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Non-destructive testing for plant life assessment

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Non-destructive testing for plant life assessment

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FOREWORD

The International Atomic Energy Agency (IAEA) is promoting industrial applications of non-destructive testing (NDT) technology, which includes radiography testing (RT) and related methods, to assure safety and reliability of operation of industrial facilities and processes. NDT technology is essentially needed for improvement of the quality of industrial products, safe performance of equipment and plants, including safety of metallic and concrete structures and constructions.

The IAEA is playing an important role in promoting the NDT use and technology support to Member States, in harmonisation for training and certification of NDT personnel, and in establishing national accreditation and certifying bodies. All these efforts have led to a stage of maturity and self sufficiency in numerous countries especially in the field of training and certification of personnel, and in provision of services to industries. This has had a positive impact on the improvement of the quality of industrial goods and services.

NDT methods are primarily used for detection, location and sizing of surface and internal defects (in welds, castings, forging, composite materials, concrete and many more). Various NDT methods are applied for preventive maintenance (aircraft, bridge), for the inspection of raw materials, half-finished and finished products, for in-service-inspection and for plant life assessment studies.

NDT is essential for quality control of the facilities and products, and for fitness — for purpose assessment (so-called plant life assessment). NDT evaluates remaining operation life of plant components (processing lines, pipes, vessels) providing an accurate diagnosis that allows predicting extended life operation beyond design life.

Status and trends on the NDT for plant life assessment have been discussed in many IAEA meetings related with NDT development, training and education. Experts have largely demonstrated that, using NDT methods, a comprehensive assessment of the life expectation of components, facilities and products is feasible. NDT technology for remaining life assessment of industrial equipment and engineering structures is already established in routine service mostly in developed countries. The NDT inspection of concrete structures and civil engineering constructions is another subject in development with much interest for developing Member States.

There is a need for training material, which will assist developing Member States in formation and continuous training and education of their NDT specialists. The training course document on NDT applications provides basic information on NDT technology as applied for plant life assessment and concrete structures. It describes principles and practical aspects of major NDT methods. It contains useful information about the quality control and accreditation in NDT work according to ISO standards. This training textbook can be used as additional technical document for further qualification of NDT specialists and as basic material for information of managers and decision makers of industry on NDT prospects. It helps in transferring NDT technology to developing Member States.

The IAEA wishes to thank all experts for their valuable contributions. The IAEA officer responsible for this publication was I. Einav of the Division of Physical and Chemical Sciences.

EDITORIAL NOTE

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1. SCIENTIFIC BACKGROUND

1.1. INTRODUCTION

Non-destructive testing (NDT) is a noninvasive technique for determining the integrity of a material, component or structure. Because it allows inspection without interfering with a product's final use, NDT provides an excellent balance between quality control and cost-effectiveness.

The main goal of NDT is to predict or assess the performance and service life of a component or a system at various stages of manufacturing and service cycles. NDT is used for quality control of the facilities and products, and for fitness or purpose assessment (so-called plant life assessment) to evaluate remaining operation life of plant components (processing lines, pipes and vessels).

NDT inspection of industrial equipment and engineering structures is important in power generation plants, petroleum and chemical processing industries, and transportation sector. State-of-the-art methodology is applied to assess the current condition, fitness-for-service, and remaining life of equipment. NDT inspection provides basic data helping to develop strategic plans for extending plant life.

NDT life extension and life assessment services include:

- Equipment integrity analysis
- Corrosion monitoring of structures and equipment
- Corrosion damage evaluation
- Fatigue and creep damage prediction
- Fitness-for-service evaluation

The long list of NDT methods and techniques includes: radiographic testing (RT), ultrasonic testing (UT), liquid penetrant testing (PT), magnetic particle testing (MT), eddy current testing (ET), visual testing VT as well as leak testing LT, acoustic emission AE, thermal and infrared testing, microwave testing, strain gauging, holography, acoustic microscopy, computer tomography, non-destructive analytical methods, non-destructive material characterization methods and many more.

