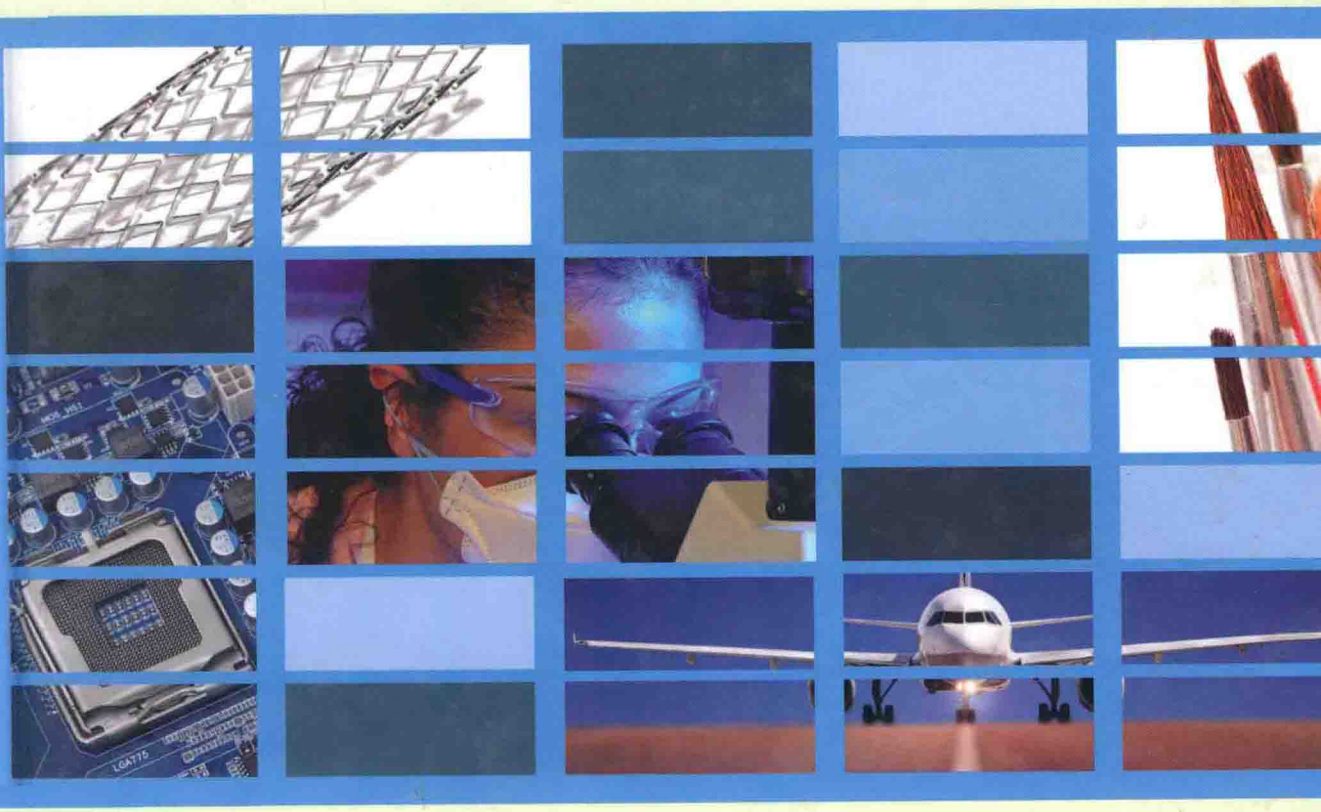
Second Edition

Handbook for CRITICAL CLEANING

APPLICATIONS, PROCESSES, AND CONTROLS



Edited by Barbara Kanegsberg
Edward Kanegsberg

CRC Press
Taylor & Francis Group

Second Edition

Handbook for CRITICAL CLEANING

APPLICATIONS, PROCESSES, AND CONTROLS

Edited by Barbara Kanegsberg
Edward Kanegsberg

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Cover design by David Kanegsberg.

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4398-2829-8 (Hardback)

Second Edition

Handbook for CRITICAL CLEANING

APPLICATIONS, PROCESSES, AND CONTROLS

To a beautiful, safe, productive world for the next generation

Noa Raeli Kanegsberg

To our most valuable collaborative efforts

Deborah Joan Kanegsberg and David Jule Kanegsberg

And to the memory and positive influence of

Israel Feinsilber

Jule Kanegsberg

Murray Steigman

Dr. Jacob J. Berman

Preface to the Second Edition

Why a Second Edition?

