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SHREIR'S CORROSION

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SHREIR'S CORROSION
FOURTH EDITION

Volume 1
BASIC CONCEPTS, HIGH TEMPERATURE CORROSION

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Editorial Board

Bob Cottis graduated from the University of Cambridge in the 1960s/70s with MA (Metallurgy) and PhD (Metallurgy) degrees. He then worked in contract research in the corrosion group at the Fulmer Research Institute, where he was involved in major research projects in the general area of corrosion, corrosion fatigue and other aspects of environmentally-assisted fracture. In addition he undertook many corrosion- and materials-related failure investigations. In 1979 he moved to the Corrosion and Protection Centre at UMIST, later University of Manchester, where he is now Professor of Corrosion Science and Engineering. His research interests are in the areas of environmentally-assisted fracture, localized corrosion, the electrochemistry of corrosion and the application of computing techniques to the control of corrosion.

Bob initiated the regular triennial EMCR (Electrochemical Methods in Corrosion Research) conference series, and has been on the organising or scientific committees of numerous other conferences. He is founding editor of the online Journal of Corrosion Science and Engineering, and co-founder of the Corros-L corrosion mailing list. He was awarded the T. J. Hull Award of NACE International in 2005 for contributions in the field of publication, and elected Fellow of NACE International in 2009. He has been active in the application of new technology to corrosion education, co-ordinating the Ecorr (Engineering Corrosion) project that developed computer-assisted learning materials for the support of the study of corrosion by engineering students, and leading the development of an online distance learning route for the established MSc in Corrosion Control Engineering offered by UMIST/University of Manchester.

Michael Graham graduated from the University of Liverpool with BSc (Chemistry) and PhD (Surface Science), before accepting in 1965 a Post-Doctoral Fellowship at the National Research Council of Canada (NRC). He was also a Research Officer at Berkeley Nuclear Laboratories, before returning to NRC, becoming in 1977 Head of Metallic Corrosion and Oxidation, and later Group Leader of Surfaces and Interfaces. He is currently an NRC Researcher Emeritus and for many years has been a Visiting Professor at the Corrosion and Protection Centre.

Professor Graham is a Past Chairman of the International Corrosion Council, recipient of the W. R. Whitney Award of NACE International, Queen Elizabeth's Jubilee Medal, H. H. Uhlig Award of the Electrochemical Society, U. R. Evans Award of the Institute of Corrosion and the T. P. Hoar Prize of the Institute of Corrosion. His research interests include

thin film formation on metals and semiconductors, high temperature oxidation, and surface passivation and film breakdown. He has over 260 publications.

Robert Lindsay received a BSc in Chemistry from the University of Bristol, and a PhD from the University of Liverpool. He has had appointments at a number of research institutions, including the Fritz-Haber-Institut (Berlin), Cambridge University, and the CSIC Institute of Materials (ICMAB) in Barcelona. Currently, he is a lecturer in the Corrosion and Protection Centre, University of Manchester.

Rob's research is concerned with studying surfaces under controlled conditions to elucidate nanoscale details, focusing primarily on geometric structure determination. Currently, he is employing such an approach to understand corrosion inhibition at the atomic/molecular level. He has published over 60 articles, including several reviews.

Stuart Lyon is Professor of Corrosion Control Technology and Head of the Corrosion and Protection Centre in the School of Materials, University of Manchester. He is a Trustee and former Executive President of the Institute of Corrosion, and Managing Director of its trading subsidiary (Correx Ltd.) as well as a Member of the Board of Administrators of the World Corrosion Organisation. Research interests, which were recognised by the award of the DSc degree by the former UMIST in 2002, include: atmospheric corrosion and degradation, corrosion protection using organic coatings, corrosion inhibition, corrosion monitoring and localised corrosion. Stuart is Editor-in-Chief of Corrosion Engineering Science and Technology, a publication of Institute of Materials.

Tony Richardson graduated from UMIST in the 1960s with BSc (Chemistry) and PhD (Corrosion) degrees. He spent most of his career in industry, working as a materials/corrosion engineer, initially for Unilever, and subsequently for ICI plc, where he led the Company's materials engineering group. For 5 years in the 1970s Tony was a full-time academic in the Corrosion and Protection Centre at UMIST. When he returned to industry, he retained his association with UMIST/University of Manchester, contributing to the Corrosion and Protection Centre as a visiting professor, and also more widely as a Royal Academy of Engineering Visiting Professor in the Principles of Engineering Design. He has also served on the Research Boards of the Welding Institute in the UK, and the Materials Technology Institute in the USA. He retired from ICI plc in 2000 to form Anticorrosion Consulting, which offers independent materials/corrosion consultancy to the chemical process industries.

