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MILITARY HANDBOOK

NONDESTRUCTIVE TESTING

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Department of Defense
Washington, DC 20301

MIL-HDBK-728
Military Handbook of Nondestructive Testing
16 December 1985

1. This Military Handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. This publication was approved on 21 October 1985 for printing and inclusion in the military standardization handbook series.

3. This document provides basic and fundamental information on nondestructive testing, inspection and evaluation useful during all phases of the DoD hardware's life cycle.

4. Every effort has been made to reflect the latest information on nondestructive examination. It is the intent to review this handbook periodically to insure its completeness and currency. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Director, U.S. Army Materials Technology Laboratory, ATTN: SLCMT-MSR-ES, Watertown, MA 02172-0001 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) at the end of this document or by letter.

FOREWORD

This handbook provides to all Department of Defense (DoD) personnel information, facts, and principles on the science of nondestructive testing, inspection, and evaluation. By proper use of this science, the safety, the reliability, and the efficiency of the procurement and use of all DoD material and hardware will be increased. This handbook information should be useful during all phases of the DoD hardware's life cycle including production, maintenance, and repair of the hardware.

This handbook, by combining the existing nondestructive testing handbooks and related materials from all DoD agencies into one document, should help to establish unity in the nondestructive testing area within and between all the agencies of the DoD. The organization and loose-leaf format will make it easy to correct, update, and tailor to fit individual needs within the DoD.

Since the handbook's effectiveness depends upon continuous feedback from its users, individuals are encouraged to contribute comments and suggestions by filling in and mailing Form DD 1426 provided at the end of this document.

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1.0 SCOPE

1.1 Scope. Although this handbook is provided as a guide to all those employed in nondestructive testing (NDT), it will be of specific interest to administrators, designers, production engineers, quality assurance personnel, and nondestructive test engineers and technicians. It has been formulated to cover both broad and specific applications of NDT, so as to satisfy individuality, as well as conformity, of interests and knowledge among the divisions of reponsibility in NDT. Not everyone will be interested in all of the specially identified sections. However, to obtain optimum benefits, it is recommended that users of this document review it in its entirety, while paying particular attention to those sections, often identified by a heading or subnote, which may be of specific concern to them.

The handbook, which currently incorporates general principles and procedures (as well as safety items) of eddy current, liquid penetrant, magnetic particle, radiographic and ultrasonic testing, will be updated to include chapters on other NDT methods as they become appropriate.

It must be emphasised that this handbook is not a training manual. Nor can it replace other written directives, procedures or specifications. However, it can serve as a ready reference to the important principles and facts relating to the employment of nondestructive testing, inspection and evaluation. It can be used to refresh one's memory of a particular NDT principle or relationship, to double check or establish a particular fact, or to review the main ideas, concepts or completeness of a particular approach.

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1.2 USERS GUIDE

1.2.1 HANDBOOK ORGANIZATION

This handbook, which is intended to make changes, additions and tailoring easy, uses chapters as independent organizational elements. Each chapter is reasonably complete and self-contained with respect to each specific topic presented and is divided into numbered sections and subsections for ease of reference and use.

Pages are numbered consecutively within each section; sections are numbered consecutively within each chapter; and chapters are numbered consecutively within the handbook. The publication or revision date of each page is located at the bottom inner edge of the page.

Tables, monographs, drawings, and other illustrative material are normally presented within the text. They are identified by the number of the section in which they first are referenced, followed by a sequence number in parentheses: e.g., the first Table in section 5.2 is designated as Table 5.2 (1), the second Table in the same section is designated Table 5.2(2), etc.

The general Table of Contents listing all chapters in the handbook is found on page iv. A Table of Contents listing all sections in a chapter is located at the beginning of each chapter.

1.2.2 REFERENCES

There are two types of references used in this handbook; (1) cross-references to paragraphs in the handbook, and (2) references to other publications which are the sources of specific material. Cross-references are used within this handbook wherever possible to avoid duplication of information.

1.2.3 INDEX

A detailed index of subject matter, keyed to section numbers, is provided at the end of each chapter.

1.2.4 FORMAT FOR DEFINITIONS

Terms which apply to a specialized area and are not defined in standard publications are usually explained in this handbook. If a term is used only once or infrequently, it is explained in the text where it occurs. If it is used frequently throughout a chapter, it will appear in the glossary at the end of the chapter. Common terms, or those whose definitions appear in standard glossaries or dictionaries, are not normally included in this handbook.

1.2.5 HANDBOOK REVISIONS

Every effort has been made to reflect the latest information on eddy current, liquid penetrant, magnetic particle, radiographic, and ultrasonic testing. It is the intent to review this handbook periodically to ensure its completeness and currency. Each revision will include a revised List of Current Pages which will show the latest issue of each page of the handbook.

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1.3 DEFINITIONS FOR NDT, NDI, AND NDE

Although extensive definitions are included in each chapter, several basic terms -- Nondestructive Testing (NDT), Nondestructive Inspection (NDI), and Nondestructive Evaluation (NDE) -- are worthy of special discussion.

Any testing, inspection, or evaluation that does not cause harm to or impair the usefullness of an object satisfies the meaning of the word "nondestructive." In common usage, testing often refers just to test methods and test equipment with only a general reference to materials and/or parts. Inspection relates to specific written requirements, procedures, personnel, standards, and controls for the testing of a particular material or a specific part. Evaluation is concerned with the decision-making process, the determination of the meaning of the results, or the final acceptance or rejection of the material or part and may be qualitative or quantitative. When only qualitative or relative values are required, the use of reference standards is minimized. For quantitative evaluations, however, extensive use of reference standards and controls is often involved.

Although these distinctions between NDT, NDI, and NDE can be (and often are) made, the terms are also often interchanged. In order to evaluate, the results of an inspection must be available. In order to have the results of an inspection, a test must be conducted. And no test or inspection is really complete without an evaluation. As a result of these interdependancies, no strict differentiations between these terms are made in this handbook.

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1.4 GENERAL PRINCIPLES AND GUIDELINES

The following section presents principles and guidelines for the general employment of NDT, as well as for specific NDT disciplines. In some cases, the material is repetitive, since several disciplines are involved in similar activities. It is important, however, to understand differences, as well as similarities, between the disciplines, and to recognize how cooperation between these disparate disciplines is vital to the overall success of NDT.