The “major six” (or basic) NDT methods, which are largely used in routine services to industry are:

- Visual inspection
- Liquid penetrant testing
- Magnetic particle testing
- Electromagnetic or eddy current testing
- Radiography
- Ultrasonic testing

In addition, more than 50 techniques are being developed for different purposes. A great number of these NDT methods complement and support each other and, in many cases, must be used in a combination in order to get more accurate results.

There is another way of classification of NDT methods according to surface and volume inspection:

Surface inspection

- dye penetrants
- magnetic methods
- eddy current testing
- electrical potential drop

Volume inspection

- radiography
- acoustic emission
- ultrasonics
- termography

Some typical applications of the NDT methods are:

- Flaw detection and evaluation
- Leak detection
- Location determination
- Dimensional measurements
- Structure and microstructure characterization
- Estimation of mechanical and physical properties
- Stress (Strain) and dynamic response measurements

There are NDT applications at almost any stage in the production or life cycle of a component:

- To assist in product development
- To screen or sort incoming materials
- To monitor, improve or control manufacturing processes
- To verify proper processing such as heat treating
- To verify proper assembly
- To inspect for in-service damage

The NDT methods and techniques well established for metallic structures have quite similar applications in concrete structures as well. The high buildings, bridges, tunnels and flyers have to be inspected by NDT methods.

1.2. USEFUL CONCEPTS IN NON-DESTRUCTIVE TESTING

1.2.1 Non-destructive testing (NDT)

The NDT is an interdisciplinary field dealing with non-invasive inspection of component and product structure and integrity. It plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective fashion. NDT methods aim to locate and characterize material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and a variety of less visible, but equally troubling events. These tests are performed in a manner that does not affect the future usefulness of the object or material. In other words, NDT allows parts and materials to be inspected and measured without damaging them. Because it allows inspection without interfering with a product's final use, NDT provides an excellent balance between quality control and cost-effectiveness. Generally speaking, NDT applies to all kind of industrial inspections, including metallic and non metallic structures.

1.2.2. Non-destructive evaluation (NDE)

Nondestructive Evaluation (NDE) is a term that is often used interchangeably with NDT. However, technically, NDE is used to describe measurements that are more quantitative in nature. For example, a NDE method would not only locate a defect, but it would also be used to measure something about that defect such as its size, shape, and orientation, as well as its effect to the remaining life of structures and components. NDE may be used to determine material properties such as fracture toughness, formability, and other physical characteristics.

1.2.3. NDT/NDE methods

The number of NDT methods that can be used to inspect components and processing vessels is large and continues to grow. Research and development in this field is going on in improving and upgrading existing methods as well as in introducing new NDT techniques. However, there are six NDT methods that are used most often. These methods are visual inspection, liquid penetrant testing, magnetic particle testing, electromagnetic or eddy current testing, radiography, and ultrasonic testing. These methods are briefly described below.

Visual inspection

Visual and optical inspection (or testing) is still a basic method for many applications. Visual inspection involves using an inspector's eyes to look for defects. The inspector may also use special tools such as magnifying glasses, mirrors, or borescopes to gain access and more closely inspect the subject area. Visual examiners follow procedures that range from simple to very complex.

Liquid penetrant testing (PT)

Test objects are coated with visible or fluorescent dye solution. Excess dye is then removed from the surface, and a developer is applied. The developer acts as blotter, drawing trapped penetrant out of imperfections open to the surface. With visible dyes, vivid color contrasts between the penetrant and developer make "bleedout" easy to see. With fluorescent dyes, ultraviolet light is used to make the bleedout fluoresce brightly, thus allowing imperfections to be readily seen.

Magnetic particle testing (MT)

This NDT method is accomplished by inducing a magnetic field in a ferromagnetic material and then dusting the surface with iron particles (either dry or suspended in liquid). Surface and near-surface imperfections distort the magnetic field and concentrate iron particles near imperfections, previewing a visual indication of the flaw.

Electromagnetic or Eddy Current testing (ET)

Electrical current is generated in a conductive material by an induced alternating magnetic field. The electrical current is called eddy current because it flows in circles at and just below the surface of the material. Interruptions in the flow of eddy currents, caused by imperfections or changes in the materials conductive and permeability properties, can be detected with the proper equipment.