In the last few years, challenges to the manufacturing community have increased and so have performance expectations. With the ever-decreasing size of components, these expectations are becoming more difficult to meet. The second edition of the *Handbook for Critical Cleaning* hopes to help you meet these expectations and produce high-quality products in a cost-effective manner. Although cleaning is a process and not a chemical, increased awareness of the consequences of chemical use to workers, to the general public, and to the environment has prompted more stringent regulatory measures worldwide. Environmental and worker safety regulations are imperative to maintaining a decent quality of life on this planet and, perhaps, to our very survival. However, the goal of manufacturing is not to jump through regulatory hoops, but to produce efficient products. Compromising on the efficacy of cleaning and thereby producing a suboptimal product can affect public safety and can compromise on the quality of life. Manufacturers face the challenge of doing it all.

What Is Critical Cleaning?

Identify, then qualify/validate and monitor the critical cleaning steps. The terms "critical cleaning" and "precision cleaning" are often used interchangeably. However, we prefer the former term. Precision cleaning suggests cleaning in a highly restricted clean room, where each individual component is perhaps cleaned separately by a highly trained technician, where there are perhaps wet benches with automated product handling, and where there may be a multichamber-automated spray system that feeds directly into the clean room. This is a limited view of the important cleaning step. Perhaps the best way to define a critical cleaning step is to consider the negative consequences that arise if that step is not performed or is performed inadequately. Based on our experience, the important cleaning step, the *critical cleaning step*, may occur in a machine shop or in a job shop (e.g., a coating facility) in what appears, at first glance, like an automotive repair facility. If the soil (matter out of place) is not adequately removed at that step, subsequent processing and cleaning steps may not resolve the problem but may actually exacerbate contamination by inadvertent chemical reaction of the soil, drying of the soil, or by embedding the soil on the surface of the product. Contamination happens long before the product enters the clean room. A clean room can only minimize recontamination, and even the most sophisticated clean room or controlled environment cannot correct a contaminated product (Kanegsberg and Kanegsberg, 2010).

Lean Cleaning and Supply Chains

Economic pressures have led to the implementation of such concepts as lean cleaning and six-sigma; thus, we have to clean smarter. In fact, it is imperative that we clean smarter. Cleaning must be value added. Assess your own processes and understand the role that cleaning plays in those processes. Sometimes the value added is only appreciated by factoring in the costs of not cleaning or undercleaning at a particular step. Critical cleaning is not just about *what* is done or *how* it is done. It is also about *when* it is done. This becomes even more important when we realize that most products are not built from scratch within one facility. There usually is a complex supply chain of autonomous or semiautonomous facilities, which may sometimes be separate divisions or departments of the same company. Regardless of whether the supply chain involves inter- or intracompany processes, it is crucial that communication take place and that process understanding and process integration occur. The most critical cleaning step may be one that needs to take place at a supplier, before the part reaches your facility.

Critical Cleaning and Surfaces

Cleaning is removing undesired materials from surfaces without changing the surface in an unacceptable manner. As products get smaller, the surface becomes a greater percentage of the product. When products are at the nanoscale, it can be said that the product *is* the surface.

New and Useful

Cleaning Is a Process

The economic and regulatory hurdles involved in introducing new cleaning agents have increased considerably (see "A balancing act" in book 2). Therefore, chemicals that have been developed for markets other than cleaning but have been adapted for the cleaning sector and complex blends have become increasingly prevalent. Therefore, the newer cleaning products are covered extensively in the second edition. Cleaning equipment has also evolved during the past decade, and meshing the appropriate cleaning agent with the right equipment requires a working understanding of chemistry, physics, and engineering. We have added discussion of ultrasonic techniques and monitoring. Partially spurred by regulatory pressures, an increased use of so-called nonchemical approaches is included.

Process Implementation

All of the knowledge in the world about cleaning agents, cleaning equipment, and process flow is of no use if you do not improve the cleaning process. We provide guidance to actually do something: to select, validate, implement, and monitor the cleaning process. We also cover new approaches to definitive, lean, analytical testing and provide discussions related to clean rooms, including construction and working in a clean room.

