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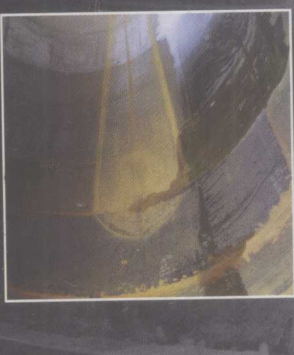
HANDBOOK OF NONDESTRUCTIVE EVALUATION



CHARLES J. HELLIER

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George R. Quinn (author, Chapter 8) has over thirty years of experience in NDT training, problem solving, and marketing. He received his Bachelor of Arts degree in English from Saint Michael's College in Vermont. He then completed five years of service in the United States Air Force as an aircraft maintenance officer, attaining the grade of Captain. After completing military service, he bean his work in ultrasonic testing at Branson Instruments as Director of Training and served as Manager of Marketing Services for Krautkramer Branson. After almost twelve years with the Branson organization, Mr. Quinn formed his own NDT marketing company, with clients including the American Society for Nondestructive Testing and Hocking Electronics. For ten years, Mr. Quinn was Vice-President of Marketing at Hellier NDT. While at Hellier, Mr. Quinn wrote training manuals and developed specialized courses. He is now senior instructor in eddy current and ultrasonic testing at the Hellier division of Rockwood Service Corp. Mr. Quinn has lectured throughout North America, as well as Europe and Asia. He holds an ASNT Level III Certificate in the electromagnetic and ultrasonic test methods.

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John R. Snell, Jr. (co-author, Chapter 9) is a leader in the thermographic profession who first used thermal imaging equipment while providing energy consulting services with the Department of Energy Weatherization Assistance program and the Residential Conservation Service (RCS) program. In 1984 Mr. Snell established Snell Infrared to better serve the needs of his clients. Snell Infrared has since expanded their training services to many new clients and developed extensive on-site offerings. In 1992 the company began certifying thermographers and currently acts as the certifying agent for several large companies. Mr. Snell also continues to be professionally active. He has been on the Thermosense Steering Committee since 1990, was Chair for Thermosense XVI, and has worked on the standards development committee of the American Society for Nondestructive Testing. He has presented a postconference seminar on thermography and was the organizer and Track Chair for the T/IRT sessions of the ASNT Fall 1995 conference. In 1994 Mr. Snell had the honor of becoming the first ASNT Level III certificate holder in thermography in the United States. He is also currently working with three ASTM committees, as well as EPRI and IEEE, on standard written procedures and has authored numerous articles and professional papers. He volunteers in the local school systems of the City of Montpelier, is Chair of the Tree Board, and is on the Board of Directors of the Vermont Historical Society. Mr. Snell is a graduate of Michigan State University.

Robert W. Spring (co-author, Chapter 9) has been actively involved in the thermographic profession. In association with Snell Infrared he has provided thermographic training and inspection services to a broad range of industrial clients. His research on program development resulted in his co-authoring four professional papers for Thermosense. Mr. Spring maintains an active professional involvement in Thermosense, ASHRAE, and ASNT, where he serves on the Standards Development Committee for Thermographers. In 1995 Mr. Spring became a partner in Snell Infrared. From 1980 to 1995 Mr. Spring was a principal in a professional engineering consulting firm specializing in providing a broad range of energy management services to industry, utilities, and commerce. These services include technical analyses, project management, program development, and educational services. During this time he conceived of, developed, and presented a nationally recognized educational program to reduce institutional energy use. Mr. Spring's previous professional experiences include three years with the U.S. Public Health Service as a district engineer providing environmental health services to Native Americans in Alaska and the Eastern United States. While with the USPHS, he developed and presented a successful cross-cultural preventive maintenance training program for the operators of water and wastewater facilities in remote Alaskan villages. Mr. Spring also spent five years with the Army Corps of Engineers, where his duties included managing a large construction group and developing and presenting a human relations course to over 800 people. A graduate engineer of Norwich University, Mr. Spring is a Registered Professional Engineer, an ASNT NDT Level III certificate holder in thermography, as well as a Certified Energy Manager with the Association of Energy Engineers.

