# X-RAY REPAIR

## ABOUT THE AUTHOR

**Joseph J. Panichello** earned his B.S. degree in Biology from Pfeiffer University, an A.A.S. degree in Biomedical Equipment Technology from Stanly Technical College, and is AAMI certified. He has worked as an in-house BMET, an x-ray field service engineer, and as a service manager for an independent x-ray service company. He lives in Medford, New Jersey with his wife and daughter.

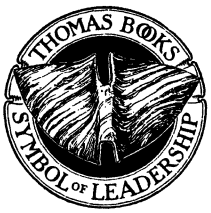
Second Edition

# X-RAY REPAIR

## A Comprehensive Guide to the Installation and Servicing of Radiographic Equipment

*By*

JOSEPH J. PANICHELLO, C.B.E.T.

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*To Caroline*

## SPECIAL DEDICATION

### To Mr. M. Maung (1941–1996)

*This book is in part dedicated to the life and memory of Mr. Maung Maung, internationally certified clinical engineer of Newcomb Medical Center in Vineland, New Jersey. Maung first introduced me to medical instrumentation, helped me to get accepted into the school for Biomedical Equipment Technology, allowed me to serve my internship under him, and helped write the resume (and initiated the phone call!) that led to my first job in this field.*

*Throughout the years, Maung was my good friend and always provided sound advice in all aspects of life for which I am truly indebted. He even provided some valuable direction when, in confidence, I informed him of my desire to write this book. He was the most giving human being I have ever met.*

# PREFACE

During the past six years since this book was first published, I have received excellent feedback from a number of readers. Most expressed that they were glad to have a book solely dedicated to their profession: some offered suggestions as to how to make the book more "comprehensive." This second edition was written in response to those comments, as well as to the suggestions made by course instructors and service engineers who are currently employed. Thanks to all for your helpful comments. The additional information provided here, I hope, will help students and engineers to better understand x-ray servicing. My goal is to make *X-Ray Repair* a single source for general x-ray servicing questions.

Since the book was first published, the medical imaging field has continued to grow at an extremely rapid pace. There have been great strides in all aspects of radiography including advances in image acquisition, image processing, and image storage. Moreover, advances in digital technology are the impetus that drive this field today.

Fortunately for service engineers, the basics of x-ray production still apply to the field of radiography and will do so for many years to come. Even though the use of digital technology is becoming commonplace, the means of x-ray production has not changed. In fact, each device currently found in a general radiographic room (i.e., the x-ray generator, tube support, table, and wall unit) is still needed to obtain that quality image.

This new edition includes all of the information found in the first edition and will cover two additional specialized areas of radiography: tomography and mammography. These new chapters provide the information required to allow a service person at the entry level to begin servicing tomography and mammography equipment with a high degree of confidence.

The chapter on tomography presents all of the essentials required to operate and service a tomographic unit. A tomographic unit is, in essence, a standard radiographic unit with the addition of a few specialized components. This chapter focuses on the design and function of those components. Tomographic theory is likewise discussed, and all of the required maintenance and calibration procedures are outlined.

Mammography, another specialized field of radiography, requires a different servicing approach from that used in general radiography. This chapter provides the "basics" of breast imaging and includes a detailed description of a mammographic unit. Electronic calibrations and troubleshooting techniques are also covered. Finally, an overview of digital mammography is included at the end of the chapter.

Readers also suggested that the subject of fluoroscopy be included. I have decided, however, not to include this subject in this edition. Although related to radiography, fluoroscopy requires servicing techniques that are somewhat advanced and, therefore, should be covered in a later edition, or separate book. In this way, I can maintain the central focus of this book, which is to cover all aspects of general radiography.

I have rearranged the order of chapters to accommodate the new material, starting with the most basic concepts and ending with the more advanced specialty fields. Consequently, the new chapters on tomography and mammography can be found at the end of the book.

I have also included an informative chapter entitled "The Seasoned Engineer" which describes specific practices that will allow engineers who are relatively new to the field to advance in their profession. The chapter provides the necessary tools needed for the novice to become proficient in x-ray servicing as quickly as possible, pointing a clear path to becoming an imaging specialist. This final chapter of the book aims to provide inspiration and the proper mindset to approach the challenging field of x-ray servicing.