Guides for applying specific NDT methods are contained in the chapters for those specific methods. The principles and guides covered in this section are all summarized in tables at the end of each subsection, and can be used as handy reference guidelines.

1.4.1 GENERAL PRINCIPLES AND GUIDELINES FOR USING NDT

Before specifing the use of NDT in any program, several things should be considered. First, determine exactly why, or if, NDT is required. There are many reasons why NDT may be desired or necessary: to increase the production rate (by assuring a higher success rate), to increase reliability, to improve or maintain safety, to meet legal requirements, to differentiate or identify improved processing methods, or to detect changes in the product before they become a problem.

There is a danger that specifying NDT has become routine practice rather than the result of a real need: i.e., it was done this way last time; it is always done this way; they did it, we have to do it; everyone else is doing it; or let's do it just to be safe. Sometimes NDT is specified just for administrative reasons: the contract requires it.

Often, although the use of NDT is specified to satisfy a legitimate requirement, it may actually be inappropriate. For example, the ultimate purpose of a test may be to ensure that a part has its required designed strength. NDT tests are often used to accomplish this determination, even though they do not directly measure the strength of a part: its strength can only be inferred by the absence of certain detectable flaws. A simple proof test, which does not require any assumptions, standards, correlations, or other inferred relationships, would have been much more appropriate. The principle here being that an effort should always be made to determine the critical properties directly. Inferring the results by secondary means should only be considered when specific circumstances warrant. Since almost all NDT methods are indirect or "secondary" types of measurements, they are often best replaced by more direct methods. Direct methods are not relevant to nondestructive test methods deployed in end items where destructive tests are not feasible, i.e. thermal damage to aircraft structure.

Whatever the reasons given for specifying NDT, it is important that everyone involved in NDT recognizes and evaluates those reasons realistically so that those responsible/for implementation are able to provide logical and effective responses. Certainly, all programs should consider specifying the use of NDT; however, its automatic use should be avoided. NDT should always have an identifiable purpose that justifies its expense. The reasons for the requirement of NDT will often affect all other decisions.

Once the reasons for the requirement of NDT have been established, it is always wise to determine if the requirement can be eliminated or reduced through the use of better materials, or better processing controls, or a better design. Nondestructive testing has no intrinsic value. Specimens do not last longer simply because they have been ultrasonically inspected. Specimens are not made stronger simply because they have been X-rayed. (If they were, we would inspect and X-ray every part ten times over.) The removing of the justification for any NDT is therefore desirable. The requirement for NDT, however, cannot always be removed. Therefore, although alternatives should ideally be considered first, NDT will often be specified.

It is the designer who has the largest responsibility in this area. (See section 1.4.3 for information on the subject as it relates to the designer.) Once it becomes clear that NDT is appropriate or otherwise required, the designer must consider other important aspects of the situation, including whether the design can be inspected and whether it can be improved to make the inspection more reliable or efficient.

Since NDT can be (and is) used for a multitude of reasons, it is important that all needs be correlated. The production engineer may want to inspect the raw material as soon as possible, even before it arrives on site. NDT engineers, if given a choice, would prefer to inspect material after it has been machined to a simple shape with smooth surfaces. Reliability and safety engineers would prefer that the NDT test be performed after all major operations have been completed. Many times, all of these tests are not affordable. Therefore, it is important to decide exactly when and where in the manufacturing process NDT should and will be specified.

For every place NDT is specified in the manufacturing process, one of the most important factors to be stipulated is the critical flaw limitations that must be detectable. Almost all materials, and all items made of materials, have imperfections of one size or another. These imperfections can be defined as flaws. However, the very small imperfections or flaws do not always impair the usefulness of an item. When this is the situation, it would be inefficient to inspect for these non-critical flaws. Therefore, the specifying of this critical size where the usefulness becomes potentially impaired is important. Those imperfections or flaws that are critical, or larger than that acceptable, are called defects. It is impossible to determine the flaw limitations required for an inspection without knowing the purposes of the inspection, as well as the complete design requirements of the finished parts.

The determination of this limitation in flaw size is not always easy. One very common limitation specified in the use of NDT is "no flaws are allowed." Certainly such an achievement would be desirable. However, no test or inspection with that kind of limitation can be expected to succeed. Often, when this impossibility is eventually understood, the next requirement specified is "find the smallest flaws possible." Again, although the desirability of this type of requirement is apparent, testing to this degree is generally not affordable.

Ultimately, the decision on the proper limitation for allowable flaw size must be made by the designer working in cooperation with production, stress, and material engineers. They must determine the types of flaws expected and the maximum allowable flaw limits required to achieve or maintain design goals.

Only after this groundwork has been completed, can the proper decisions for the requirements for NDT be made. Depending upon the NDT capabilities that exist, trade-off studies may be necessary to ensure that the critical flaws, at their specified limits, can be effectively and reliably detected. Although trade-off studies and decisions should be accomplished at the design level, they often are not because of insufficient information. When not made at the design level, choices become more limited, often resulting in either a reduction of the original design goals or the acceptance of unreliable products.

Once these flaws and flaw limitations have been determined, then NDT engineers must respond by finding answers to more questions -- What NDT method must be used? What equipment, personnel, and controls are necessary? Many times, one method alone may not be adequate.

No test or inspection is complete without the proper and adequate evaluation of the data. If a permanent test record is required, the documentation must be considered in the NDT test itself. Since some methods of NDT do not provide results in terms of a permanent record, specifying permanent records or documented proof of the passing of a test does limit the choices available. This limitation of test methods should be considered before such requests are made.

Principles and guidelines for specific disciplines are given in the paragraphs that follow. The assignment of principles and guidelines to specific disciplines clarifies who is responsible for implementing the concepts of NDT and how each discipline must support the other if success is to be achieved.

Table 1.4(1). General principles and guidelines for NDT.

