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JUSTIFICATION OF NONDESTRUCTIVE TESTING

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Abstract: *Progress in technology has enabled improvement in performance of materials and processes. These advancements lead to reduction in size and weight of engineering structures. But these structures become more sophisticated and expensive, and these lead to introduce quantitative nondestructive measures to ensure quality throughout all production process. This is particularly true for these applications, where the cost of the failure of a component can be unavoidable high compared to the cost of preventive measures, or the failure may cause catastrophic consequences.*

The following paper reviews present philosophy and justification of use of nondestructive testing (NDT).

1. Introduction

In a broad sense, NDT can be viewed as the methodology used to assess the condition of an object without compromising its performance. However, many technical societies and their respective handbooks, as well as many respectable researchers and scientists, have rendered their interpretations of the term NDT in various terms.

Related terms included the term “nondestructive” (nondestructive evaluation, (NDE), nondestructive inspection (NDI) etc.) are used to describe different aspects, but all of them have the same concept of nondestructive assessment of materials. The terms are essentially synonymous; however, NDE is well accepted in the scientific research and development community, NDT is used more in industrial engineering-oriented practices, and NDI is commonly used in the military for field or depot facilities [1]. For our case we use the term nondestructive testing (NDT) as a general term.

Independently of definitions, the crucial is the fundament of NDT – to assess or even to predict the performance of the product at concerned stages of life cycle. NDT uses sensors for data acquisition about the subject and to perform modeling, analysis, and data conversion into material and defect parameters for performance and life prediction (Fig. 1).

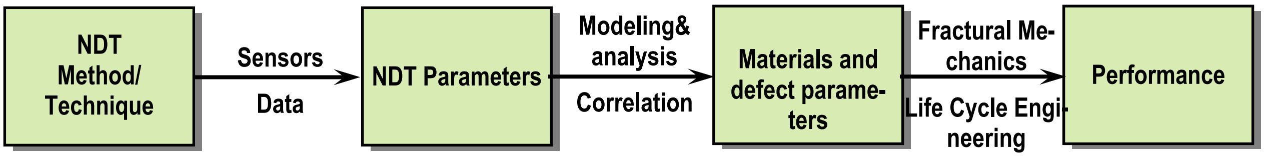


Fig.1. Depiction of functionalities of NDE

It is important to monitor more essential variables because improper values are often causes of latent defects. Research is needed to establish the correlation between the value of an NDT parameter with error bands. After the research, the NDT parameter may be measured, and the value of the intrinsic variable can be predicted within the empirical errors. The contemporary NDT methods are rapid enough, the cost is lower, therefore neither interfering with production nor increasing its cost.

The required quality of the products is the basic motive factor for NDT implementation. The ISO-9000 standard is the document around which present-day quality is managed. It provides the set of priorities by which quality is managed. Regardless of rarely using of term “testing” this is the standard that exculpates using of NDT, because the monitoring of product characteristics is addressed here. Incoming, in-process, and outgoing inspection also are specified. They must be documented in the quality plan and procedures, and records of their performance must be kept. This includes all final inspection and testing as well as all the rectification of incoming inspection deviations and in-process deviations.

Manufacturing industries are the areas, where the need for NDT technology is more apparent. But where ultimately NDT take place into the control of quality? The answer is – everywhere (Fig.2).