I would like to mention a few people who have provided technical input for this edition: Tom Avellino Jr., senior field service engineer; Hugh Hudson, technical support engineer (Hologic Inc.); Dennis King, mammography specialist; Fred Lacy, senior applications engineer (Varian Products); and Karl Schmidt, field service engineer.

The diagrams for the new chapters were created by Bob Verstege, graphics designer and friend. I am very grateful for his help.

Thanks, again, to Dr. Vallin D. Estes for his help with this edition and for his continual support and friendship.

Lastly, I want to thank Michael Payne Thomas, editor of Charles C Thomas Publisher, Ltd., for encouraging me to offer this second edition and for his valuable suggestions regarding new material for the book.

It has been a great pleasure working on this project and I am thankful for having the opportunity. Good luck to all students.

Joe Panichello

# PREFACE TO FIRST EDITION

This book is intended to be used as a field guide and reference manual for field service engineers and in-house biomedical engineers when servicing radiographic equipment. It is also written in a way so as to prepare the student of x-ray servicing for all the specific duties involved for the safe and proper maintenance of radiographic equipment. The goal is to provide standard servicing practices that, at the present time, are not available.

The idea for this book arose during my career as an x-ray service engineer.[1] While working as a field service engineer, I observed many different approaches to the installation, preventive maintenance, and repair of radiographic equipment. Some of these approaches were more successful than others, but since standards for servicing x-ray equipment were nonexistent, the service engineer would not always know if he or she had made the best choices while performing service. As a result, any two x-ray service engineers may perform preventive maintenance (or PM) on identical radiographic rooms in completely different ways. This is a serious problem that often reflects badly on our profession. When a customer pays for a PM, what service is he or she actually getting?

The background of the x-ray service engineer of today varies greatly, ranging from no formal education in electronics to degreed electrical engineers. X-ray servicing is one of the few remaining technical fields where minimum requirements for education and practical training have not yet been established, although this situation is slowly changing. A typical x-ray service engineer working in the field may

1. The term "x-ray service engineer" has become the accepted title for individuals who install, repair, and maintain radiographic equipment and will be used throughout this book. It encompasses all the commonly used titles such as, x-ray engineer, x-ray service technician, field service engineer, and imaging specialist.

have some electronic background, but most of his or her x-ray servicing skills are developed on the job.

To better understand the wide discrepancy in educational background of the x-ray service engineer, we must look back at the history of x-ray servicing. In the early years, servicing x-ray units mainly required physical strength and good mechanical ability. The reason for this was that x-ray units generally were large and cumbersome, usually requiring several men to install and service.[2] In fact, the physical size of the individual was often a major criterion for hiring in this field.

Not only was physical strength needed to install and repair equipment, but an exceptional mechanical ability was also a requirement. Service engineers had to work proficiently with mechanical parts and complicated gear assemblies. They needed skills for cutting, grinding, drilling, and tapping metal parts in order to make covers, brackets, and supports fit properly into place. Moreover, if a part was needed for a particular repair but could not be purchased, the x-ray service engineer would have to design and make the part himself! Also, since many of the devices in a radiographic room had to be securely mounted to ceilings, walls, and floors, the service engineer required some knowledge of building construction.

X-ray equipment found in the early radiographic rooms predominantly utilized electromechanical devices to perform the various functions. These included large mechanical tap switches, relay contactors, electromagnetic lock assemblies, AC motors, and motor drive systems. Sophisticated electronic components and circuit boards were not widely used in these early machines and, consequently, it was advantageous for the service engineer to mainly possess the technical skills required to properly service electromechanical devices.

Along with the technical requirements, there were also a certain amount of safety risks associated with working in this field. Because of the potentially lethal voltages involved in x-ray circuits, and the nature of radiation itself, this job was definitely not for the fainthearted. These factors would limit the number and type of individual who would enter this field.