Radiography testing (RT)

Radiography (or radiographic testing) involves the use of penetrating gamma or X radiation to examine parts and products for imperfections. An X ray generator or radioisotope sealed source is used as a source of radiation. Radiation is directed through a part and onto film or other imaging media. The resulting shadowgraph shows the dimensional features of the part. Possible imperfections are indicated as density changes on the film in the same manner as medical X ray shows broken bones.

Ultrasonic testing (UT)

Ultrasonic testing uses transmission of high-frequency sound waves into a material to detect imperfections or to locate changes in material properties. The most commonly used ultrasonic testing technique is pulse echo, wherein sound is introduced into a test object and reflections (echoes) are returned to a receiver from internal imperfections or from the part's geometrical surfaces.

1.3. DRIVERS FOR NDT INSPECTION

There are many reasons for carrying out NDT and it is useful to summarize the more important ones.

Safety

Safety is the prime driver in operating process plant; both the safety of those working on the plant and the safety of the general public who may be affected by plant failures. It is well known that safety can only be ensured by establishing and maintaining good working practices. Inspection is not a substitute for such good practices; it is rightly said that "you cannot inspect safety into a plant component". However, sound inspection by the most appropriate NDT method is a key part of the safe plant operation.

Reliability

Within the constraint of operating safely, the plant owner try to ensure that their assets meet their performance requirements at optimum cost. Plant reliability is an important factor here, with the avoidance of breakdowns and the need for unplanned maintenance. This will be achieved by the development and execution of a technically-based programme of equipment maintenance; well-planned and appropriate NDT has a vital part to play in this.

Codes, standards and regulations

The construction and operation of most process plant is controlled by a series of codes, standards and regulation. In some cases the codes simply define best practice but some may have the weight of legislation, for example codes for the operation of pressure vessels, usually imposed by the insurer, and licenses for the operation of plant, imposed by the state regulator. Such codes, standards and regulations will cover requirements for inspection but will not usually specify the NDT method and technique in detail. The plant owner needs to work closely with NDT specialists in order to agree an inspection regime which meets the code requirements in the most effective and cost-beneficial way. Codes, standards and regulations can only deal with general matters. There is always a risk of some unexpected occurrence, especially when dealing with novel materials, processes and inspection methods, and a simple observance of codes will not automatically ensure either safe or reliable operation. A plant owner must consider the detailed nature of their plant requirements and must not 'hide behind' codes.

Inspection qualification and performance demonstration

In recent years, the concept known as either 'inspection qualification' or 'performance demonstration' has been introduced. This concept requires a demonstration that an inspection is capable of meeting its stated objectives, usually endorsed by an independent body. The plant owner will need to agree the requirement for qualification with the regulatory body and will then need to work closely with NDT specialists to ensure that the qualification is performed in the most effective and cost-efficient way.

Risk based inspection

Maintenance programmes have traditionally been based on fixed intervals but the concept of risk based inspection is now well-established. Essentially, the process involves a careful assessment of all components of the plant to identify the risk and consequences of failure of each component. The maintenance interval is then determined on a basis of this risk. Effective NDT is clearly essential here in mitigating risk.

1.4. SCOPE FOR NDT INSPECTION

The main scope of NDT applications is to help ensure the safety, integrity and reliability of plant items such as pressure vessels, boilers, heat exchangers, pipe work and pipelines.

The inspection of concrete structures is part of plant life assessment since these materials often forms an important part of the construction of such plant items. The failure of concrete structures presents a risk in itself and may contribute to the consequent failure of other plant items.

Stages of use

Inspection is employed at all stages in the lifetime of a plant item. The reasons for needing inspection differ in subtle ways for each stage and different factors need to be considered.