1.	Determine exactly why NDT is required.
2.	If unreasonable, to remove the NDT requirement or minimize it.
3.	If the need for NDT cannot be denied, design for inspection.
4.	Determine the proper place(s) in the life cycle for performing NDT.
5.	Establish critical flaw limitations in quantitive items. These limitations cannot be: "No flaws allowed" or "Find the smallest possible flaws." They should be in terms such as "No cracks shall exceed a length of 4 mm in any direction or "any pores or combination of contiguous pores that equal or exceed the volume of a 3 mm sphere shall be rejected".
6.	Determine the appropriate method(s), equipment, personnel, standards, and controls. Remember, most NDT methods do not reveal flaws directly and interpretation is often possible only through the use of proper standards. NDT methods usually only find indications or differences. These indications are significant only to the degree that they can be interpreted correctly. Also remember that complete answers (positive answers) cannot always be obtained by a single inspection method. Two or more methods may be required for a complete analysis.
7.	Establish the means for complete, proper, or adequate evaluations (to include reports and documentation).

1.4.2 PRINCIPLES AND GUIDELINES FOR ADMINISTRATORS

The success for any NDT program will always rest upon managers. It is the manager who must decide the overall goals, the proper division of the available funds, and the coordination that must be maintained. It is the manager who determines the degree to which the total life cycle of a component is considered -- including the production of raw stock to the final salvage of worn-out parts. The manager must often accept the responsibility if proper funds have not been set aside for adequate NDT, if designers did not properly coordinate with production and NDT engineers to design a system that could be efficiently inspected and built, and if completed parts cannot be properly inspected in the field. Because the manager plays such an important role, special administrative directives have been published by DoD. The guidelines and principles given in DAP 11-25, should receive serious attention.

Managers must recognize and maintain consistent control over the integrity of the total inspection system by separating quality inspection command from the production group, while simultaneously encouraging communication and coordination between the two areas. The manager must determine the relative degree of this separation, effectively balancing the pressure of meeting production rates with the necessity for successful inspection by using independent managers.

Keeping communications active between functional groups is important, especially during the design phase. Communication, which can be either formal or informal, often takes the form of written release statements required on all design drawings by Quality Assurance (QA) and NDT engineers. Since the effectiveness of communications depends on the time, money and personnel available to make analyses, it is up to the manager to determine the degree of effort to devote to specific communications actions.

Communication during the production phase is especially required if there are incomplete design decisions, since QA and NDT engineers cannot do their jobs effectively until designers have established specific flaw limitation requirements and allowable trade-offs. Although it is true that many testing decisions cannot be made during the design phase, until the flaw limitations are established, the designer must remain on the project and in communicaton with QA personnel.

The manager must employ sound management practices to encourage quality results by fostering high morale and positive motivation among his subordinates. Most importantly he must be provided with the means to establish accountability and given the power and the authority to take definitive action when necessary.

Table 1.4(2). Guidelines for administration of NDT (managers).

1. Maintain integrity (clear separation of responsibilities) between:
   - o Rate of production (Production Engineering).
   - o Quality of production (Inspection, QA, etc.).
2. Ensure adequate communications (before, during, and after) between:
   - o Designer.
   - o QA.
   - o Production Engineer.
   - o NDT Engineer.
   - o Materials Engineer.
3. Provide adequate personnel, facilities and avenues for implementation.
4. Employ sound management practices.

1.4.3 PRINCIPLES AND GUIDELINES FOR DESIGNERS

To achieve a successful design, a designer has to deal with several constraints, such as size, weight, weight distribution, dimensional tolerances and fits, material compatabilities, production capabilities, cost limitations, strength, fatigue life, appearance, surface finish, etc. Although a designer should be careful about adopting unnecessary constraints, he should be aware of the inspectability of his design and whether it will require NDT or whether choices exist that could render NDT nonessential. A designer who has a background in NDT can more readily reach this determination (taking into account cost-effectiveness, safety, and legal obligations associated with safety and reliability) and can make decisions, when required, that favor a successful NDT program.

One of the most important obligations of the designer, when NDT is determined to be necessary, is to establish the requirements for the inspection, with the help of stress, material, and test engineers. If these limits are not reasonable relative to the NDT methods available, then trade-offs must be considered.

One area that is seldom considered by designers is the use of internal standards. For example, almost all ultrasonic inspections require a special setup with comparisons to reference standards. Ideally, there must be a like correspondence between significant factors within the comparison. Reference standards should perfectly match the test article in the type of material, the hardness, the thickness, the surface finish, etc. Test setups should produce equal indications for equivalent flaws. With very little extra cost, components can be developed that have their own internal standards designed into them as an alternative. When standards are designed into the component, all the correlations required for surface finish, for type of material, hardness, etc., are all automatically achieved and the inspection is greatly improved in terms of time and reliability. The arrangement of having the designer create the NDT standard saves time and provides the designer with important NDT knowledge.

Almost all NDT tests, including radiographic, eddy current, and ultrasonics, can be improved by similar considerations. Designers should exercise a direct effort to improve the inspectability of the parts they design, not just in the development and construction phase, but also in terms of inspection required during the service and repair phases of the component's life. Only a designer can accomplish this desirable total life cycle approach.

Table 1.4(3). Guidelines for designers.

1. Determine if NDT is really required.

2. Determine if the need for NDT can be removed by:

   Improving the design.

   Using an over-design approach.

   Using redundancy.

   Using better materials.

   Selecting better production methods.

   Establishing better production controls.

   Accepting more risks.

   Substituting proof tests.

3. If NDT requirements cannot be removed:

   Does the design allow NDT?

   Will trade-offs be necessary, or can trade-offs be found, to make possible and/or improve the NDT inspection?

   Will internal standards be necessary and/or practical?

NOTE: Sometimes NDT will be required by contract. Therefore, if NDT must be done, use it to your advantage. The use of cheaper material may be feasible, etc.

1.4.4 PRINCIPLES AND GUIDELINES FOR PRODUCTION ENGINEERS

Production engineers also work under constraints. They must produce acceptable products within an assigned time schedule and fixed budget. Their success depends upon the employment of both basic and technical knowledge, of which optimal use of NDT is an important part.

Production engineers must constantly assess the amount of NDT required and determine exactly where it is to be accomplished. For example, expensive machine time cannot be spent cutting raw material into a finished product only to find, at the last cut, an internal flaw that requires rejection of the part. Such flaws should be found before such operations are initiated.

Production engineers normally desire to perform NDT at the earliest possible point in time, usually at receipt of raw stock. The NDT engineers, however, usually want to do NDT when the parts have the simplest shape with the most uniformly prepared surfaces. Reliability engineers often want to do the NDT after all possible disturbing operations are completed. Usually, there is not sufficient time or money to do all these inspections. The final decisions often rest with the project engineer who must meet overall budget and time constraints.