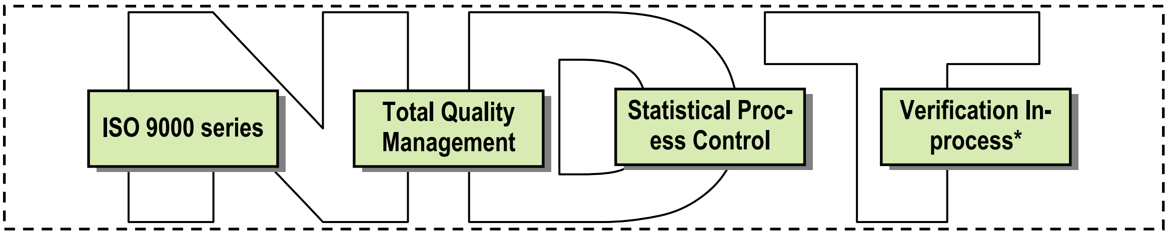


Fig.2. NDT and inspection place in general into the quality systems in existence

All things considered, we forego NDT when it costs time and money. When we perform NDT, we expect to find something wrong with considered testing object. And if something is wrong with the test object, the use and the cost of considered method is justified. Otherwise our efforts were wasted.

For existing products, especially when we have a huge costs and/or safety considerations, replacement of damaged elements or extension of the utilization phase, NDT take significant part.

In every industry, advances in materials and processes have enabled reduction in size and weight of new products together with increased performance. As a result, the designs are usually complicated and the materials used are often close to their physical limits. Because of the lack of a statistical data base, lack of working experience, and the safety considerations, the level of confidence in the use of advanced materials is low determined. And here is the role of NDT technology to ensure quality of these advanced materials, designs and manufacturing processes.

Hence, the NDT ensure the quality and performance of a product is gaining and the need for improved safety, reliability, durability, maintainability, and increased performance is satisfied. And it is very important for all staff to establish the efficiently implementation of the NDT methodology in design, manufacturing, and utilization of the product.

2. Modern philosophy for NDT applications

NDT is a multidisciplinary and interdisciplinary in nature. A modern NDT system integrates different science and engineering technologies for data acquisition, correlation of NDT data with parameters in consideration, and performance prediction (Fig. 3).

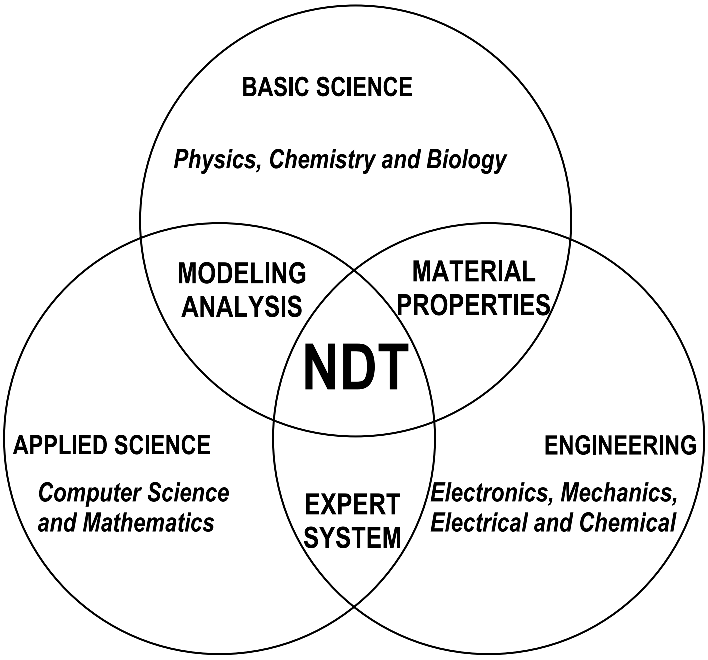


Fig.3. Inter- and multidisciplinary nature of NDT

NDT is not a distinctive scientific field. As a matter of fact, NDT is multidisciplinary and interdisciplinary in nature; it is a field that involves all branches of science and engineering.

As a measurement science NDT requires knowledge of physics, chemistry, and biology in the basic science areas; electrical, electronic, mechanical, and chemical engineering in the engineering areas; and computer, materials, mathematics, and statistics in the applied science areas. This makes the field of NDT broad enough.

With the variety and versatility of the available NDT methods, it is desirable, for improved performance, to apply NDT technology to every phase of the product life cycle (Fig. 4). This modern philosophy of NDT use is effective to most of the manufacturing industries especially for high-technology ones.