As a result, only a small number of skilled x-ray service engineers were available in those days to work in this potentially hazardous occu-

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2. Until very recently, x-ray servicing was a male-dominated field.

pation. These men were highly skilled and commanded great respect in the medical field. Also, because they were small in number, the engineers had to be self-reliant and capable of working independently, oftentimes for long hours, until the equipment became operational.

Since there was little formal training available for most engineers at that time, and proper documentation was often sketchy at best, no standard methods of servicing radiographic equipment ever evolved. X-ray servicemen would simply develop their own style and approach to servicing the equipment.

This individualistic approach to servicing was successful for some engineers, but tended to cause many service problems in the long run. Engineers often had different ways of testing and repairing equipment, and would use different calibration accuracy standards. Under these circumstances, there would be no way of actually knowing whether or not a radiographic unit was operating at an optimum performance level. In addition, because there were different methods of installing equipment, two identical x-ray units, installed at separate sites (by different engineers), could have completely different performance characteristics and, may have even operated differently. Consequently, these two units could not be serviced in exactly the same way, which poses many problems for the engineer who was unfamiliar with the particular installation.

This approach to servicing is totally unacceptable in the healthcare industry of today. Standards in servicing must be established so that radiographic equipment found in every hospital and clinic will operate at a consistent level of performance. By standardizing installation procedures, routine preventive maintenance, and calibration procedures, consistent performance levels in equipment can easily be achieved. This book will describe those standard procedures in detail. After reading *X-ray Repair,* the student and entry level engineer will gain a better understanding of what we are trying to accomplish in x-ray servicing and, in turn, improve the overall level of the services that are provided.

The book begins with a brief history of the discovery of x-rays and describes their early use in the medical field. An overview of basic x-ray principles is included, as well as a chapter on the individual components of an x-ray system. A chapter on the safety hazards related to working with radiographic equipment is also included. This chapter is

especially important to students and entry-level engineers because of the potentially lethal hazards associated with this field.

Next, a step-by-step guide for the proper installations of radiographic equipment is given. Here, all aspects of an installation are discussed, starting with the initial planning of the room to user inservicing and final room checkout. A chapter on preventive maintenance explains why PM's are performed, and demonstrates the correct procedure for performing preventive maintenance on radiographic equipment.

A troubleshooting chapter provides effective troubleshooting techniques that can be used on any type of radiographic equipment. Once a failure has been identified through these troubleshooting techniques, the proper steps for repairing and testing the x-ray system are given so that there will not be any service recalls on the repair. In addition, specific problems that regularly occur in radiographic rooms are discussed with suggestions included on how to correct them. Finally, a chapter describing ways to establish (and maintain) good customer relations is included.

In order to limit the size of the book, the discussions concentrate on the General Radiographic Room. Specialized areas such as Mammography, Tomography, Special Procedures, Cath Labs, and Computerized Tomography (CT) are not included. Although these special applications of x-ray use the same basic principles as in general radiography, they require different servicing techniques and would best be covered in another text. Mobile x-ray units, however, are discussed because of their widespread use in general radiography.

At the end of the book the service engineer will find convenient charts to make his or her job easier when working out in the field. Also included in the Appendix is a complete list of the tools and test equipment needed to properly service x-ray equipment. The glossary will provide a quick reference for any unfamiliar terms used throughout the text.

It is my hope that this book will greatly aid the x-ray service engineer in servicing radiographic equipment and that it will play a role in improving the overall level of x-ray service that is currently being provided.

Joseph J. Panichello

# ACKNOWLEDGMENTS

There are many people who have helped and inspired me while pursuing a career in the medical electronics field. I would like, at this time, to acknowledge those who most influenced me as my career progressed to the x-ray servicing field and, ultimately, to the writing of this book.

First and foremost, I would like to thank the original "Boys in Blue" of Deborah Heart and Lung Center, located in Browns Mills, New Jersey: Larry Melson for demonstrating a standard of excellence in servicing medical equipment; John Ludwig for advising me to pursue a career in the field of x-ray service and for his support over the years; Arch Tannock for demonstrating "the basics" of x-ray servicing; and finally, Ed Rourke for teaching me the finer points of x-ray imaging and demonstrating the rewards that this field has to offer. Ed has been a role model and good friend throughout my career.