Production engineers should also be aware that production methods and controls, many times, establish the need for NDT. Although selection of production methods and controls that prevent flaws from occuring would, of course, be ideal, trade-offs between the costs of using a more expensive but less flaw-inducing method, versus the cost of testing and possible rejection, must be a consideration for every choice being made.

One of the most productive uses of NDT is the direct employment of inspection during the actual manufacturing process. For example, a method that completely changes the approach to the manufacturing process and greatly increases the reliability of the finished product is the use of ultrasonically controlled cutting machines which determine material thickness as each cut is made. Automatic NDT controls such as these provide great opportunities for increased productivity and reliability.

Table 1.4(4). Principles and guidelines for production engineers.

1. Determine the earliest point in time when NDT is desired.

2. Ensure that the rate of inspection is adequate or initiated early enough to maintain adequate stock levels.

3. Know the material, the reputation of the sources of the material, and the characteristics of the production operations as affected by the material.

4. Select production operations and controls that minimize material problems.

5. Coordinate the NDT tasks with requirements from QA and Design.

6. Use the science of NDT as a direct production control method where developed and appropriate

1.4.5 PRINCIPLES AND GUIDELINES FOR QUALITY ASSURANCE PERSONNEL

The information given herein should be taken only as general guidelines for Quality Assurance (QA) personnel. Specific detailed instructions are provided by each of the separate branches of the DoD. All QA personnel should refer to their respective manuals for specific instructions.

Quality Assurance (QA) responsibilities extend over the full NDT spectrum. The total magnitude of administrative and technical responsibilities depends upon the size of the operation involved. However, whether only one individual or many individuals are involved in the QA task, the following areas must be considered as part of the QA responsibilities:

1. Train, test, and classify inspection personnel and maintain their records.

2. Know the availability, effectiveness, and costs of NDT facilities and operations.

3. Maintain test records and reports.

4. Establish and maintain communications with design, production, and program managers.

5. Maintain a "corrective action" system.

6. Maintain an advanced technological improvement program.

Administration of the QA task includes control over personnel, NDT facilities and data records. Personnel rosters, showing NDT related education, training, tests, test scores, qualifications, classifications, and appropriate medical records should be maintained on all individuals responsible for NDT (including those outside of QA who are involved in NDT). Comments on their abilities and limitations should also be included. These records should be continually checked and updated. In addition, QA administration should provide a formal training, testing, scoring, and classification program utilizing assigned instructors and personnel to administer these areas. Retesting and reclassification of personnel should be done periodically on a continuous basis with maximum time periods specified for retesting each time a classification is assigned.

QA should maintain a current inventory of all NDT equipment with ready references to the accuracy, resolution, reliability, maintenance schedule, average downtime, and inspection rate of each item. In addition, records should be kept on all other factors that might impact on time, money, and personnel. Cost of labor, maintenance, electricity, and other power sources must all be monitored and kept current. All of this information is vital for making the decisions that must be made by QA.

One of the major administrative duties performed by QA includes maintaining inspection records and reports. As a result, the following questions should be considered by QA:

1. What records are to be kept?

2. How long should they be kept?

3. How shall they be maintained?

4. How should they be purged or corrected?

5. Who shall have access?

Many of these records must be maintained for the life of the program or the parts involved.

Communication is another large area of administration for QA. Communication with upper management, project engineers, designers, production and material engineers, facilities, and laboratory standards personnel should be established and maintained by QA.

In the technical area, QA should provide predesign support to help the designers develop parts that are inspectable to the degree necessary to assure the required reliability. QA should also be able to check the completeness of the designers' approach to NDT.

Quality assurance must support the setup, or initiation, of production runs. This support requires an understanding of exactly what is required, why it is required, and all appropriate trade-offs that may be present. Decisions on exact methods to be used must be made, whether those methods are NDT or others, and the standards or verifications required must be established. It then becomes necessary for QA to monitor the existing production runs to ensure that all original assumptions are still valid, that all procedures are being followed, and that proper records, reports, and interpretations are being developed.

It is essential that QA maintain systems for detecting potential or actual problems and expeditiously solving those problems. These "corrective action" systems may consist of several items, including formal report procedures, review boards, and rejection tags for defective parts.

In addition, for any QA department to be successful over a long period of time, it must recognize that changes must be made as technology is improved. QA should have a formal interest and obligation to stay up-to-date with the state-of-the-art of NDT, thus allowing personnel to become knowledgeable and experienced, so they can periodically improve NDT capabilities as new developments occur. Although funding for this area of effort is not always available, it is essential to effective preplanning activities that personnel have access to current technology.

It does not have to be assumed that QA accomplishes all the details of every assigned task in all these areas, either administratively or technically. But it is QA's responsibility to see that, overall, these details are accounted for or that reports to the contrary are made. Much of QA's success will depend upon the quality of communications established with all the involved areas and the formulation of decisions based upon their combined inputs.

Table 1.4(5). Guidelines for quality assurance personnel.

A. Administrative Areas:

1. Administer Personnel Training and Classification (including rosters, NDT education, training, tests, test scores, qualification ratings, work classifications, medical histories, NDT work experiences, and evaluations by supervisors).

2. Maintain Current Inventories of NDT Facilities to include specified accuracy, resolution, reliability, maintenance schedule, average down-times, inspection rates, availability of operators, operator costs, depreciation rates, maintenance costs, availability of power, operating costs, etc.

3. Maintain Inspection Data Records - What records, how maintained, how long, how purged and/or corrected, who has access.

4. Establish Communications (Policies, Planning, Scheduling, Coordination, Proposals, etc.) with and between administrators, project engineers, designers, production, material, and facilities.

B. Technical Areas

1. Support Design Drawing Reviews - Assist in checking and approving completeness of designers approach, trade offs, and decisions.

2. Support the Program - Determine exactly what is required, why it is required, and what methods are to be used. Establish procedures for chosen method, standards, reports, and data controls.

3. Detect and Solve Problems (Corrective Action) - Establish corrective action review boards, and rejection tags.

4. Encourage Research and Development (R & D) - Staying up with the state-of-the-art.

1.4.6 PRINCIPLES AND GUIDELINES FOR NDT ENGINEERS

Some NDT engineers may be directly involved with receiving and inspection, quality assurance, or production activities, while other NDT engineers are associated with research and development efforts. Different qualifications are often required in each of these areas. Basically, however, it is the NDT engineer who must understand the principles of each type of nondestructive test and the specific limitations of those tests. He must be able to recognize which inspection procedures are proper or adequate for the desired results and he must understand the results and their interpretation.