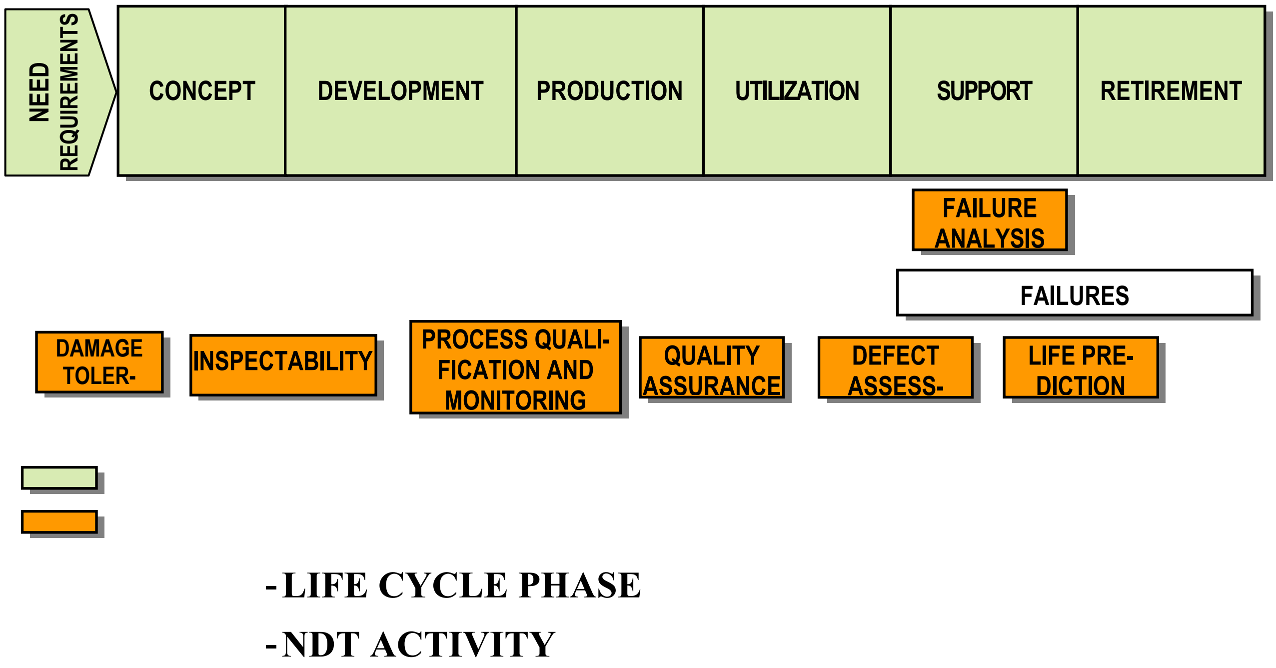


Fig.4. NDT and the product life cycle

At the requirements phase can help define damage tolerance as one of the requirements of a system. At the development stage, NDT may provide guidance for inspectability. In the future, the inspectability of structurally critical areas will really dictate the design of a product.

After that, NDT can qualify proposed manufacturing processes and when production runs, NDT can perform process monitoring. After a component is made or a device assembled, NDT can perform quality assurance. During utilization phase, NDT can monitor crack initiation and growth and when critical failure occurs, NDT can support failure analysis. For routine maintenance, NDT can characterize a defect and predict the residual life.

Each material has its inherent parameters exhibited through various mechanical properties. As a measuring methodology, NDT can be used to determine the physical and chemical, and thus the mechanical, properties of a material or device. Use of NDT for materials qualification, selection, and verification to meet design requirements is common.

The defects may exist in the raw materials, produced in manufacturing processes or induced in utilization phase. NDT can be applied to detect and characterize defect indications to assess these defects. Through fracture mechanics and life-cycle engineering, NDT information can infer or predict performance and useful life of the material under consideration.