Tony has been a regular organiser and contributor to international corrosion conferences, served on the editorial board of Corrosion Engineering, Science & Technology for many years, and has contributed regularly to the research and practice literature. In 1979, he was a first recipient of the Guy Bengough medal of the Institute of Materials, Minerals and Mining.

David Scantlebury

My research interests and my major teaching are closely interrelated. For the whole of my academic career (nearly forty years!), I have been interested in the strange situation between a potentially corroding metal and the organic coating that is placed on that metal with the intention of preventing corrosion of that metal. There is a fascinating mixture of knowledge and disciplines overlapping, that I find attractive, including metallurgy, surface science, adhesion, electrochemistry, and polymer science. And all this arises from real problems with real solutions. My other related research interests include marine corrosion, cathodic protection, and the corrosion and corrosion control of rebar steel in concrete. I teach all these subjects mainly in Module 6 in the MSc in Corrosion Control Engineering but as well I give most of the year two undergraduate lectures in the Materials Science degree course. Since 1989, I have organised a five yearly international conference on corrosion protection by organic coatings, the next and fifth is in September 2009 at Christ's College Cambridge. My next and second Cathodic Protection Conference is here in Manchester 6/7th February 2006.

My administrative duties include being the course director for the MSc course in Corrosion Engineering and Control and the one week annual Short Course in Corrosion Engineering, now in its 35th year.

I have supervised some sixty successful PhD students from every part of the world and this social, intellectual and cultural interaction is one of the most satisfying features of my work. I currently hold a visiting Chair in the Department of Chemistry, University of Xiamen, China.

Link to Original Source: http://www.materials.manchester.ac.uk/aboutus/staff/davidscantlebury/

Howard Stott graduated from the University of Cambridge with a BA (Metallurgy) degree in 1967 and from UMIST with a PhD degree in High Temperature Oxidation in 1970. He was a Post-Doctoral Research Associate before being appointed Lecturer in the Corrosion and Protection Centre, UMIST in 1972. He was promoted to Senior Lecturer followed by Reader then Professor in 1990. He was administrative Head of the Corrosion and Protection Centre for three 3-year periods from 1987 until 2003 and was Operations Director of The Materials Performance Centre for the following two years. He was awarded a DSc degree by the University of Manchester in 1984.

During his career at UMIST, he led a research group in the field of high temperature degradation and protection of materials, with over 50 research students and 30 PDRAs. He served on the Editorial Advisory Boards of Oxidation of Metals, Corrosion Science, Materials and Corrosion and Materials at High Temperature for many years. He was elected Fellow of the Royal Academy of Engineering in 2001 and was awarded the UR Evans Award by the Institute of Corrosion in the same year.

He retired from the University of Manchester (formerly UMIST) in 2006 and now lives in Vancouver, Canada.

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PART VI
CORROSION MANAGEMENT

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Foreword

In keeping with most of the colleagues who have edited this book, I had the good fortune to meet and know Lionel Shreir. We knew him first through the 1st edition of Corrosion, published in 1963, that was our introduction to the subject as we embarked on our postgraduate research. In the UK, Shreir's Corrosion was the one-stop-reference work that provided an introduction to most aspects of corrosion and its control, authored by the great and good of corrosion and heavily laced with scientific fundamentals. Later, we got to know Lionel personally as a very active educator, researcher and consultant during his tenure as Head of Metallurgy at Sir John Cass College in London. After Lionel's retirement, my predecessor, Graham Wood, invited Lionel to join us in the Corrosion and Protection Centre that had been established in Manchester in the early 1970s and we were delighted when he accepted an honorary position. He provided valuable advice and support and, in addition to his considerable professional talents that spawned an impressive collection of awards, he was a great encourager of the young and a very affable, charming colleague.