In order for the NDT engineer to perform his duties to the fullest, he must have certain specific information. He must know the materials involved and how the part was fabricated. He must know what defects and/or properties are to be detected and/or measured. He must be able to identify the kinds of false indications that may be encountered so that they may be properly considered. It is the NDT engineer who must often communicate and explain the differences and difficulties when what is requested differs from what can actually be obtained.

Because the NDT engineer knows the equipment and personnel available, he can provide a significant amount of data necessary for scheduling nondestructive tests. Sometimes an NDT engineer receives complete instructions from QA where test plans, procedures, and standards have all been predetermined. It is a requirement that the NDT engineer double check these procedures and standards, and essentially, reverify their effectiveness.

The NDT engineer will normally have NDT technicians under his direction, and the training and instruction of these technicians will be one of his primary concerns. He must understand each technician's ability to handle complicated tasks and the limits or the "confusion" level with which an individual technician can adequately cope. These factors will greatly influence the assignment of tasks and the degree of independence that can be given to each technician.

All of the preceding factors will affect the type of inspection routine that an NDT engineer will institute. The NDT engineer should also be cognizant of the sorting routines and scanning methods that have proven to be the most reliable for his personnel to follow in any particular situation. When a variety of flaws are to be detected, the approach, sorting routines, order of the search, number of repeats in the search operation, direction of scanning, scanning rate, and type of data comparisons (digital or analog) that must be observed will affect the reliability of the results. Often, a search for one kind of flaw at a time, on one type of part, will serve to remove some of the complexities which exist for multiple parts and flaws, as well as to establish reliability.

One parameter beyond the control of the NDT engineer is the rate at which the presence of flaws is indicated. When parts are relatively "clean" and free of indications, or alternately, when there are a great many indications, the percentage of flaw indications missed usually increases for most inspectors. NDT engineers should be aware of the frequency of occurence of the flaws to be detected and adjust the inspection routine as necessary to maintain the required reliability.

Table 1.4(6). Guidelines for NDT engineers.

*1. Know exactly what is wanted and why.

*2. Know the part and/or material to be inspected.

*3. Know the defect and/or property to be detected and/or measured.

4. Know limitations of equipment and personnel.

5. Establish time requirements and schedule.

6. Double check exact procedures and standards required.

7. Provide the technician with adequate material, facilities, and working conditions.

8. Ensure that an honest and complete report is made (that both assumptions and limitations are known to those receiving the report). Provide information and training to technicians, and guidance and suggestions to QA, designers, and managers. This is done both formally and informally. These lines of communications should be established and well used.

* Information that should be provided to the NDT engineer by QA or project engineer.

1.4.7 PRINCIPLES AND GUIDELINES FOR NDT TECHNICIANS

Technicians are the final key to successful NDT. The personal efforts of knowledgeable and experienced technicians can often save a program otherwise doomed to failure. Likewise, a seemingly successful program can fail if proper responses to indications are not maintained by the technicians.

Even though a technician's task -- to note all exceptions to that which is normal -- appears fairly simple, it can often become complicated. In NDT, meaningful observations may consist of only slight changes or fleeting signals that can easily go undetected -- particularly if they randomly occur between extensive amounts of unimportant data. Sometimes, the problem can develop from too much information. If a technician is being presented with a multitude of nonrelevant or false indications that must be continuously rejected, valid indications can sometimes be automatically rejected as well, through force of habit. A good technician will be aware of these problems and their impact on NDT and will consciously guard against them.

The danger of fatigue and hypnotic effects on the technician must also be consciously fought against, and the technician should not hesitate to ask for a break or change in routine that might prevent these kinds of difficulties from developing. Present efforts to automate all inspections exist mainly because of these human weaknesses.

However, since automatic inspection systems are incapable of noticing all the various types of exceptions that a technician can, technicians will still be needed and valued for their technical knowledge and attentiveness to detail.

General guides for technicians include: 1) Not hesitating to ask questions or double-checking procedures relating to the NDT work; 2) Recording all NDT tasks and results; 3) Always checking all dial settings each time an instrument is used for a new setup; 4) Knowing the capabilities and limitations of the equipment is essential.

Table 1.4(7). Guidelines for NDT technicians.

1. Be aware of the dangers of fatigue and hypnotic effects (Know how to fight these effects. Do not hesitate to ask for a break when any sign of these effects are present).

2. Always note all exceptions to that which is normal - they may be important.

3. If you are not sure if you should ask about something, you probably should.

4. Always record everything done in NDT.

5. Always check all dial settings each time an instrument is used for a new setup.

6. Know your equipment and your own limitations.

1.5 CHOOSING TEST METHODS

Choosing a proper NDT method requires a knowledge of the types of flaws that must be found, their maximum acceptable limits in size and distribution, and their possible locations and orientations. Also the presence of all other possible variables that may affect the inspection must be known. This might include the orientation and accessibility of the part, the part geometry and size, internal variables in densities, etc. This knowledge must then be coupled with knowledge of the basic principles and limitations of all NDT methods, their availability, and costs. One must also be familiar with the requirements and availability of standards to employ these methods and the type of records required. (See Table 1.5(1) at end of this section.)

The appropriate method may consist of several separate inspections. One inspection by itself may indicate the presence of a possible flaw and other inspections may be required to confirm or verify the original indication.

When the choosing of NDT methods is done routinely, then it is important that a list of average basic costs of each available method is formulated. An example would be as follows:

LIST OF AVAILABLE METHODS	PRELIMINARY SET UP REQUIREMENTS		ACTUAL TEST COSTS		
	LABOR	STANDARDS	LABOR MH/Part	ADDITIONAL COSTS	AVAILABILITY
Liquid Penetrant	Minor	Minor	0.8	Minor	Good
Mag Particle	Minor	Minor	1.1	Minor	In heavy use
Eddy Current	Possibly extensive	Yes	1.2	None	Good
Ultrasonic (C-scan)	Possibly extensive	Normally extensive	2.0	Paper	Not working until next month
X rays	Minor	Routine	2.0	Film and development	Good

With such a chart, one can start with the cheapest method available and then progress through the list to the first available method that will meet acceptable detection limits. These lists must be individualized for each operation, taking into consideration how modern the available equipment and facilities are and the level of personnel staffing. Although these lists can provide some broad guidance, they should not be used as a definitive standard. Costs for each test vary and the maximum or minimum of one test method may, in some cases, overlap the costs for another test method.