Manufacture

The manufacture of a plant item covers both the selection of materials (castings, forgings, etc) and the fabrication of the final product (usually by welding but possibly including such processes as surface coating, etc). Inspection is likely to be carried out both during production of the materials and in the fabrication stage. For many materials and manufacturing processes the NDT methods and the procedures for using them will be well-established and usually defined in standards. The inspection requirements and acceptance criteria will similarly be well-established: the inspections will be designed to search for manufacturing defects and the acceptance criteria will be defined in terms of workmanship standards. There are some cases, however, where the requirements are not so well defined. This may occur where novel materials are being used. It may also occur where a new NDT method is being introduced. An example of this is the increasing use of automated ultrasonic inspection of pipeline girth welds which, for reasons of speed, economy and safety is currently replacing radiographic inspection.

Routine maintenance

All plant items will be subject to routine maintenance and this will include inspection. The maintenance regime may be based on regular time intervals or the intervals may be established by a process of risk based inspection, as discussed later. In either case, the NDT method and the inspection procedure will be designed to detect in-service deterioration.

Possible deterioration mechanisms include:

- Corrosion, leading to wall thinning.
- Stress-corrosion cracking.
- Fatigue cracking arising from system loads, often at stress raisers such as weld toes and changes of section.
- Thermal fatigue, often at changes in section such as valve bodies.

Engineering judgment and experience is needed in order to define what deterioration mechanisms need to be detected. In many cases NDT methods and techniques used in manufacture will not be appropriate for inspections carried out in a maintenance regime. In the manufacture of a weld, for example, a radiographic technique searching for porosity, lack of fusion, etc may be appropriate. But if the in-service degradation mechanism is fatigue cracking at the weld toe, a more appropriate technique might be surface crack detection by the magnetic or penetrant method, or a volumetric inspection using the ultrasonic method.

It must also be recognized that the inspection of items on plant may impose access limitations. These limitations may arise from the presence of adjacent components, or even from the fact that pipelines are buried. There may also be economic constraints: pipe work, for example, may be insulated with a consequent cost in time, effort and materials in removing the isolation to carry out the more usual ultrasonic thickness survey to detect internal corrosion. In such cases it may be worth considering the use of NDT methods, which are capable of detecting corrosion without the need to remove the insulation.

Repair

Repair situations may arise as part of a planned plant upgrade or in response to some deterioration found by maintenance inspections. The aim of such work will usually be to return the plant to its original condition and the inspections will thus, as far as possible reflect those carried out in manufacture.

The fact that the work is carried out on the plant will, however, impose certain restrictions such as:

- The access for inspection will usually be more limited than that for the original manufacturing inspection.
- The repair process may not be able to be carried out to the original standards. For example, it may not be possible to meet the requirements for pre- and post-weld heat treatment of the

original welding procedure. Such restrictions may introduce the possibility of further defects and the inspection carried out as part of the repair will need to take account of these.

Emergency situations

Situations may arise where there is an unexpected plant failure. NDT is essential here for several reasons:

- Detailed inspection of damaged components can help establish the cause of failure.
- Where a defect is detected before it has led to failure, inspection may be used to define the extent of the defect. This provides an input to an engineering critical assessment which will establish if the plant item needs immediate repair or if it can be allowed to run until the next planned outage. This will often require a programme of defect monitoring.
- Where an unforeseen defect has been found in a certain component, it will usually be necessary to develop inspection techniques for all similar components.

1.5. ROLE OF NDT SPECIALIST

Proper application of NDT methods would help to produce valid results applicable for plant life assessment. For this reason, NDT specialists are part of the team responsible for this activity, right from the planning stage to the analysis of data.

The roles of NDT specialist in this activity include:

- To advice the plant life assessment team on the selection of an appropriate NDT method or combination of NDT methods applicable for a specific plant component that is/are capable of providing optimum information required for assessing the status of the components
- To provide an advice for the selection of appropriates NDT service providers to ensure that they have the required technical and administrative capability necessary for the implementation of NDT activity.
- To review and validate NDT procedures to be used by service provider for inspection of components under assessment.
- To ensure that NDT is always performed by personnel having the right qualification and certification. In cases where the NDT activity involved the use of sophisticated, non-conventional equipment, the NDT specialist shall be able to organize mock-up tests to ensure that the NDT personnel are capable of detecting pre-fabricated defects by using such equipment.
- To provide a continuous supervision and to ensure that all NDT activities are performed in accordance with approved written procedures.
- To and advice the plant life assessment team on the reliability of NDT test results.
- To work together with the PLA team during the analysis of the test results.