We are well placed in Manchester to take on the task of editing a 4th edition of Corrosion in having world class academics in most areas of corrosion science and engineering. Even so, I know that my colleagues thought long and hard before taking on such a challenging task and our affection and respect for Lionel were undoubtedly key influences on their decision to proceed. I applaud their efforts in delivering a 4th Edition of Corrosion, not least those of our retired and visiting professors, Howard Stott, Mike Graham and Tony Richardson, and I am delighted to see contributions from Manchester alumni from around the world. The Corrosion and Protection Centre is proud to be associated with this 4th Edition of Corrosion, which we dedicate to the memory of one of corrosion's godfathers, Lionel Shreir.

G E Thompson, OBE FREng,
Head, Corrosion and Protection Centre,
School of Materials,
University of Manchester

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Preface to the Fourth Edition

Over the 46 years since it was first published, Shreir's Corrosion has sustained its reputation as a major educational and reference work on all aspects of corrosion science and engineering. For the 3rd Edition, Lionel enlisted the assistance of Tim Burstein and Ray Jarman to edit the work and his good judgement was reflected in its continuing quality and popularity. So, in agreeing to take on the task of editing a 4th Edition of Shreir, we were keenly aware of our responsibility to maintain the reputation that the work has earned amongst our peers in the corrosion science and engineering communities, not to mention the wider engineering community, worldwide.

In approaching a 4th Edition, we decided to depart from the structure of previous editions and rebalance the content of the work to reflect the major advances that have been made since the work was first published in the techniques available for corrosion research, in our understanding of the mechanisms of aqueous and high temperature corrosion, and in the development of practices for the control and management of corrosion. Thus, we have commissioned new contributions on experimental techniques for the study of corrosion and the modeling and prediction of corrosion behaviour, and in an era of intense societal pressures to prevent major incidents that threaten safety, health and the environment, we have commissioned contributions on the management of corrosion in mature industries.

In making significant changes, we have been concerned to retain the essential character of Shreir's Corrosion, which has always doubled as part textbook and part reference work. As such, we hope that it will retain its wide appeal to all with a professional interest or involvement in corrosion, including graduate and post graduate students, academics who teach corrosion courses, or with active corrosion research interests and scientists and engineers of any discipline working as corrosion professionals in research or consulting, in supplying corrosion control services or corrosion resistant materials, or in organisations that operate physical assets of any type that are vulnerable to corrosion.

We would like to record our gratitude to our many authors from around the world for their willingness to produce chapters in times when both effort and time are scarcer commodities than used to be the case in professional life. We decided to retain some 'old master' contributions from Lionel himself, Tim Burstein, Robin Proctor, Jack Mayne and Redvers Parkins on fundamental topics that are essentially timeless. We have contributed some chapters ourselves and, as anyone previously involved in editing an undertaking such as this will understand, have attempted to update one or two existing chapters in haste where prospective authors were unable to deliver. While the outcome may not be perfect, we hope sincerely that it will prove as valuable to the corrosion science and engineering communities worldwide as its predecessors and, in so doing, will help repay our collective dues to Lionel Shreir, who started it all.

Finally, we record our gratitude to the Elsevier development and production staff who kept us on task throughout the project and worked so hard for a successful outcome, in particular Arnout Jacob, Adrian Shell, Natalia Kennedy, Nicola Lally, Simon Wood, Hilary Broadribb, Melinda Debreczeni, Beckie Brand, Fiona Geraghty, Hazel Harris, Gareth Steed, Bob Donaldson and last, but very definitely not least, Kostas Marinakis.

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L. L. Shreir, OBE, 1914–1992

In keeping with most of the colleagues who have edited this book, I had the good fortune to meet and know Lionel Shreir. We knew him first through the 1st edition of Corrosion, published in 1963, that was our introduction to the subject as we embarked on our postgraduate research. In the UK, Shreir's Corrosion was the one-stop-reference work that provided an introduction to most aspects of corrosion and its control, authored by the great and good of corrosion and heavily laced with scientific fundamentals. Later, we got to know Lionel personally as a very active educator, researcher and consultant during his tenure as Head of Metallurgy at Sir John Cass College in London. After Lionel's retirement, my predecessor, Graham Wood, invited Lionel to join us in the Corrosion and Protection Centre that had been established in Manchester in the early 1970s and we were delighted when he accepted an honorary position. He provided valuable advice and support and, in addition to his considerable professional talents that spawned an impressive collection of awards, he was a great encourager of the young and a very affable, charming colleague.

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