The choice of a proper NDT method requires an understanding of the basic principles, and advantages and disadvantages of all available NDT test methods. Detailed knowledge of their comparative effectiveness, availability, and costs are all critical in making the correct decisions. Tables 1.5(2) through 1.5(6) (at the end of this section) list some of the general advantages and disadvantages of a number of general NDT methods. All NDT users should maintain similar lists, based upon experience with their particular equipment.

There are times when the choice of methods is very clear. When small delaminations between layers deep within a flat composite panel must be detected, an ultrasonic test of some type will almost always be chosen. If surface cracks on an iron part were to be detected, liquid penetrant, magnetic particle, ultrasonic, eddy current and X-ray tests could all be individually considered. If porosity were to be found, a quick ultrasonic C-scan might be used to locate potential areas, followed by X rays concentrated in those areas identified by the C-scan, to confirm if porosity is really involved and, if so, to what extent.

Since the difference between success or failure depends on knowing the details of the specimen and/or material being inspected, many NDT courses properly begin with a study of raw material manufacturing processes to indicate the origin and causes of flaws in castings, ingots, and forgings. The reshaping and redistribution of the flaws in subsequent manufacturing processes must be understood.

Although a study of these flaws and processes will not be given in this handbook, the importance of this area should not be minimized. All NDT personnel should be familiar with: porosity, nonmetallic inclusions, pipe, macrosegregation, cold shots, cold shuts, hot tears, shrinkage cracks, blowholes, misruns, forging laps, stress cracks, grinding cracks, fatigue cracks, galling, and scale. They should know where they occur or can be expected to exist, and what impact they may have in each of the test methods. The comprehension that flaws are to be expected does not always exist with those who are inexperienced. Yet it is the first step in choosing a proper NDT method. Knowing what the flaws might be and where to look for them is the next step. Therefore, a study of materials, as well as the relevant production and manufacturing processes, is vital to the choice and administration of an NDT program.

Lastly, the most critical (and often the most unavailable) data for determining an appropriate method involves what the acceptable limits on the size of the defect are. Those limits determine whether the method would be feasible and how expensive an effort would be required. Figure 1.5(1) expresses the importance of this size tolerance. References to sections 1.4.3 (Designers), 1.4.4 (QA) and 1.4.1 (General Principles) all discuss the importance of defining this limit.

Table 1.5(1). Choosing proper NDT methods.

1. Determine the material to be inspected and the type of flaws or difficulties common to that material.

2. Determine the material manufacturing processes and the type of flaws or inconsistancies associated with those processes.

3. Know the part to be inspected and determine its design requirements so that critical flaw limits can be established.

4. Know the basic principles and limitations of all NDT methods.

5. Know costs and availability of NDT personnel and facilities.

6. Determine what standards are required and their availability.

7. Determine what records and controls are required.

Table 1.5(2). Advantages and disadvantages of liquid penetrant.

Advantages:

1. Usually very cheap (often is the cheapest method).

2. Usually quick, even for large parts.

3. Can be portable (taken to test site).

4. Reasonably easy to interpret.

Disadvantages:

1. Can only detect defects opened to the surface.

2. No automatic or permanent records.

3. Often requires a pre-cleaning step.

4. Use of fluorescence required for maximum sensitivity.

5. Not good for rough or porous surfaces.

6. Penetrants chemically attack some rubbers and plastics, and should have a low sulfur and/or chlorine content when used with certain stainless steel, nickel, or titanium materials.

Table 1.5(3). Advantages and disadvantages of magnetic particle.

Advantages:

1. Surface or near surface flaws can be detected.
2. Reasonably cheap and quick.

Disadvantages:

1. Magnetic type materials only.
2. No permanent records.
3. Must often demagnetize parts following test.
4. Surfaces can be marred where contact probes are used.

Table 1.5(4). Advantages and disadvantages of eddy current.

Advantages:

1. Surface or near surface flaws can be detected.
2. Very sensitive to many variables such as:
   - geometry (thickness, stand-off).
   - surface roughness.
   - frequency.
   - electrical conductivity.
   - magnetic properties.
   - cracks.
3. Direct go/no-go type answers can be obtained quickly.
4. Portable.
5. No physical contact required (can be accomplished in a vacuum).
6. Not too expensive.
7. Easily adaptable to production line situations (electrical signals for electrical controls).

Disadvantages:

1. Must involve one or more layers and/or surfaces that are electrically conductive or magnetic in nature.
2. Requires skill when many variables are involved.
3. Adequate separation of variables cannot always be achieved.

Table 1.5(5). Advantages and disadvantages of ultrasonics.

Advantages:

1. Internal inspection method (the deepest penetrating method).
2. Can be adapted for thick or thin panels.
3. Extremely sensitive to many specimen variables:

   porosity.

   delaminations.

   micro cracks.

   geometry

   density changes.

   grain or fiber size.

   orientations.

4. Many test control variables:

   transducer frequency.

   transducer size.

   transducer type.

   transducer focal length.

   type of test (immersed, contact, or jet).

Disadvantages:

1. Non-linear responses (variable relationship between flaw size and indication size).
2. Sometimes too sensitive (impossible to separate out desired parameter).
3. Often limited by geometry and surface roughness.
4. Often must have special standards (especially when details are as small or smaller than the width of the inspection beam).

Table 1.5(6). Advantages and disadvantages of X-rays (radiography).

Advantages:

1. Good internal inspection method.

2. Excellent geometric representations.

3. Good sensitivity, 2% is reasonable.

4. Small details are visible (the limit is often the size of the grains on the film being used).

Disadvantages:

1. The image is a shadow only (The shadow varies only as the amount or density of the material varies. Therefore, it can "see" missing material, but if a delamination exists perpendicular to the X-ray beam with material pulled apart but not missing, an X ray will not detect it).