Not only material is significant – it is now generally recognized that process control is a key to increasing strength and reliability. This has engaged the use of NDT for manufacturing process control as well as for material choice. NDT is emphasized in measurements that provide stricter process control and fewer end-product measurements.

NDT have scientific aspects too. As above mentioned, to establish a NDT system usually requires a broad knowledge of various branches of science and engineering disciplines.

3. Numerical methods justifying NDT

Statistical process control (SPC) might not eliminate all nonconforming parts. Certainly inspection would be an option. Full inspection by NDT nevertheless added or not to other techniques may eliminate as many defect parts as possible. The probability of detection of the method determines the percentage of defect parts founded out.

There are three principal financial methods (Table) for calculating the propriety of choosing to perform 100% inspection on an item of production. The good news is in each method, the answer may come out “yes” or “no”.

Table

Numerical Methods for Justifying 100% NDT
(1) BREAK-EVEN: The Deming Inspection Criterion
(2) INVESTMENT: The Time-Adjusted Rate of Return (TARR) or Internal Rate of Return (IRR)
(3) PRODUCTIVITY: Productivity, Profitability, and Revenue **(Quality, Productivity, and Profit leading to enhanced competitive position)**

The key to each financial method of calculation is what cost is bigger – the detrimental cost of not testing or the costs of testing. Of course, there is big probability this never happen, but we hope that it will. These calculations must include the assumption that the investment in the inspection equipment (total life cycle cost) will pay for itself in the period of time before adequate improvements are completed and before the production of the part is terminated.

3.1 The Deming Inspection Criterion (DIC) Method

This method uses the cost of inspecting, the negative or detrimental cost if one nonconforming part goes further into production, and the part of nonconformities known to determine when to do complete inspection. This method is suitable for inspection technologies where the equipment investments can be written off in the fiscal year and where variable costs are bigger. It is also useful where the inspection is done by a vendor who will define part costs. The equation for the Deming inspection criterion (DIC) is:

$$DIC = \left({}^{k_2}\!/\!{}_{k_1} \right).p \qquad [1]$$

Where:

k_2 is the detrimental cost of one nonconforming part going further into production;

k_1 is the cost to inspect one part;

p is the part of production that is nonconforming.

In order to use equation [1], the manufacturing process must be under control. If the process is out of control, equation [1] may be used in case the process is intrinsically never under control or that the time to gain control of the process will be long in terms of the continuing production of nonconforming material. The time must be long enough for the inspection effort. Given equation provides the inspection decisions are as follows:

$$\begin{aligned} &YES \quad for \quad DIC \geq 1{,}0 \\ &NO \quad for \quad DIC \leq 1{,}0 \end{aligned} \qquad [2]$$

The higher the cost ratio ${}^{k_2}\!/\!{}_{k_1}$ is in equation [1], the lower the proportion of nonconforming p must be to preclude the need for 100% inspection.

3.2 The Time-Adjusted Rate of Return (TARR) or the Internal Rate of Return (IRR) Method

The method can be used on any new investment, such as a new factory to replace old facilities, a machine to replace manual operations, or in our case – inspection apparatus to replace warranty expenditures.