Applications

The application portion of the *Handbook for Critical Cleaning* has been expanded to include critical cleaning processes for high-value product such as for medical devices, pharmaceutical, food processing, aerospace, and military. Electronics cleaning, which had been considered to be "solved" a decade ago, has resurfaced as a critical issue due to such developments as miniaturization, increased component

density, and replacement of lead solders with lead-free, higher temperature solders. Conservation of fine art may not immediately be thought of along with manufacturing, but this involves critical cleaning and the requirements are in some ways similar. Two art conservators outline the thought processes and trial-and-error determinations to match cleaning agents to the soil when cleaning or restoring paintings.

Safety/Environmental Considerations

Safety and environmental considerations are not only global issues but are also important concerns at the national and local levels, and they do not always coordinate or mesh well. You cannot ignore them, and you should not ignore them. We have not attempted to outline all regulations. Dealing with such a moving target would be frustrating and futile, and most engineers would develop glazed eyeballs. Instead, we have attempted to discuss a few topics that are important to the critical cleaning community and to provide strategies for working constructively with the regulatory world. Some of this guidance comes from members of the regulatory community.

Resource conservation is becoming an important topic in the twenty-first century. Efforts to minimize or recycle water, chemicals, and energy will increasingly become a factor in keeping process costs competitive. Green cleaning, which considers both safety and environmental impact, is discussed throughout the two books. The definition of green is not set in stone; it will continue to evolve.

Web-Based Material

Some of the authors have submitted non-print media (color illustrations, animations, film clips, etc.) to augment their chapters. These can be accessed via the "Downloads & Updates" tab on the web pages for these books at CRCPress.com.

The Lady in the Saffron Sari

Barbara Kanegsberg

"You must run, you must flee," implored the earnest gentleman as he ran toward us.

Puzzled and slightly alarmed, our daughter Deborah and I peered down a corridor of immense, multicolored marble slabs while balancing a finished wood cabinet door, a celadon green tile, and some decorative hardware. It was a brilliant, Southern California morning. The silhouette of the plaster Disneyland Matterhorn broke through a cloudless blue sky. The only obvious danger was the trauma of remodeling the kitchen.

"Why do we need to run?" I asked.

"You must hide, my wife must not see you," he replied.

"Why can't your wife see us?" our daughter asked.

"Because, you see, I told her, first we will select the marble, then the cabinets, then the tile, then the door pulls. You are coordinating. If she sees you, she will want to coordinate."

At that very moment, an elegant woman wearing a luminous, saffron-yellow sari came gliding across the marble yard.

"You see, dear," she said, putting her arm around the gentleman and steering him purposefully toward the exit, "they are coordinating. Let's go, we must coordinate too."

Coordinate, Extrapolate, Optimize

The lady in the saffron sari had the right idea. You, too, must coordinate. Achieving a high-quality manufactured product in a cost-competitive manner requires coordination of critical cleaning and contamination control within your company and perhaps coordination with the efforts of a complex supply chain. If you are in charge of selecting cleaning equipment, please read over the chapters on cleaning agents and coordinate the two efforts (and vice versa). Coordinating cleaning efforts with regulatory requirements, including safety, environmental, and validation requirements, is also time well spent. Whether you are a job shop, an initial fabricator, a final assembler, or you have a repair facility, understanding the importance of critical cleaning is a must to achieve a cost-competitive advantage.

It is reasonably safe to say that your manufacturing situation is unique. We suggest that you consider, blend, and extrapolate from the information and advice provided in both books, even perusing those chapters that seem outside of your field. We often combine the approaches of what, at first glance, seem to be unrelated fields. As you read the chapters, think about how approaches might apply to your application and where cleaning is really necessary. Always clean critically.

Acknowledgments

We want to express our profound gratitude to all contributors. Many of you composed your chapters during a time of professional and/or personal challenges; we thank all of you for your wonderful, useful, practical chapters. The information, expertise, and guidance provided in these chapters are invaluable. We would also like to thank Cindy Carelli, Jessica Vakili, Jennifer Smith, and the staff at CRC Press for supporting us throughout the process. A special thanks to Dr. Vinithan Sedumadhavan, the production project manager, for careful attention to detail and to turning the manuscripts into printed pages.