PREFACE

One may wonder why the title of this Handbook contains the word "evaluation" instead of the generic term "testing" that is usually used in connection with "Nondestructive." The *American Heritage Dictionary* properly defines "nondestructive" as "Of, relating to, or being a process that does not result in damage to the material under investigation or testing." The most appropriate definitions of the word "test(ing)" from the same source, are "to determine the presence or properties of a substance" and, "to exhibit a given characteristic when subjected to a test." There are also several other definitions that do not really apply. "Evaluate," on the other hand, has a definition that seems to be more fitting for the intent of this handbook: "To examine and judge carefully; appraise." "Evaluation," as defined in ASTM E-1316, is: "A review following interpretation of the indications noted, to determine whether they meet specified acceptance criteria."

In reality, these terms have been used interchangeably with other expressions such as "inspection," "examination," and "investigation." In general, all of these terms refer to the same technology, one that is still widely unknown or misunderstood by the general public. And the use of these different terms may have, in fact, contributed to this misunderstanding. Assuming it is acceptable to take some liberties with these definitions, I would like to suggest that the an appropriate definition of NDE, NDT, or NDI would be: "A process that does not result in any damage or change to the material or part under examination and through which the presence of conditions or discontinuities can be detected or measured, then evaluated."

It is the intent of this Handbook to introduce the technology of nondestructive testing to those who are interested in a general overview of the most widely used methods. There are many excellent reference books on the various methods that can provide additional in-depth information, if desired.

The key ingredient in the NDT process is the practitioner. Many times, NDT personnel are subjected to unfavorable environments and hazardous working conditions. These same individuals are required to complete extensive training programs and fulfill lengthy experience requirements as a prerequisite to becoming certified. And it doesn't stop there. Many codes and specifications require periodic retraining and recertification. Most inspectors/examiners are under constant scrutiny by client auditors or third party overseers. At times, travel to remote locations is required, resulting in extended periods away from home and long workdays. There should always be that desire to "do it right." Think of the consequences if a serious discontinuity is missed and some type of failure results. Conscientious examiners are concerned and caring individuals. In NDT, there is no room for those who are "just doing their job." It takes a special kind of dedicated person, but the rewards are great! The thought of helping mankind by being involved in a technology that is devoted to making this world a safer place is motivation for many. NDT is an honorable profession for those who are honorable. When NDT practitioners lose their ethics, they have lost everything!

This Handbook has been created by a group of professionals who all believe this to be true. It is our desire that it will be a source of knowledge and reference for many who are interested in this unique and challenging technology. The quest for excellence should be never-ending. As Robert Browning once wrote, "Ah! But a man's reach should exceed his grasp, or what's a heaven for?"

ACKNOWLEDGMENTS

This Handbook is the result of the combined efforts of many. Each contributor spent untold hours in the preparation of his segment and had to persevere through the many phone calls and e-mails received from the primary author. But this book would not have been possible without the support, encouragement, and dedication of Michael and Sheryl Shakinovsky. They did more than help. They worked, motivated; but mostly, they cared. I shall always be in their debt.

In addition to Mike and Sheryl, and the contributing authors, the efforts of the following added so much: Alice Baldi (tables and word processing), Christina Hellier (word processing and much encouragement), Lynne Hopwood (graphic design and illustrations), and William Norton (text review).

Finally, this Handbook would have taken much longer if it wasn't for the understanding, patience and support of the Rockwood Service Corporation management, especially Peter Scannell and James Treat. It seems that the word "thanks" just isn't enough.