I would also like to thank Dr. J. Eldridge of Deborah Heart and Lung Center for selling to me, at a very reasonable price, his notebook computer on which I wrote this book. Thanks Jay!

I would like to thank Mr. Tom Avellino of Avellino X-ray Corporation for sharing much of the knowledge that he accumulated while servicing x-ray equipment over the last thirty years.

To Mr. David Eveland of South Jersey X-ray for helping me to understand x-ray servicing from the business point of view. Thanks Dave!

I would like to thank Mr. Mark DePalma of Atco, New Jersey for creating all of the line drawings that are included in this book. Mark, an artist who normally works in the freehand environment, had his skills (and patience) tested as he had to create these precision drawings. He lived up to the challenge by producing high quality, detailed drawings in a relatively short period of time. Thanks Mark!

I would like to acknowledge the faculty of Stanly Community College for the great job they did in preparing me for a career in medical electronics. In particular, I would like to thank Mr. Doug Weaver, CBET, for his advice and friendship over the years.

I would like to thank Pfeiffer College, Misenheimer, North Carolina, for providing me with a quality education and the tools that I will use throughout my life, and in particular, those members of the science faculty who showed me a different way to view the world.

I would especially like to acknowledge Dr. Vallin D. Estes, Professor of Language and Literature at Pfeiffer College. If not for Dr. Estes, I'm not sure this book could have been written. Dr. Estes, my Latin professor at that time, introduced me to the "classics" of literature and in doing so, demonstrated the beauty of life through art and ultimately provided me with what I term "a real education." He became my mentor while in college and in the last fifteen years, a close friend. Dr. Estes edited the first drafts of this book and continually provided the encouragement and motivation that I desperately needed to complete it. Thanks Dayton–for everything.

I would like to thank Charles C Thomas, Publisher for considering my manuscript. It was a pleasure working with such a prestigious publishing firm.

Finally, I would like to thank my wife, Caroline, for her patience and understanding while I was writing this book. This project proved to be more difficult than I ever imagined and I could not have done it without her. Thanks Caroline!

## THE LAWS OF X-RAY SERVICE

I. When radiographic equipment is installed properly, it will perform more reliably and for a longer period of time. When a failure does occur, it is more easily repaired.

II. If PM's are performed properly and at regular intervals, equipment failure rate will be greatly reduced and the equipment will operate well beyond its predicted life expectancy.

III. When servicing equipment, if the problem is correctly diagnosed, properly repaired, and thoroughly tested, there will be no service recalls for that service call.

The service engineer should adhere to these laws at all times when servicing radiographic equipment. Without question, if the engineer performs his or her duties as outlined in this book, equipment reliability and longevity will absolutely increase. In addition, there will be a greater level of customer satisfaction, which is, of course, the ultimate goal.

The actual quality of the particular x-ray equipment can, however, alter any predictions made by the "Laws." If the equipment is of exceptional quality, but the service engineer does not follow the "Laws of X-ray Service," the higher failure rates will result in lower customer satisfaction. If the equipment is just average in performance and price, a good service engineer who follows the "Laws" will get optimum performance out of the room and achieve a high level of customer satisfaction. Cheaply manufactured equipment, regardless of quality of service, will fail often and will eventually be removed from the site!

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# Chapter I

## THE DISCOVERY OF X-RAYS

The use of x-rays is so prevalent in today's society that it is difficult to imagine how many industries, especially the medical profession, could function without their daily use. Indeed, most people have had some contact with x-rays in their lifetime and are aware of their importance. For example, doctors, structural engineers, research scientists, and even airline personnel all use x-rays routinely in their respective careers. Hardly anyone would argue that the discovery of x-rays was one of the most important discoveries of our time. Mankind has certainly benefited from their use.

Because of their widespread use, it is difficult to imagine that x-rays were discovered only a century ago. Grandparents of some of the readers of this book were growing up during the time when x-rays were first being demonstrated. And though there have been many advancements made in radiographic equipment design since that time, most of the devices used today in the general radiographic room very closely resemble those early units. The service engineer can gain a much better understanding of general x-ray theory by learning just how x-rays were first discovered and then following the development of the x-ray tube and radiographic system.