Our thanks also to our children, Deborah Kanegsberg and David Kanegsberg, daughter-in-law, Sandra Hart, and parents, Ruth Feinsilber and Mimi Steigman, for standing by us during the writing and editing process. Our granddaughter, Noa Raeli Kanegsberg, was a very special inspiration for creating this second edition.

Reference

Kanegsberg, B. and Kanegsberg, E. Contamination detection basics, *Controlled Environments Magazine*, June 2010.

Ed Kanegsberg
Barbara Kanegsberg

Preface to the First Edition

Adapted from: What is critical cleaning?, First Edition, *Handbook for Critical Cleaning.*

Critical cleaning is required for the physical manifestation of technology.

We are in the information age, an age of thought, ideas, communication. However, this technology is based on physical objects, parts, or components. Many of these objects require precision cleaning or critical cleaning because they are either intrinsically valuable, or they become valuable in the overall system or process in which they are used. Some parts or components require critical cleaning not because of the inherent value of the part itself but instead due to their place in the overall system. For example, inadequate cleaning of a small inexpensive gasket can potentially lead to catastrophic failure in an aerospace system.

Nearly all companies which manufacture or fabricate high-value physical objects (components, parts, assemblies) perform critical cleaning at one or more stages. These range from the giants of the semiconductor, aerospace, and biomedical world to a host of small to medium to large companies producing a dizzying array of components.

Soil

The concepts of contamination, cleaning, and efficacy of cleaning are open to debate and are intertwined with the overall manufacturing process and with the ultimate end-use of the assembled product.

Contamination or soil can be thought of as matter out of place (Petrulio and Kanegsberg, 1998). During manufacture, parts or components inevitably become contaminated. Contamination can come from the environment (dust, smog, skin particles, bacteria), from materials used as part of fabrication (oils, fluxes, polishing compounds), as a by-product of manufacturing, and as from residue of cleaning agent ostensibly meant to clean the component.

Cleaning

Cleaning processes are performed because some sort of soil must be removed. In a general sense, we can consider cleaning to be the removal of sufficient amounts of soil to allow adequate performance of the product, to obtain acceptable visual appearance as required, and to achieve the desired surface properties. You may notice that surface properties are included because most cleaning operations probably result in at least a subtle modification of the surface. If a change in the cleaning process removes additional soil and if as a result the surface acquires some undesirable characteristic (e.g., oxidation), then the cleaning process is not acceptable. Therefore, surface preparation and surface quality can be an inherent part of cleaning.

Identifying the Cleaning Operation

Cleaning processes and the need for cleaning would seem to be trivial to identify. If you had a child who appeared in the doorway covered with mud, you would do a visual assessment of the need for cleaning, perform site-directed immersion or spray cleaning in an aqueous/saponifier mixture with hand-drying. However, people perform critical cleaning operations without knowing it. This lack of understanding can detrimental to process control and product improvement.

Recognizing a cleaning step when it occurs is probably one of the major challenges in the components manufacturing community. Cleaning is often enmeshed as a step in the overall process rather than being recognized as a concept in itself. It may be considered as something that occurs before or after another process, but not as a process to be optimized on its own (Dorothy Rosa, personal communication). A cleaning process often not called a cleaning process. For example, optics deblocking (removing pitches and waxes), defluxing, degreasing, photoresist stripping and edge bead removal in wafer fabrication, and surface preparation prior to adhesion, coating, or heat treatment can all be thought of in terms of soil removal (cleaning). Sometimes the cleaning process is identified only by the name of the engineer who first introduced it.

The sociological and psychological bases for this aversion to discussing cleaning are no doubt fascinating, but are beyond the scope of this book. The important thing is for you to recognize a cleaning process when you see it.

There are several reasons. One obvious reason is process control. A second is trouble-shooting or failure analysis. If the product fails and you need to fix the process, it is crucial to identify not only where soil might be introduced but also what steps are currently being taken in soil removal. If the chemical being used comes under regulatory scrutiny, identifying cleaning is even more important. If a supplier provides the component and a problem arises, it is important to be able to recognize where the cleaning steps occur. Finally, identifying the cleaning steps allows you to apply technologies developed in other industries to your own process.