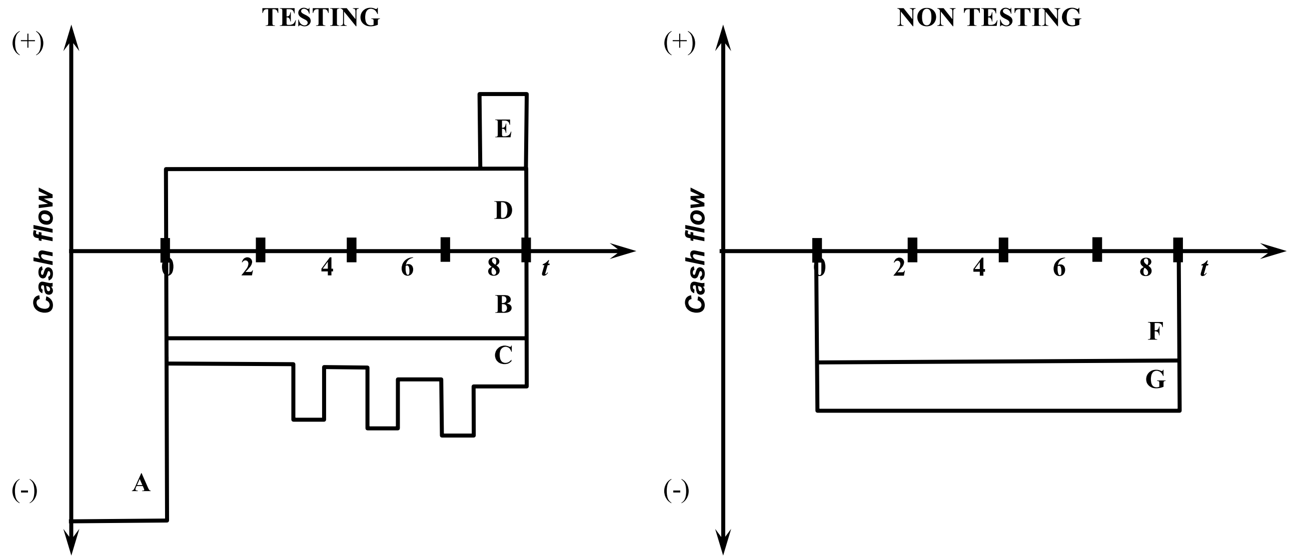
The principle is that if the current practice is continued, one stream of costs will charge year by year; if a new practice is introduced, it will change the stream of costs. The different stream is the result of the investment item put in place at time zero. After the streams are projected out a certain number of years, the two streams can be used as input information in the IRR program to determine if there a net savings, and to determine what effective rate of return would be earned on the investment. This method was formally introduced into the inspection and nondestructive testing business by Papadakis et al. [12].

This method is when the investment in the inspection equipment is large and will be written off over several years of use during which there will also be variable costs.

The data include the rate of production of parts, the rate of production of nonconformities, the detrimental cost per nonconformity going further into production, the lifetime of the inspection before it is rendered unnecessary by continuous improvement, the residual value of the equipment after that time, and the interest rate the organization is willing to pay on money borrowed to purchase capital equipment.

These methods calculate the interest rate to be realized on an investment to be made at the beginning and used for several years.

In the case of investment in NDT equipment with associated automation, the operating costs yearly are an expense and the income tax savings due to depreciation are on the positive side. This stream would typically be compared with warranty costs if the inspection equipment were not installed to eliminate the nonconforming material. Two typical cost streams to be compared are shown diagrammatically in Figure 5. As a rule this is a variable figure.



Legend: A – Initial investment cost; B - Operating cost; C – Logistics support cost; D – Depreciation; E – Residual cost of NDT equipment; F – Warranty cost; G – Indirect cost, related with poor quality.

Fig. 5. Two cost streams to be compared by the method of TARR or IRR to determine whether to purchase inspection equipment for use over several years: (adapted from Papadakis, E. P. et al., Inspection Decision Theory: Deming Inspection Criterion and Time-Adjusted Rate-of-Return Compared," Engineering Costs and Production Economics, Vol. 13, 1988)

3.3 The Productivity, Profitability, and Revenue Method

This method traces money earned vs. money expended by any process in terms of productivity written as money per money in an input–output equation where all resources are translated into currency equivalents. The detrimental costs of nonconforming products going further into production reduce the money earned and therefore reduce productivity. Inspection reduces the total detrimental cost while increasing production costs.

The net calculation can increase productivity and profitability, resulting in increased revenue.