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CHAPTER 1
INTRODUCTION TO NONDESTRUCTIVE TESTING

I. WHAT IS NONDESTRUCTIVE TESTING?

A general definition of nondestructive testing (NDT) is an examination, test, or evaluation performed on any type of test object without changing or altering that object in any way, in order to determine the absence or presence of conditions or discontinuities that may have an effect on the usefulness or serviceability of that object. Nondestructive tests may also be conducted to measure other test object characteristics, such as size; dimension; configuration; or structure, including alloy content, hardness, grain size, etc. The simplest of all definitions is basically an examination that is performed on an object of any type, size, shape or material to determine the presence or absence of discontinuities, or to evaluate other material characteristics. Nondestructive examination (NDE), nondestructive inspection (NDI), and nondestructive evaluation (NDE) are also expressions commonly used to describe this technology. Although this technology has been effectively in use for decades, it is still generally unknown by the average person, who takes it for granted that buildings will not collapse, planes will not crash, and products will not fail. Although NDT cannot guarantee that failures will not occur, it plays a significant role in minimizing the possibilities of failure. Other variables, such as inadequate design and improper application of the object, may contribute to failure even when NDT is appropriately applied.

NDT, as a technology, has seen significant growth and unique innovation over the past 25 years. It is, in fact, considered today to be one of the fastest growing technologies from the standpoint of uniqueness and innovation. Recent equipment improvements and modifications, as well as a more thorough understanding of materials and the use of various products and systems, have all contributed to a technology that is very significant and one that has found widespread use and acceptance throughout many industries. This technology touches our lives daily. It has probably done more to enhance safety than any other technology, including that of the medical profession. One can only imagine the significant number of accidents and unplanned outages that would occur if it were not for the effective use of nondestructive testing. It has become an integral part of virtually every process in industry, where product failure can result in accidents or bodily injury. It is depended upon to one extent or another in virtually every major industry that is in existence today.

Nondestructive testing, in fact, is a process that is performed on a daily basis by the average individual, who is not aware that it is taking place. For example, when a coin is deposited in the slot of a vending machine and the selection is made, whether it is candy or a soft drink, that coin is actually subjected to a series of nondestructive tests. It is checked for size, weight, shape, and metallurgical properties very quickly, and if it passes all of these tests satisfactorily, the product that is being purchased will make its way through the dispenser. It is common to use sonic energy to determine the location of a stud behind a wallboard. The sense of sight is employed regularly to evaluate characteristics such as color, shape, movement, and distance, as well as for identification purposes. These examples, in a very broad sense, meet the definition of nondestructive testing—an object is evaluated without changing it or altering it in any fashion.

The human body has been described as one of the most unique nondestructive testing instruments ever created. Heat can be sensed by placing a hand in close proximity to a hot object and, without touching it, determining that there is a relatively higher temperature present in that object. With the sense of smell, a determination can be made that there is an unpleasant substance present based simply on the odor that emanates from it. Without visibly observing an object, it is possible to determine roughness, configuration, size, and shape simply through the sense of touch. The sense of hearing allows the analysis of various sounds and noises and, based on this analysis, judgments and decisions relating to the source of those sounds can be made. For example, before crossing a street, one can hear a truck approaching. The obvious decision is not to step out in front of this large, moving object. But of all the human senses, the sense of sight provides us with the most versatile and unique nondestructive testing approach. When one considers the wide application of the sense of sight and the ultimate information that can be determined by mere visual observation, it becomes quite apparent that visual testing (VT) is a very widely used form of nondestructive testing.

In industry, nondestructive testing can do so much more. It can effectively be used for the:

1. Examination of raw materials prior to processing
2. Evaluation of materials during processing as a means of process control
3. Examination of finished products
4. Evaluation of products and structures once they have been put into service

Nondestructive testing, in fact, can be considered as an extension of the human senses, often through the use of sophisticated electronic instrumentation and other unique equipment. It is possible to increase the sensitivity and application of the human senses when used in conjunction with these instruments and equipment. On the other hand, the misuse or improper application of a nondestructive test can cause catastrophic results. If the test is not properly conducted or if the interpretation of the results is incorrect, disastrous results can occur. It is essential that the proper nondestructive test method and technique be employed by qualified personnel, in order to minimize these problems. Conditions for effective nondestructive testing will be covered and expanded upon later in this chapter.