Critical Cleaning

Defining critical cleaning or precision cleaning is a matter of ongoing debate among chemists, engineers, production managers, and those in the regulatory community. Certainly the perceived value or end-use of the product is a factor as are the consequences of remaining soil. The level of allowable soil remaining after cleaning is a consideration. Precision cleaning has been defined as the removal of soil from objects that already appear to be clean in the first place (Carole LeBlanc, personal communication). In some instances, however, high levels of adherent soil are involved in the processing of critical devices. Precision cleaning was once euphemistically said to be YOUR cleaning process for YOUR critical application, whereas everyone else's process could be considered as general cleaning (Kanegsberg, 1993). In one sense, there is some truth that the manufacturer is often the one best able to understand process criticality. At the same time, recognizing general cleaning and critical cleaning as parts of other operations can lead to overall industrial process improvement.

Why Should You Be Concerned about Critical Cleaning?

Critical cleaning issues are becoming increasingly important. Competitive pressure is increasing. Higher demands are being made of industry. A clean component produced efficiently and in an environmentally preferred manner (or at least in an environmentally acceptable manner) is a given in today's economy.

Performance, Reliability

Products are becoming smaller, with tighter tolerances and higher performance standards. Some products, such as implantable biomedical devices, are expected to perform for decades without a breakdown. Small amounts of soil and very tiny particles can irreparably damage the product.

To successfully remove the soils, you have to understand the various cleaning chemistries and cleaning equipment, and how they are combined and meshed with the overall build process.

Costs

Pressure to keep costs down increases constantly. The costs of the effective processes have tended to increase. Choosing the best option for the application can keep costs down.

Safety and Environmental Regulatory Requirements

The manufacturing community needs a wide selection of chemicals and processes to achieve better contamination control at lower costs. However, our understanding of health and the environment has led to restrictions on chemicals and processes. The manufacturer needs an understanding of atmospheric science and of the approaches used by regulatory agencies to foresee future trends.

Overview of This Book

Philosophy

In setting out to put together this comprehensive book on critical cleaning, I sought inputs from the experts in the field. Frequently these are people associated with vendors of cleaning equipment and/or cleaning agents. Naturally, each person's viewpoint is somewhat colored by their own portion of the market. However, on the whole, I was impressed with the scope and fairness of the material submitted. An attempt has been made to minimize use of brand names. In some cases, there are several contributors in a similar area. In general, my philosophy has been to include all but the most blatant material; by having a large number of contributors, a wide range of products and viewpoints are presented; the reader is expected to be intelligent enough to weigh the advantages and/or disadvantages of each approach for his or her own application.

Conclusions

While each application is very site specific, contamination control problems cut across industry lines. At the same time, each industry still tends to work in a separate little world. It is hoped that this book will provide a synthesis of cleaning approaches.

A diverse assortment of components and assemblies require critical or precision cleaning. Some examples include

Accelerometers
Automotive parts
Biomedical/surgical/dental devices (e.g., pacemakers)
Bearings
Computer hardware (metal, plastic, other composites—the insides of your computer and printer)
Consumer hardware (telephones)
Digital cameras
Disk drives

Electronics components
Flat panel displays
Gaskets
Gyroscopes
Motion picture film
Optics
Space exploration hardware
Wafers/semiconductors/microelectronics
Weapons, defense systems (missiles)

Acknowledgments

This book is the result of a phenomenal level of effort by those involved in the worlds of critical cleaning, surface preparation, and environmental issues. The information, expertise, and guidance provided by the contributing authors is invaluable. Dr. Ed Kanegsberg, business associate and spouse, provided support, encouragement, and invaluable participation in the editing process. He also provided the viewpoint and experiences of a physicist and practicing engineer. Bob Stern and the staff at CRC Press provided excellent guidance throughout the process.

I would also like to thank family members Deborah Kanegsberg, David Kanegsberg, Ruth Feinsilber, and Mimi and Murray Steigman for their patience and encouragement.

Finally, I would like to thank Dr. Shelley Ventura-Cohen, a wise colleague and adviser. She tells the story of her aunt, who, on observing Shelley staring blankly at a cookbook while an inert, raw chicken sat on the counter, exclaimed: "look at the chicken, not the book." Dear reader, critical cleaning, surface preparation, and contamination control are complex subjects, but they are also intensely practical subjects which relate to a product—your product. My suggestion, therefore, is to look at this book, and at the same time look at the chicken.

References

Carole LeBlanc, Toxics Use Reduction Institute, Lowell, MA, personal communication.

Dorothy Rosa, *A^2C^2 Magazine*, personal communication.