The method is a quantitative expression in four equations of the title of Deming's 1982 landmark treatise, Quality, Productivity, and Competitive Position. This method is pioneered in [15] and the equations are:

$$P = {(A-B)}\big/{C} \tag{3a}$$

$$E = P - 1 \tag{3b}$$

$$M = E.C \tag{3c}$$

$$G = \sum M \tag{3d}$$

Where:

A is the value for which you can sell the output, namely the number of pieces N times the transfer price T, or: $A = N.T$;

B is the sum of all the detrimental costs V that come about because of the production of n nonconforming parts among the N: $B = n.V$;

P is productivity;

E is the economic profitability of the process;

M are money realized from the process as profit

C is the cost to run process.

G is the gross profit for the factory.

The meaning of the equations is as follow:

If you increase quality by lowering nonconformity proportion, you will raise productivity, and get more revenue to spend on any appropriate strategy to improve your competitive position.

The first three equations refer to any single process within a factory, while equation [3d] is the sum over all the processes in the factory. The equations must be understood in terms of the two diagrams of a process shown in Figure 6.

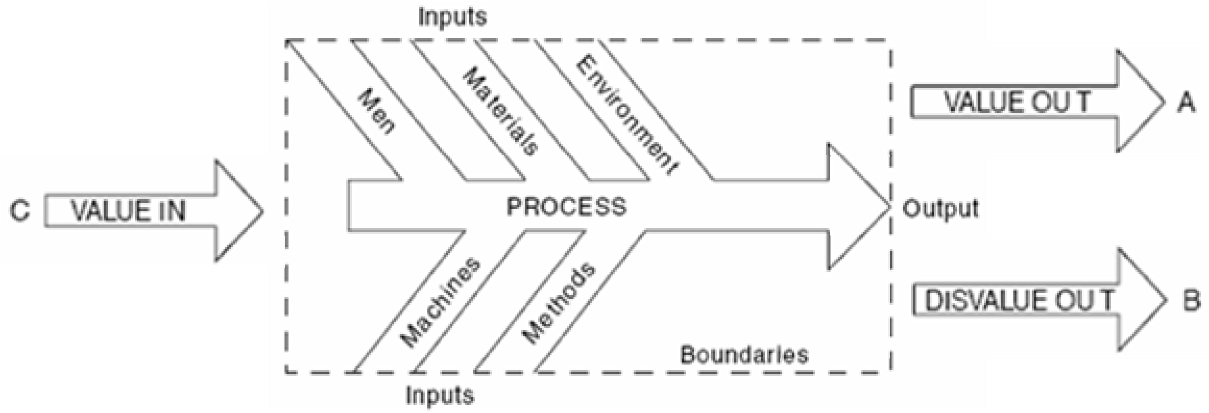


Fig. 6 Diagram of value flow through a process

Figure 6 shows the main branches of the fishbone diagram of a process working inside a boundary and producing an output. The value C-in runs the process. The value A-out is the revenue from the sale of its output. The disvalue B-out is the detrimental cost of having nonconformities in the output. B can become very large if the potential cost of a single nonconformity is large. The process fishbone chart defining the possible variables: men, materials, machines, methods, and environment.

The consequences of poor quality can be analyzed as follows. Since the detrimental costs can be very high, it is possible to have $V>>T$ and also $n<<N$.

This pair indicates that the value of B can be comparable to the value of A. This means that productivity P could go to zero or become negative [Eq. 3a]. Economic profitability E could be zero or negative [Eq. 3b], and the revenue M [Eq. 3c] could become negative.

Inspection fits into this regimen by being capable of making B smaller as capable, essentially zero. NDT fits into inspection because many latent defects can be detected only by NDT methodologies and this guarantee larger reduction in B than other methods can.

Inspection will add some cost to the production costs C and will lower the number of salable items from N to $N - n$, reducing the value A. Extra production, possibly at overtime rates, will be needed to fill the contracts for N items. Thus, while using inspection, the productivity will be somewhat lower than for perfect production, but certainly higher than if B remains large. It will be obvious that inspection should be instituted and continued in certain cases.