To summarize, nondestructive testing is a valuable technology that can provide useful information regarding the condition of the object being examined once all the essential elements of the test are considered, approved procedures are followed, and the examinations are conducted by qualified personnel.

II. CONCERNS REGARDING NDT

There are certain misconceptions and misunderstandings that should be addressed regarding nondestructive testing. One widespread misconception is that the use of nondestructive testing will ensure, to a degree, that a part will not fail or malfunction. This is not necessarily true. Every nondestructive test method has limitations. A nondestructive test by itself is not a panacea. In most cases, a thorough examination will require a minimum of two methods: one for conditions that would exist internally in the part and another method that would be more sensitive to conditions that may exist at the surface of the part. It is essential that the limitations of each method be known prior to use. For example, certain discontinuities may be unfavorably oriented for detection by a specific nondestructive test method. Also, the threshold of detectability is a major variable that must be understood and addressed for each method. It is true that there are standards and codes that describe the type and size of discontinuities that are considered acceptable or rejectable, but if the examination method is not capable of disclosing these conditions, the codes and standards are basically meaningless. Another misconception involves the nature and characteristics of the part or object being examined. It is essential that as much information as possible be known and understood as a prerequisite to establishing test techniques. Important attributes such as the processes that the part has undergone and the intended use of the part, as well as applicable codes and standards, must be thoroughly understood as a prerequisite to performing a nondestructive test. The nature of the discontinuities that are anticipated for the particular test object should also be well known and understood.

At times, the erroneous assumption is made that if a part has been examined using an NDT method or technique, there is some magical transformation that guarantees that the part is sound. Codes and standards establish minimum requirements and are not a source of assurance that discontinuities will not be present. There are acceptable and rejectable discontinuities that are identified by these standards. There is no guarantee that all acceptable discontinuities will not cause some type of problem after the part is in service. Again, this illustrates the need for some type of monitoring or evaluation of the part or structure once it is operational.

Another widespread misunderstanding is related to the personnel performing these examinations. Since NDT is a "hands-on" technology, the qualifications of the examination personnel become a very significant factor. The most sophisticated equipment and the most thoroughly developed techniques and procedures can result in potentially unsatisfactory results when applied by an unqualified examiner. A major ingredient in the effectiveness of a nondestructive test is the personnel conducting it and their level of qualifications. This will be addressed in greater detail later in this chapter.

III. HISTORY OF NONDESTRUCTIVE TESTING

Where did NDT begin? There are those who would answer this question by referring to the account of the creation of the heavens and the earth in *Genesis:* "In the beginning, God created the heavens and the earth and He *saw* that it was good" (Figure 1-1). This is a theme that has been used from time to time when discussing the history of nondestructive testing. Seeing that the "heavens and the earth were good" has been identified as the first nondestructive test—a visual test!

It is impossible to identify a specific date that would indicate exactly when nondestructive testing, as we know it today, began. In ancient times, the audible ring of a Damascus sword blade would be an indication of how strong the metal would be in combat. This same "sonic" technique was used for decades by blacksmiths (Figure 1-2) as they listened to the ring of different metals that were being shaped. This approach was also used by early bell-makers. By listening to the ring of the bell, the soundness of the metal could be established in a very general way. Visual testing, while not "offi-