Kanegsberg, B. Options in the high-precision cleaning industry: Overview of Contamination Control Working Group XIII, in *International CFC & Halon Alternatives Conference*, Washington, DC, October, 1993.

Petrulio, R. and Kanegsberg, B. Back to basics: The care and feeding of a vapor degreaser with new solvents, in *Presentation and Proceedings, Nepcon West '98*, Anaheim, CA, 1998.

Barbara Kanegsberg
BFK Solutions
Pacific Palisades, California

About the Second Edition

Philosophy

We want to help you clean critically, productively, and profitably; our goal was thus to make the second edition of the *Handbook for Critical Cleaning* even more comprehensive than the first edition. Contributors are experts in their field. We have included the viewpoints of manufacturers of parts/components of those who supply cleaning chemistries and cleaning systems, of people in regulatory agencies, and even of other consultants. We have minimized the use of brand names, but have included enough information to be unambiguous. Our philosophy is to include a range of viewpoints, some differing from our own. We urge you to make the optimal decision for your application.

Organization

Chapters in the Second Edition

The second edition of the *Handbook for Critical Cleaning* is substantially new. While we have reprinted a few classic chapters from the first edition, most chapters are new or have been substantially updated. We suggest that readers peruse not only the chapters related to their line of work and applications, but also look at what might at first glance appear to be unrelated applications. By providing a synthesis of cleaning approaches, we hope to help you make better decisions about your own cleaning processes.

We strive to achieve the impossible (or highly improbable)—a perfect balance of topics. After the publication of the first edition, we received comments that we did not devote enough space to aqueous processes, an approximately equal number of comments that we did not devote enough space to discussions on solvent processes, and assorted comments about a lack of attention to other advanced cleaning processes. We thank everyone for their comments; you are probably correct. Therefore, if you have a different viewpoint or unique cleaning application, let us know. This is how we keep learning and improving.

This series is divided into two books with five parts:

- Book 1: *Handbook for Critical Cleaning: Cleaning Agents and Systems*
  - Part I: Cleaning Agents
  - Part II: Cleaning Systems
- Book 2: *Handbook for Critical Cleaning: Applications, Processes, and Controls*
  - Part I: Process Implementation and Control
  - Part II: Applications
  - Part III: Safety and Regulations

Following is a capsule summary of each of the book chapters.

Book 1: *Handbook for Critical Cleaning: Cleaning Agents and Systems*

Part I: Cleaning Agents

An overview of cleaning agents is presented by the editor, Barbara Kanegsberg. In this expanded overview, Barbara attempts to capture the diversity of cleaning chemistry options and to put those options in perspective.

The part begins with a discussion on aqueous cleaning agents (see Chapter 1, Kanegsberg). Water is the most common cleaning agent. Michael Beeks and David Keller of Brulin & Company, a producer of aqueous cleaning equipment, expand and update their chapter from the first edition and give a comprehensive review of aqueous cleaning essentials (Chapter 2). Much of the information is also applicable to nonaqueous solvent cleaning.

Many of today's chemicals, both aqueous based and solvents, are blends. JoAnn Quitmeyer of Kyzen Corporation presents a new chapter that is a comprehensive review of cleaning agent chemistries, including single components and blends (Chapter 3).

John Burke of the Oakland Museum of Art, California, updates his particularly informative discourse on solubility and the techniques used to classify solvents (Chapter 4). It becomes clear from this chapter as to why certain solvents are applicable to removing certain types of soil.

John Owens of 3M updates his chapter on the hydrofluoroethers (HFEs), a class of solvents that have been introduced as replacements for the ozone-layer depleting chemicals (ODCs) (Chapter 5).

Joan Bartelt of DuPont updates the chapter by Abid Merchant (retired fom DuPont) that discusses the hydrofluorocarbons (HFCs), another class of ODC replacements (Chapter 6).

John Dingess and Richard Morford of EnviroTech International Inc. update the chapter by Ron Shubkin (retired from Albermarle Corporation and Poly Systems U.S.A. Inc.) on normal-propyl bromide (NPB), a substitute for the aggressive ODC solvent, 1-1-1-trichloroethane (Chapter 7).

Stephen P. Risotto, formerly of the Halogenated Solvents Industry Association (HSIA) and now with the American Chemistry Council, updates his contribution on the chlorinated solvents, a group of traditional solvents that are seeing a resurgence of use in certain applications (Chapter 8).