In cases where defects are detected but still within an acceptable limit, NDT specialists may work together with other PLA members for the planning of inspection program applicable for that particular component.

1.6. TRENDS IN NDT

Aging infrastructure, from roads to buildings and aircraft, presents a new set of measurement and monitoring challenges for NDT engineers and technicians. The trend in NDT applications is the increased emphasis on the use of NDT to improve productivity of manufacturing processes. Quantitative nondestructive testing (QNDT) both increases the amount of information about failure modes and the speed with which information can be obtained and facilitates the development of in-line measurements for process control.

The phrase, “you can not inspect in quality, you must build it in”, exemplifies the industry's focus on avoiding the formation of flaws. Nevertheless, flaws and the need to identify them, both during manufacture and in service, will never disappear and continual development of flaw detection and characterization techniques is necessary.

Advanced simulation tools that are designed for inspectability and their integration into quantitative strategies for life management will contribute to increase the number and types of engineering applications of NDT. With growth in engineering applications for NDT, there will be a need to expand the knowledge base of technicians performing the evaluations. Advanced simulation tools used in the design for inspectability may be used to provide NDT specialist with a greater understanding of sound behavior in materials. As globalization continues, companies will seek to develop, with ever increasing frequency, uniform international practices. In the area of NDT, this trend will drive the emphases on standards, enhanced educational offerings, and simulations that can be communicated electronically.

Keeping installations in service is one of the most important subjects in the industry. Despite the fact that regular maintenance to pipelines, tanks and piping is of great importance, it is not always necessary to shut down (part of) the installation for these maintenance inspections. More and more installations are being inspected on-stream and the trend towards Risk Based Inspection is increasing more and more

New equipment is being developed to reduce the operator’s involvement as much as possible through automating functions and computerizing results. Continuing technical advances result in novel and improved techniques for carrying out NDT. These may allow NDT to be carried out cheaper and more effectively, and in some cases investigations, which were previously considered impossible may become practicable.

On the other side, there are significant efforts to quantify or standardize the human element through training and certification. These trends will continue. In addition, there is an increasing demand from users’ side for a higher precision, reliability and speed. As users become more dependent on NDT results, the need for specialist technicians will grow to cope with the various opportunities offered. There is a new factor coming into NDT, which is likely to bring major modifications to most NDT methods: the application of computer techniques, using small computers. NDT is fast becoming an on-line and process-control oriented technology.

Quality control and accreditation is another trend. Organizations carrying out NDT development and providing NDT services need to have quality systems to ensure that their work meets the required quality level. Such quality systems need to meet recognized standards and to be accredited by third parties to demonstrate compliance to customers and regulatory authorities. For this to be carried out in the most cost-effective way there must be just an internationally accepted quality standard and all accreditation bodies have to be mutually accepted.

There are many international, regional and national standards applied in NDT field so far. They are approved by the American National Standards Institute (ANSI) mostly in North America and part of Asia, and by International Organization for Standartization (ISO) in cooperation with International Electrotechnical Commission (IEC) in Europe and part of Latin America and Africa. In fact, ISO and IEC form the specialized systems for worldwide standartization. The so called EN (Euronorm) standards are replaced by ISO/IEC standards.

At present, in the NDT field the international standards ISO 9001 and ISO/17025 are applied, in particular for accreditation and services. In the field of qualification and certification of personnel the ISO 9712:1999 NDT seems to be well accepted worldwide.