2. Sometimes expensive in time, labor, and facilities.

3. Personnel safety requirements.

4. Sensitive to orientation of cracks.

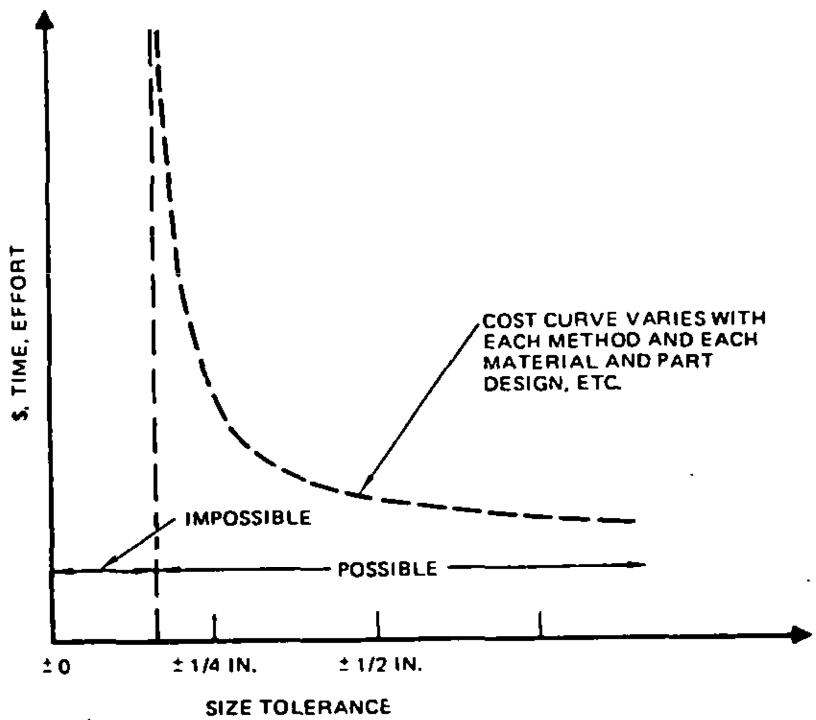

Figure 1.5(1). Cost curve.

1.6 GLOSSARY

Classifications (for NDT personnel). Personnel classifications can be made by nondestructive test methods, by specific equipment, or by specific product lines in which qualifications have been obtained.

Corrective Action. Action taken (or plans for actions to be taken) for solving problems that occur during production.

Correlations. Establishing relationships between facts or events.

Critical Flaw Size. The minimum extent of a flaw (e.g., minimum depth, length, etc.) that prevents achievement of the designed goals for a particular part.

Defect. Any condition of a part that prevents achievement of a designed goal is a defect. A flaw that is of critical size or larger is a defect.

Delamination. A delamination is a partial or complete separation between two layers of a material which should be bonded together.

Discipline. A specialty of profession or training.

Documentation. Written or recorded proof, usually includes a "picture" or other data recording made in a controlled test. Documentation should include names, date, equipment, and all other vital information necessary to confirm the status of a part or the results of a test.

Fatigue Life. The expected number of load cycles that a part can withstand and still perform adequately.

Flaw. Any imperfection in a part can be considered to be a flaw. By this definition, all parts have flaws. Many flaws are too small to be of concern. Some flaws may be large enough to cause a part to fail. When flaws are large enough to cause failure, they can be called "defects."

Flaw Size Limitation (see critical flaw size).

Indications. Any signal or markings obtained in a test is an indication. Indications must be interpreted. There can be false indications (not due to the material variable of concern) and valid indications. There can be acceptable indications and rejectable indications.

Integrity. Integrity is a measure of the completeness of a part, or the property of being solid or continuous, with no break in the uniformity of the part.

Life-Cycle. The complete history or activities associated with a part, from its manufacturing, to its ultimate utility as a waste product.

Nondestructive Evaluation. (See Section 1.3).

GLOSSARY (CONTINUED)

Nondestructive Inspection. (See Section 1.3).

Nondestructive Testing. (See Section 1.3).

Permanent Record. Any automatically produced "picture" or recording of data (e.g., X-ray negatives, C-Scans) obtained from a test which is permanent and can be used at any time to confirm the results of a test. It forms part of the Documentation that might be specified for particular inspections.

Qualifications (for NDT personnel). The minimum education, knowledge and experience required of an individual to use a particular NDT method. ASNT qualifications include three levels: I, II and III. All inspection supervisors should be level II or higher.

Quality Assurance (QA). Quality Assurance can be the organization, the control, or the actions taken to ensure that parts will meet all design goals. A particular group is often assigned responsibility to ensure that parts are correctly built, inspected and tested to confirm their quality and reliability.

Reliability. Confidence in the achievement of specific goals, often expressed in statistical terms.

Reference Standards. Any part or image that is used to judge the status or acceptability of another part or image can be called a reference standard.

Standards. The base upon which or by which other variables are judged or measured.

Tailoring. The act of changing something from one state or condition to another state or condition to better fit or apply to particular circumstances.

Trade-off. Mutually exclusive events or conditions often require a choice between them. A trade-off is exchanging one state or condition for another, with subsequent gains and losses.

1.7 BIBLIOGRAPHY

The following lists of Specifications, Standards, Handbooks and other publications are provided as additional sources of information to aid in any particular NDT problems that may arise.

1.7.1 GOVERNMENT DOCUMENTS

TECHNICAL ORDERS

Air Force	TO 00-25-224	Welding High Pressure & Cryogenic Systems (Section 4 - Nondestructive Inspection by Ultrasonic and Eddy Current Methods)
Air Force Navy Army	TO 33B-1-1 NAVAIR 01-1A-16 TM 43-0103	Nondestructive Testing Methods (Chapter 1 - General, Chapter 2 - Magnetic Partical Method, Chapter 3 - Eddy Current Method, Chapter 4, Ultrasonic Inspection Method, Chapter 5, Radiographic Inspection Method, Chapter 6, Flourescent and Dye Penetrant Method).

MILITARY STANDARDS AND SPECIFICATIONS

MIL-STD-271	Nondestructive Testing Requirements for Metals (Radiography, Magnetic Particle, Liquid Penetrant, Leak Testing, Ultrasonics).
MIL-STD-798	Nondestructive Testing, Welding Quality Control, Material Control & Identification & Hi-Shock Test Requirements for Piping System Components for Naval Shipboard Use (Radiography, Magnetic Particle, Penetrant).
MIL-I-6870	Inspection Requirements, Nondestructive for Aircraft Materials & Parts (Magnetic Particle, Penetrant, Radiographic, Ultrasonic, Eddy Current).
MIL-STD-410	Qualification of Personnel.
MIL-STD-721	Definition of Terms for Reliability, Maintainability, Human Factors, and Safety.