Ross Gustafson of Suncor Energy discusses critical cleaning applications of the bio-based D-limonene (Chapter 9).

Dan Skelly of Riverside Chemicals reviews benzotrifluorides, a group of VOC-exempt compounds (Chapter 10).

Part II: Cleaning Systems

This part reflects the wide range of process choices. The importance of drying is emphasized. Advanced and so-called nonchemical systems, such as CO_2 cleaning, steam cleaning, and plasma cleaning, are also covered. In these systems, the cleaning agent and the cleaning equipment are inseparable.

The part begins with an overview of cleaning systems contributed by the editors (Chapter 11). As with the overview for cleaning agents, this reviews processes that are treated in this book by other authors as well as those for which there are no additional chapters.

There are six chapters dealing with ultrasonics and the closely related megasonics technologies. The technology is widely used, and the diverse insights of the authors will be helpful to select equipment. John Fuchs, retired from Blackstone—Ney Ultrasonics, and Sami Awad of Ultrasonics Apps., LLC each give an overview of ultrasonics (Chapters 12 and 13). Sami Awad then teams up with K.R. Gopi, from Crest Ultrasonics Corp., to provide a new chapter on multiple frequency ultrasonics (Chapter 14). Mark Beck of Product Systems Inc. covers the basic technologies of megasonics (Chapter 15). The theory of cavitation has been absent from most discussions of critical cleaning geared to the manufacturing community. Further, the important yet elusive topic of ultrasonics metrics has seen much progress. Along these lines, we are pleased to present two new chapters. In the first chapter, Mark Hodnett of the National Physical Laboratories (U.K.) provides graphics covering theory and discusses a new technique

for ultrasonics metrics along with case studies (Chapter 16). In the second chapter, Lawrence Azar of PPB Megasonics covers the principles and theoretical/mathematical basis of cavitation and discusses ultrasonics metrics (Chapter 17).

Edward Lamm of Branson Ultrasonics Corp. contributes a useful chapter, on optimizing the equipment design, covering solvent, aqueous, and semiaqueous cleaning equipment as well as rinsing, drying, automation, and other ancillary equipment (Chapter 18).

Ron Baldwin of Branson Ultrasonics Corp. contributes an important new chapter on equipment design for aqueous cleaning to help you during scale-up from laboratory cleaning to production cleaning (Chapter 19).

Dan Skelly of Riverside Chemicals contributes a chapter on equipment for cold cleaning, that is, where cleaning agents (notably solvents) are used below their boiling point (Chapter 20).

Richard Petrulio of B/E Aerospace provides a revised, expanded, and very readable chapter on the design of flushing systems (Chapter 21). This is one example where a company was able to design equipment for its own cleaning application. The chapter also provides very good guidance for the process of developing and testing a cleaning process.

Joe McChesney of Parts Cleaning Technologies updates and revises techniques for minimizing waste streams in solvent vapor degreasers, including methods for calculating the size or capacity of the required equipment (Chapter 22). Some recent case studies for the minimization of emissions have also been added.

Arthur Gillman of Unique Equipment Corporation contributes retrofitting vapor degreasers to allow the use of different cleaning chemicals or to meet newer emission control standards (Chapter 23). This option can obviate the need for new equipment.

John Durkee of precisioncleaning.com and Dr. Don Gray of the University of Rhode Island update their chapter on contained airless and airtight solvent systems, one approach for remaining in compliance with air regulations while using emissive chemicals (Chapter 24).

Wayne Mouser of Crest Ultrasonics Corp. contributes a new chapter on vapor phase organic solvent cleaning, a classic critical cleaning technique (Chapter 25).

In some cases, the cleaning agent and the cleaning equipment are inseparable. In particular, this is true for what are called "nonchemical" cleaning approaches. Several examples are provided in the next five chapters.

Ed Kanegsberg of BFK Solutions provides a new chapter, an overview to nonchemical cleaning, that addresses aspects covered in more detail by four of the authors and also reviews additional approaches, such as laser, UV/ozone, and fluidized dry bath cleaning (Chapter 26).

Jawn Swan of Crystal Mark, Inc. contributes a new chapter on micro-abrasive blasting, a technique with applications ranging from electronics and medical devices to architectural restoration (Chapter 27).