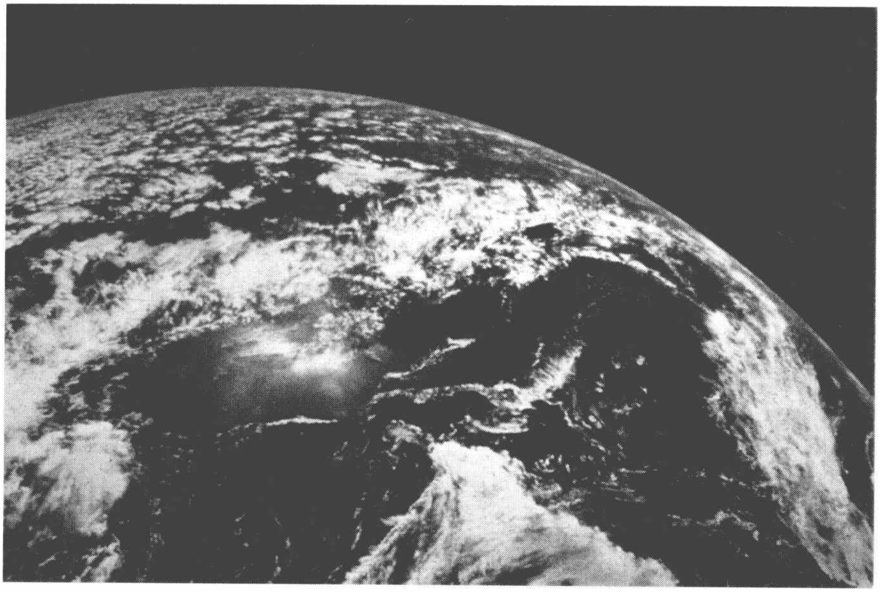

FIGURE 1-1 Earth from Space. (Courtesy of Library of Congress.)

cially" considered a part of early NDT technology, had been in use for many years for a wide range of applications. Heat sensing was used to monitor thermal changes in materials, and "sonic" tests were performed well before the term "nondestructive testing" was ever used.

Table 1-1 lists some of the key events in the chronology of NDT and the individuals who were mostly responsible for these developments. Certainly there were many other individuals who have made significant contributions to the growth of NDT, but it is impossible to name them all.

From the late 1950's to present, NDT has seen unprecedented development, innovation, and growth through new instrumentation and materials. The ability to interface much of the latest equipment with computers has had a dramatic impact on this technology. The ability to store vast amounts of data with almost instant archival capability has taken NDT to a level once only imagined, yet NDT technology is still in its infancy. This chronology will continue to grow as exciting new challenges present themselves through technology expansion and unique material developments. The quest to detect and identify smaller discontinuities will not end until catastrophic failures can no longer be related to the existence of material flaws.

The roots of nondestructive testing began to take form prior to the 1920s, but the majority of the methods that are known today didn't appear until late in the 1930s and into the early 1940s. Much of the latter developments came about as a result of the tremendous activity during the Second World War. In the 1920s, there was an awareness of some of the magnetic particle tests (MT) and, of course, the visual test (VT) methods, as well as X-radiography (RT), which at that time was primarily being used in the medical field. In the early days of railroading, the forerunner of the present day penetrant test (PT), a tech-

FIGURE 1-2 Early blacksmith. (Courtesy of C. Hellier.)

nique referred to as the "oil and whiting test," had been widely used. And there were also some basic electrical tests using some of the basic principles of eddy current testing (ET). The sonic or "ringing" method, as well as some archaic gamma radiographic techniques using radium as the source of radiation, were both used with limited success. From these roots, NDT technology has evolved to encompass the many sophisticated and unique methods that are in use today. (See Table 1-2 for a comprehensive overview of the major NDT methods.)

Prior to World War II, design engineers were content to rely on unusually high safety factors, which were usually built or engineered into many products, such as pressure vessels and other complex components, of that time. As a result of the war effort, the relationship of discontinuities and imperfections relative to the useful life and application of a product or system became a concern. In addition, there were a significant number of catastrophic failures and other accidents relating to product inadequacies that brought the concern for system and component quality to the forefront. Some of the improvements in fabrication and inspection practices can be attributed to boilers (Figure 1-3) and some of their early catastrophic failures.

One such failure occurred on a sunny and unseasonably warm day in Hartford, Connecticut, in March of 1854. People were just returning to their offices and shops after