In this respect, the NDT laboratories in developing Member States need assistance in the following issues:

- Guidance on the relationship between ISO 9001 and ISO 17025.
- Guidance on how ISO 17025 has to be applied to organizations carrying out NDT development or providing NDT services.
- Guidance on the calibration and routine checking of NDT equipment to meet the requirements of ISO 17025.
- Guidance on how to set up qualification and certification system according to ISO 9712

It is usually difficult, however, for NDT users, particularly those in developing countries to be aware of these new developments and to judge their value to real NDT needs. This training material will assist them in receiving updated information on:

- advanced NDT techniques, including both those which have recently become available and those which are near-market.
- capability and limitations of each technique for a range of common NDT applications
- international standards and their implementation.

2. REVIEW OF NDT METHODS

The major NDT techniques are described in this chapter analyzing their performances, accuracy, class of applications and advantages.

2.1. VISUAL INSPECTION

Visual inspection refers to an NDT method which uses eyes, either aided or non-aided to detect, locate and assess discontinuities or defects that appear on the surface of material under test (Fig. 1). It is considered as the oldest and cheapest NDT method. It is also considered as one of the most important NDT method and applicable at all stages of construction or manufacturing sequence. In inspection of any engineering component, if visual inspection alone is found to be sufficient to reveal the required information necessary for decision making, then other NDT methods may no longer considered necessary.

FIG. 1. Visual inspection of an object.

Visual inspection is normally performed by using naked eyes. Its effectiveness may be improved with the aid of special tools. Tools include fiberscopes, borescopes, magnifying glasses and mirrors. In both cases, inspections are limited only to areas that can be directly seen by the eyes. However, with the availability of more sophisticated equipment known as borescope, visual inspection can be extended to cover remote areas that under normal circumstances cannot be reached by naked eyes. Defects such as corrosion in boiler tube, which cannot be seen with naked eyes can easily be detected and recorded by using such equipment.

Although considered as the simplest method of NDT, such an inspection must be carried out by personnel with an adequate vision. Knowledge and experience related to components are also necessary to allow him to make correct assessment regarding the status of the components.

Advantages:

- Cheapest NDT method
- Applicable at all stages of construction or manufacturing
- Do not require extensive training
- Capable of giving instantaneous results

Limitation:

- Limited to only surface inspection
- Require good lighting
- Require good eyesight

2.2. LIQUID PENETRANT TESTING

Liquid penetrant is an NDT method that utilizes the principle of capillary action in which liquid of suitable physical properties can penetrate deep into extremely fine cracks or pitting that are opened to the surface without being affected by the gravitational force.

Liquid penetrant testing (PT) method consists in depositing on the object surface of a special liquid, which will be drawn into any surface defect by capillary action. A liquid with high surface wetting characteristics is applied to the surface of the part and allowed time to seep into surface breaking defects (Fig. 2). Following removal of excess penetrant an application of a developer reverses the capillary action and reveals the presence of the flaw so that it can be visually inspected and evaluated. The PT method can be used on metallic parts of civil engineering equipments.

Liquid penetrant inspection generally involved the following sequence:

Pre-cleaning
At this stage, surface of the inspected item is cleaned to avoid the presence of any dirt that may close the opening of discontinuity. Cleaning is accomplished by various methods such as vapor cleaning, degreasing, ultrasonic cleaning etc.

Penetrant application
Once the surface is cleaned, penetrant either in the form of dye penetrant or fluorescence penetrant is then applied. The application of penetrant can be achieved either by dipping, spraying or brushing depending on the nature or item to be inspected. This penetrant is then allowed to remain on the surface for some duration. Such duration is termed as a dwell time. During this period, if there is any discontinuity, penetrant will penetrate deep into it.