The discovery of x-rays, like many other important discoveries, occurred accidentally while scientists were experimenting with glass vacuum tubes. The vacuum tubes that were used were made of thin-walled glass and contained two metal electrodes. They were partially evacuated by a mercury pump and then filled with a specific gas. When a high tension discharge from an induction coil was applied to the vacuum tube, beautifully-colored streams of light were produced between

the two electrodes of the tube. These streams of light mostly were a source of fascination and curiosity for the scientists at that time.

After further experimentation with improved vacuum tube designs, scientists began to learn more about the streams of light. They determined that the stream of light originated at the negative electrode (cathode) within the tube and flowed to the positive electrode (anode). In addition, as the tube's vacuum level was increased, the streams would likewise change in color and character, until they finally became invisible.

These "rays" were labeled ***cathode rays*** by William Crookes in 1878, who was the first to observe their directional properties while experimenting with vacuum tubes.[3] During his experiments performed in the dark, Crookes noticed that the cathode rays appeared outside of the glass tube as a bluish glow. He later modified the glass tubes by placing an aluminum window in the tube so that the cathode rays could pass through more easily. These modified tubes then became known as ***Crookes Tubes*** and were commonly used for experimentation.

The cathode rays could easily pass through the aluminum window of the tube and would produce luminescent effects on phosphor materials. They would also affect photographic plates. These rays, however, were of very low energy and, consequently, would be absorbed in only a few centimeters of air. Unfortunately, Crookes had not realized that what he really was observing were low energy x-rays.

Seventeen years later, scientists were still experimenting with the Crookes Tubes. Philip Lenard demonstrated that the cathode rays scattered in all directions at the point where they exited the aluminum window. He also made shadow pictures termed "sciagraphs" on photographic plates. After many experiments he concluded that there was another unidentified component to the cathode rays.

The person credited with the discovery of "x-rays" was a German physicist by the name of Wilhelm Conrad Roentgen. Roentgen was born in Lennep, Germany, in 1845. By the age of twenty-four, he had already published many scientific papers on the properties of gasses. During his career as professor and scientist, he published more than forty papers on scientific phenomena and was highly respected by his fellow scientists.

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3. The cathode ray phenomenon is commonly used today in video monitors which use a CRT (cathode ray tube).

It wasn't until June of 1894, at age forty-nine, however, that Roentgen began to experiment with vacuum tubes. Roentgen began his own experiments with the Crookes Tubes and made several important observations. He noticed that he obtained better results when the tubes were highly evacuated, and he would often spend days evacuating a tube for his experiments. Also, he felt that if more current was applied to the tubes, cathode ray production would increase. Incidentally, he damaged many tubes during his experiments and thus began using heavier walled tubes.

While experimenting with the modified tubes in the fall of 1894, he noticed a faint glow in the room that precisely coincided with the discharge of the Crookes Tube. To be certain that the light was not coming from the tube or from the induction coil, he completely covered the Crookes Tube with cardboard so that no light could escape. He also covered the induction coil completely to eliminate any light caused by arcing within the machine. To his amazement, the glow still appeared in the darkened room.

The source of the glow turned out to be a screen made of a photographic material (barium platinocyanide) that was located several feet away from the tube. Some heretofore unknown invisible energy was being emitted from the vacuum tube and was traveling across the room, exciting the photographic screen. This was a highly significant observation since cathode rays had never been known to travel more than a few inches from the tube!

Roentgen experimented with the "new kind of ray" for nearly a year before he published his findings. On November 8 of 1895, at age fifty, he presented his paper "The First Communication," announcing his discovery.[4] He called the mysterious rays "x-rays," using the letter "x" (borrowing the mathematics symbol) to represent the "unknown" energy. Along with his paper he included several fascinating photographs that he had obtained by using the x-rays. These x-ray photographs included a metal compass, a box containing scientific weights, a double-barreled shotgun, and various types of metals.

Of all the published photographs, however, the one that immediately caught the attention of the media and general public was the x-ray

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4. November 8 of the year this book was written (1995), marked the 100 year anniversary of this great discovery.