Summary

There are many relevant subjects associated with use of a specific NDT application (the detection limits, probability of detection (POD), standards, calibration etc.). From a technological point of view, a given NDT technique has physical and detection limits. From an operational point of view, an NDT system for a particular NDT method has environmental and throughput constraints. A NDT system or technique cannot precisely characterize all the indications, modeling, and statistical analyses that have to be performed on NDT results to determine the POD and establish the confidence level for the defect.

Many factors, such as humidity, temperature, and operator, will influence the results. It is essential to calibrate and verify the functionality of the equipment before routine inspection. Calibration will ensure the comparability of all the data sets and inspection results. Calibration requires standards. However, every NDT technique is different; thus the design of the calibration standard for each technique would be different. It is necessary to produce a standard or a set of standards that achieves the purpose of calibrating instruments with minimum effort.

Another important subject is education and training. Technical knowledge is still necessary to supervise the operation. To train and certify the operator, evaluator, and administrator, various degrees of educational, course, and reference materials must be developed. Because of economic, environmental, and other constraints, various levels of automated NDT systems have to be used concurrently. Also, extensive research, engineering, and development efforts have to be performed before an NDT system can be devised, automated, and perfected.

Modern philosophy for NDT makes it suitable for every life cycle phase of the product. The old products require NDT to determine their status for disposition – to discard, to repair, or to return to service. NDT is essential in monitoring the manufacturing processes and to ensure product quality. NDT is recognized as one of the key elements for technology advances.

Because the NDT requires investment, the three methods for calculating the propriety of using 100% inspection have been outlined and analyzed. They lead to unambiguous and unbiased objective results and can be used as proof in the presence of differing opinions.

Reference

[1]ASTM “Nondestructive Testing”, American Society for Testing and Materials, Philadelphia, 2005

[2]Deming, W. E., Quality, Productivity, and Competitive Position, MIT Center for Advanced Engineering Study, Cambridge, MA, 1982.

[3]ISO (1990). Quality Systems-Model for Quality Assurance in Design, Development,

[4]Production, Installation, and Servicing. ISO/ANSI, New York.

[5]ISO 9001:1994, Quality Systems — Model for Quality Assurance in Design, Development, Production, Installation, and Servicing, 1994.

[6]ISO 9002:1994, Quality Systems — Model for Quality Assurance in Production, Installation, and Servicing, 1994.

[7]ISO 9001:2000, Quality Management Systems — Requirements, 2000.

[8]Lipson, C. and N. J. Sheth, Statistical Design and Analysis of Engineering Experiments, McGraw-Hill, New York, 1973.

[9]Papadakis, E. P., Future Growth of Nondestructive Evaluation, IEEE Trans., SU-23(5), 284–287, 1976.

[10] Papadakis, E. P., Challenges and Opportunities for Nondestructive Inspection Technology in the High-Volume Durable Goods Industry, Materials Evaluation, 39(2), 1981.

[11] Papadakis, E. P., Sampling Plans and 100% Nondestructive Testing Compared, Quality Progress, 1982

[12] Papadakis, E. P., Stephan, C. H., McGinty, M. T., and Wall, W. B., Inspection Decision Theory: Deming Inspection Criterion and Time-Adjusted Rate-of-Return Compared, *Engineering Costs and Production Economics* , Vol. 13, 111–124, 1988.

[13] Papadakis, E. P., Inspection Decisions Based on Costs Averted, Materials Evaluation, 50(6), 774–776, 1992.

[14] Papadakis, E. P., Cost of Quality, Reliability Magazine, January/February, 8–16, 1995.

[15] Papadakis, E. P., Quality, Productivity, and Cash Flow, Society of Automotive Engineers, Warrendale, PA,1996.

[16] Papadakis, E. P., A Cost of Quality: Three Financial Methods for Making Inspection Decisions, Materials Evaluation 55(12), 1997.

Walton, M., The Deming Management Method, Putnam Publishing Group, New York, 1986.