Robert Sherman of Applied Surface Technologies authors a new chapter on solid carbon dioxide cleaning, with applications for removing particles and small levels of soils from such critical surfaces as semiconductor wafers and precision optics (Chapter 28).

William Nelson of the U.S. EPA updates his chapter on supercritical and liquid CO_2 cleaning (Chapter 29).

William Moffat of Yield Environmental Systems (YES) teams with Kenneth Sautter, also of YES, to update the chapter on another approach to removing organics, plasma cleaning (Chapter 30).

Max Friedheim of PDQ Precision Inc. teams with his process engineer, Jose Gonzalez, to update and expand the chapter on the use of steam vapor cleaning for critical cleaning applications; additional case studies are included (Chapter 31).

John Russo of Separation Technologists has completely revised his chapter on selecting the best waste water treatment for aqueous operations (Chapter 32). This comprehensive chapter discusses pretreatment, posttreatment, and water recycling techniques.

Cleaning with liquids frequently means that drying is required. The final three chapters in Part II deal with this sometimes neglected process.

Barbara Kanegsberg of BFK Solutions provides an overview to drying (Chapter 33). Daniel VanderPyl of Sonic Air Systems updates his chapter on physical methods of drying (Chapter 34). Robert Polhamus of RLP Associates along with Phil Dale of Layton Technologies, Ltd. update their chapter on chemical displacement drying techniques (Chapter 35).

Book 2: *Handbook for Critical Cleaning: Applications, Processes, and Controls*

Part I: Process Implementation and Control

Part I integrates the topics of process selection and maintenance, contamination control, analytical techniques, and materials compatibility.

Barbara and Ed Kanegsberg lead off the part with a revised, expanded discussion of "How to Work with Vendors?" that applies to print, electronic, telephone, and face-to-face communication of information (Chapter 1). Barbara Kanegsberg continues with a new chapter, "The Balancing Act," discussing the technical, economic, political, and regulatory trade-offs and conflicts involved in developing and maintaining a process (Chapter 2).

Art Gillman of Unique Equipment Corporation contributes a new chapter, drawing on his many decades of experience as well as the experiences of his colleagues to present "Blunders, disasters, horror stories, and mistakes you can avoid," a compilation of cleaning lore that should be read and absorbed by all readers (Chapter 3).

Mike Callahan of Jacobs Engineering expands his chapter about optimizing and maintaining the process (Chapter 4). A number of topics such as fixturing, process monitoring, and process improvements are included.

Part I contains four new chapters related to clean room design, operation, and behavior. Controlling the cleaning environment improves the success of the cleaning process by minimizing product contamination. Scott Mackler of Cleanroom Consulting provides a comprehensive chapter on "Basis of design for life sciences cleanroom facilities" (Chapter 5). Kevina O'Donoghue of Specialised Sterile Environments brings a view from "across the pond" in Ireland with her chapter on "Validating and monitoring the cleanroom" (Chapter 6). Jan Eudy of Cintas Corporation provides a chapter on "Cleanroom management and gowning" (Chapter 7). Howard Siegerman of Siegerman & Assoc. and Karen Bonnell of Production Economics coauthor a chapter on the "Principles of wiping and cleaning validation" (Chapter 8). Ed Kanegsberg of BFK Solutions provides an overview of issues related to detection and measurement of contamination (Chapter 9). Finally, Ben Schiefelbein of RJ Lee Group provides a new, insightful chapter on the philosophy of and choices for analytical analysis with "Practical aspects of analyzing surfaces" (Chapter 10). Many of the techniques should be considered whether or not you operate in a clean room.

The next four chapters in this part address knowing when to clean, when the part is clean enough, and materials compatibility.

Mantosh Chawla of Photo Emission Tech. (PET), Inc. updates his chapter on the important topic of "How clean is clean? Measuring surface cleanliness and defining acceptable levels of cleanliness" (Chapter 11).

Two chapters are a must for those involved in process validation for implantable medical devices. Kierstan Andrascik of QVET Consulting brings her experience with analysis of medical devices in a new chapter on "Cleaning validations using extraction techniques" (Chapter 12). David Albert of NAMSA has expanded his chapter on "Testing methods for verifying medical device cleanliness" (Chapter 13).

Eric Eichinger of Boeing North America has expanded his chapter on the critical issue of materials compatibility both for metals and nonmetals (Chapter 14).