MILITARY QUALITY ASSURANCE PAMPHLETS

AMCP 702-3 Reliability Handbook (Army Material Command)

DAP 11-25 Life Cycle Management Model for Army Systems (Department of the Army)

NASA PUBLICATIONS

NASA SP-3079, Nondestructive Evaluation Technique Guide, A. Vary (U. S. Government Printing Office, Washington, DC) 1973

NASA SP-5113, Nondestructive Testing - A survey, (U. S. Government Printing Office, Washington, DC) 1973

NBS PUBLICATIONS

NBS Handbook 14, General safety standard for installations using non-material x-ray and sealed gamma ray sources, energies up to 10 Me V (U. S. Government Printing Office, Washington, D.C.)

NBS Handbook 50, X-ray protection design (U. S. Government Printing Office, Washington, D.C.)

NBS Handbook 57, Photographic dosimetry of X and gamma rays (U. S. Government Printing Office, Washington D.C.)

NBS Handbook 66, Safety design and use of industrial beta ray sources (U. S. Government Printing Office, Washington, D.C.)

NBS Handbook 114, General safety standards for installation using non-medical x-ray and sealed gamma ray sources, energies up to 10 Me V (U. S. Government Printing Office, Washington, D.C.) 1975

1.7.2 OTHER PUBLICATIONS

ASME Boiler and Pressure Vessel Code (Section I, Section III, Section IV, Section V, Section VIII, Section IX, Division 2, and Section IV)

ASNT-TC-1A Recommended Practice Nondestructive Testing Personnel Qualification and Certification (Supplement A, Radiographic Testing; Supplement B, Magnetic Particle; Supplement C, Ultrasonic Testing; Supplement D, Liquid Penetrant; and Supplement E, Eddy Current)

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1.7.2 WHERE TO OBTAIN SPECIFICATIONS AND STANDARDS

All U.S. Department of Commerce, National Bureau of Standards Handbooks are available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

All other government agency specifications or standards are under the control of the Department of Defense.

All requests for copies of specifications, standards, and qualified products lists should state the title and identifying number and should be submitted to Commanding Officer, Naval Supply Depot, 5801 Tabor Ave., Philadelphia, PA 19120, Attn. - Code CDS, except:

a. Copies of specifications, standards and qualified products lists required by contractors in connection with specific procurement functions should be obtained from the procuring agency awarding the contract or as directed by the contracting officer.

b. Federal Specifications and Standards and Military Book Form Standards will not generally be furnished by the Naval Supply Depot to commercial concerns unless required in conjunction with a bid or contract, or for sufficient other justification. Copies of federal documents may be purchased from the Business Service Center, General Service Administration, Washington, D.C. 20405. Most book-form Military Standards may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

c. Only current, "in effect" issues of standardization documents will be available from the Naval Supply Depot. Copies of canceled or superseded documents required for contractual purposes will have to be obtained from the contracting office of the concerned service.

d. Information regarding obtaining DoE standards relative to the Division of Reactor Development and Technology may be obtained from Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, TN 37830.

All specifications or standards as issued by the organizations listed below are available directly from the organization at the address given.

ABS	American Bureau of Shipping 45 Broad Street New York, NY 10004
AIA	Aerospace Industries Association of America 1725 De Sales St., NW Washington, DC 20036
AISI	American Iron and Steel Institute 1000 16th St., NW Washington, D.C. 20036
Al. Assoc.	The Aluminum Association 420 Lexington Avenue New York, NY 10017
ANS	American Nuclear Society 555 N. Kensington Avenue La Grange Park, IL 60525
ANSI	American National Standards Institute, Inc. 1430 Broadway New York, NY 10018

API	American Petroleum Institute 50 West 50th Street New York, NY 10019
ASME	American Society of Mechanical Engineers 345 East 47th Street New York, NY 10017
ASNT	American Society for Nondestructive Testing, Inc. 4153 Arlingate Plaza Caller 28518 Columbus, OH 43228
ASTM	American Society for Testing and Materials 1916 Race Street Philadelphia, PA 19103
AVS	American Vacuum Society 335 East 45th Street New York, NY 10017
AWS	American Welding Society 2501 N.W. 7th Street Miami, FL 33125
ICRU	International Commission on Radiation Units 7910 Woodmont Avenue, Suite 1016 Washington, D.C. 20014
MSFC	National Aeronautics and Space Administration George C. Marshall Space Flight Center Huntsville, AL 35812
NCRP	National Commission on Radiation Protection NCRP Publications P.O. Box 4867 Washington, D.C. 20008
SAE	Society of Automotive Engineers, Inc. 400 Commonwealth Drive Warrendale, PA 15096

1.8 INDEX

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1.9 NOTES

1.9.1 MIL-HDBK-728/1, /2, /3, /4, /5 and /6 supersede the following documents:

MIL-HDBK-54
15 October 1965

MIL-HDBK-55
1 April 1966

MIL-HDBK-726
10 June 1974

MIL-HDBK-333
10 April 1975

AMCP 702-10
April 1970

Custodians:

Army -- MR
Navy -- AS
Air Force -- 20

Review activities:

Army -- AR
Navy -- OS

Preparing activity:

Army -- MR

Project No. NDTI-0047

(WP# ID-1336P/DISC 0010v. FOR AMMRC USE ONLY.)

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1. DOCUMENT NUMBER	2. DOCUMENT TITLE
MIL-HDBK-728/1	NONDESTRUCTIVE TESTING

3a. NAME OF SUBMITTING ORGANIZATION

b. ADDRESS (Street, City, State, ZIP Code)

4. TYPE OF ORGANIZATION (Mark one)

☐ VENDOR

☐ USER

☐ MANUFACTURER

☐ OTHER (Specify): ______

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER (Last, First, MI) – Optional

b. WORK TELEPHONE NUMBER (Include Area Code) – Optional

c. MAILING ADDRESS (Street, City, State, ZIP Code) – Optional

8. DATE OF SUBMISSION (YYMMDD)

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