



FOURTEENTH INTERNATIONAL SYMPOSIUM

# ZIRCONIUM *in the* NUCLEAR INDUSTRY



INTERNATIONAL

Standards Worldwide

STP 1467

**Peter Rudling  
Bruce Kammenzind  
Editors**

STP 1467

# *Zirconium in the Nuclear Industry: Fourteenth International Symposium*

*Peter Rudling and Bruce Kammenzind, editors*

ASTM Stock Number: STP1467



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

Printed in the U.S.A.

ISBN: 0-8031-3493-2

ISSN: 1050-7558

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# Foreword

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This publication, *Zirconium in the Nuclear Industry: Fourteenth International Symposium*, contains papers presented at the symposium with the same name held in Stockholm, Sweden, June 13–17, 2004. The sponsor of the symposium was ASTM International Committee B10 on Reactive and Refractory Metals and Alloys.

The symposium chairman was Peter Rudling, ANT International, the symposium co-chairman was Mangnus Limback Westinghouse Electric Sweden, and the editorial chairman was Bruce Kammenzind Bettis Laboratory Bechtel Corporation. Serving as editors of this publication were Peter Rudling and Bruce Kammenzind.

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# Overview

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This STP contains the papers presented at the 14<sup>th</sup> International Symposium on Zirconium in the Nuclear Industry held in Stockholm, Sweden June 13 through 17, 2004. The first symposium was held in Philadelphia in 1968, and symposiums have been held ever since in two to three year intervals. The proceedings of each symposium in the series have been documented with an STP.

This symposium series has been one of the premier forms for the presentation of worldwide research in the area of zirconium alloy performance in a nuclear reactor environment. Forty-two papers and twenty-two posters were selected for presentation at the 14<sup>th</sup> Symposium from 113 abstracts submitted. The forty-one papers published in these proceedings were peer reviewed and edited, and are also published in the ASTM On Line Journal, (JAI). In addition, the most significant parts of the discussions that followed the oral presentation of each paper at the symposium are included in these proceedings. Finally, E. Tenckhoff and G. Sabol, made presentations on historical aspects of research in Zirconium alloys when they received their Kroll Awards at the 14<sup>th</sup> Symposium. In all, two hundred three delegates from sixteen countries attended the 14<sup>th</sup> Symposium with presentations from North America, Europe and Asia, making the conference truly international in scope and content.

Historically, in commercial reactors, Zircaloy-2, Zircaloy-4 and Zr-1Nb alloys have been used as material for fuel assembly components, while Zr-2.5Nb materials have been used for pressure tubes. During the 1980's and 1990's, the increased fuel element corrosion observed in the "hot" Swiss and German PWR plants prompted the PWR fuel vendors to replace the Zircaloy-4 cladding material with more corrosion resistant materials. This situation was the driving force for the development of the various PWR corrosion resistant Zr-Nb materials and the Zircaloy materials with low tin contents that are commercially available today. The deregulation of the electricity market and increased competition from other sources of electricity continue to require utilities reduce fuel cycle costs through increased fuel burnup, more aggressive fuel management schemes, and increased operating flexibility (such as load following). At the same time the regulatory agencies require that safety margins be maintained or enhanced, maintaining pressure for zirconium alloys and components with improved corrosion, deformation and fracture resistance, and for improved predictive capabilities of zirconium alloy performance.

The papers and posters presented at the 14<sup>th</sup> Symposium covered all aspects of the fuel cycle, with the oral presentation divided into seven sessions. The Basic Metallurgy and the Fabrication and Processing sessions represented the beginning of the fuel cycle from component design and manufacture; the BWR Corrosion, the PWR Corrosion, and the Deformation Mechanism sessions represented component performance under nominal service conditions; the Primary Failure Mechanism and the Transient and High Temperature Performance sessions represented aspects that might end the useful service life of the component. Finally, some papers and posters covered post service life of the component in a dry storage and in a repository environment representing the final disposal portion of the fuel cycle. In all, the current material related issues facing the industry are well reflected and represented in the papers and poster displays presented at the Stockholm conference.

As a whole, several themes were evident throughout the 14<sup>th</sup> Symposium. First the Industry has readily embraced new analytical tools and applied them to better understand old problems. Examples include the use of Focused Ion Beam (FIB) for TEM sample preparation of corrosion film cross

sections; the Orientation Imaging Microscope (OIM) to consider the meso-scale microstructure, relating grain to grain texture variations to processing and deformation behavior; and synchrotron radiation to more clearly understand fine scale microstructure and microchemistry variations within the metal and the corrosion film. Second, the Industry has maintained a focus on improving component performance through alloying element and processing modifications and successfully introduced several such modifications into the marketplace. Examples include the ZIRLO and M5 cladding alloys that now make up the majority of new cladding tube orders for PWR applications. Third, the Industry has maintained a strong mechanistic focus as to why these alloy and processing modifications matter, and a desire to improve the fundamental understanding of zirconium alloy performance in a nuclear environment with improved analytical models that may someday reduce dependence on expensive experimentation. Fourth, the industry is embracing advances in computational science and finite element methods and considering their use in the up-front design of experiments. Finally, the conference was well attended by a healthy mix of established experts in the field who have made many contributions in the past, and by a large number of younger new scientists who bring new ideas and enthusiasm to the work and who represent the community that will carry the industry into this next century.

The John Schemel Award is awarded following each symposium for the best paper presented at the symposium. The selection is based upon the technical content of the paper, the usefulness of the work reported to the worldwide reactor component community, and the technical difficulty in doing the work. This year a committee of technical experts in several aspects of the zirconium industry selected the paper entitled "Plastic Deformation of Irradiated Zirconium Alloys: TEM Investigation and Micro-Mechanical Modeling" by F. Onimus, J. -L. Bechade, S. Doriot, I. Monnet, D. Gilbon, B. Verhaegue, C. Prioul, P. H. Pilvin, L. Robert, L. Legras, and J. -P. Mardon to receive the John Schemel Award.

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ISBN 0-8031-3493-2  
Stock #: STP1467