaxial Loading with an Increasing Temperature Ramp—D. R. DUNCAN AND C. W. HUNTER 443

Microstructure and Swelling


Microchemical Evolution of Neutron-Irradiated Stainless Steel—H. R. BRAGER AND F. A. GARNER 470

Comparison of High-Fluence Swelling Behavior of Austenitic Stainless Steels—R. A. WEINER AND A. BOLTAX 484

Response to Annealing and Reirradiation of AISI 304L Stainless Steel Following Initial High-Dose Neutron Irradiation in EBR-II—D. L. PORTER, G. L. MCVAY, AND L. C. WALTERS 500

Point-Defect Clustering in the Presence of Mobile Helium and Immobile Traps—B. O. HALL 512

Effects of Dose Rate on the Precipitate Distribution in an Ion-Irradiated Nickel-Aluminum Alloy—J. A. SPRAGUE, J. E. WESTMORELAND, F. A. SMIDT, JR., AND P. R. MALMBERG 528

Gamma Prime Coarsening and Redistribution in Nimonic PE16—D. S. GELLES 562

Effect of Material Variables on the Irradiation Performance of Boron Carbide—J. A. BASMAJIAN AND G. W. HOLLENBERG 583

A Microstructural Explanation for the Low Swelling of Ferritic Steels—R. BULLOUGH, M. H. WOOD, AND E. A. LITTLE 593

Irradiation-Induced Precipitation in Binary Palladium-Refractory Metal Alloys—L. WEAVER AND A. J. ARDELL 610

Void Swelling in Molybdenum Alloys In Situ Observed by a High-Voltage Electron Microscope—N. IGATA, A. KOHYAMA, AND S. NOMURA 627

A Study of Radiation Damage Produced in Thinned Specimens of 316 Stainless Steel by Energetic Helium Ions—L. L. HORTON AND W. A. JESSER 642

Helium Bubble Growth in Vanadium—S. K. TYLER AND P. J. GOODHEW 654

Creep Swelling Behavior

Irradiated Materials Measurement Technology—E. R. GILBERT AND B. A. CHIN 665


Reduction of Irradiation-Induced Creep and Swelling in AISI 316 by Compositional Modifications—J. F. BATES, R. W. POWELL, AND E. R. GILBERT 713