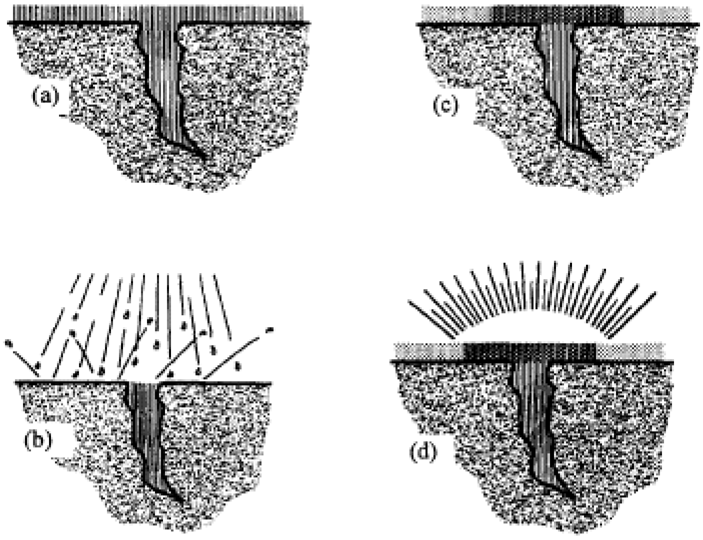

FIG. 2. Liquid penetrant testing principle.

(a) Penetrant application and seepage into the discontinuity.
(b) Removal of excess penetrant.
(c) Application of developer.
(d) Inspection for the presence of discontinuities.

Figure 3 shows preparation of an object for the liquid penetration inspection.

FIG. 3. Preparation of the object for the liquid penetrant inspection.

Removal of excess penetrant

Excessive penetrant need to be removed from the surface to allow inspection to be made. Such removal can be achieved by applying water, proper solvent or emulsifier followed by water (depending on the type of penetrant used) on the surface. At this stage, all unwanted penetrant will be removed from the surface, leaving only those trapped inside the discontinuity.

Developer application

Developer is then applied to the surface of the inspected item. This developer either in the form of dry powder or wet developer acts as a blotting paper which draws penetrant out of the discontinuity.

In doing so, penetrant will bleed to form an indication whose shape depends upon the type of the discontinuity presence in the material. Such an indication is recorded either by the application of a special tape or by taking its photograph.

Post-cleaning

Application of penetrant and developer causes the surface to be contaminated. Thus, upon completion of the inspection, it is important for the item to be cleaned so that no corrosive material remains on its surface that may affect its serviceability.

As for other NDT methods, liquid penetrant has its own advantages and limitations.

Advantages:
- Simple to perform
- Inexpensive
- Applicable to materials with complex geometry

Limitation
- Limited to detection of surface breaking discontinuity
- Not applicable to porous material
- Require access for pre- and post-cleaning
- Irregular surface may cause the presence of non-relevant indication

2.3. MAGNETIC PARTICLE TESTING

Magnetic particle testing (MT) is a NDT method that utilizes the principle of magnetism. Material to be inspected is first magnetized through one of many ways of magnetization. Once magnetized, a magnetic field is established within and in the vicinity of the material. Finely milled iron particles coated with a dye pigment are then applied to the specimen. These magnetic particles are attracted to magnetic flux leakage fields and will cluster to form an indication directly over the discontinuity. They provide a visual indication of the flaw.

The presence of surface breaking and subsurface discontinuity on the material causes the magnetic field to 'leak' and travel through the air. Such a field is called 'leakage field'. When magnetic powder is sprayed on such a surface the leakage field will attract the powder, forming a pattern that resembles the shape of the discontinuity. This indication can be visually detected under proper lighting conditions

Figures 4 and 5 present the principle of magnetic testing.

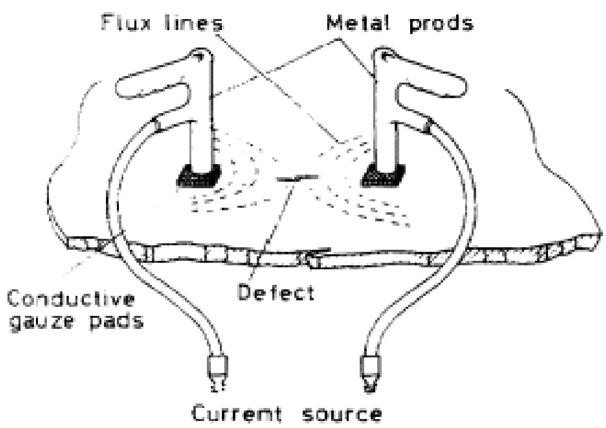

FIG. 4. Principle of magnetic testing.

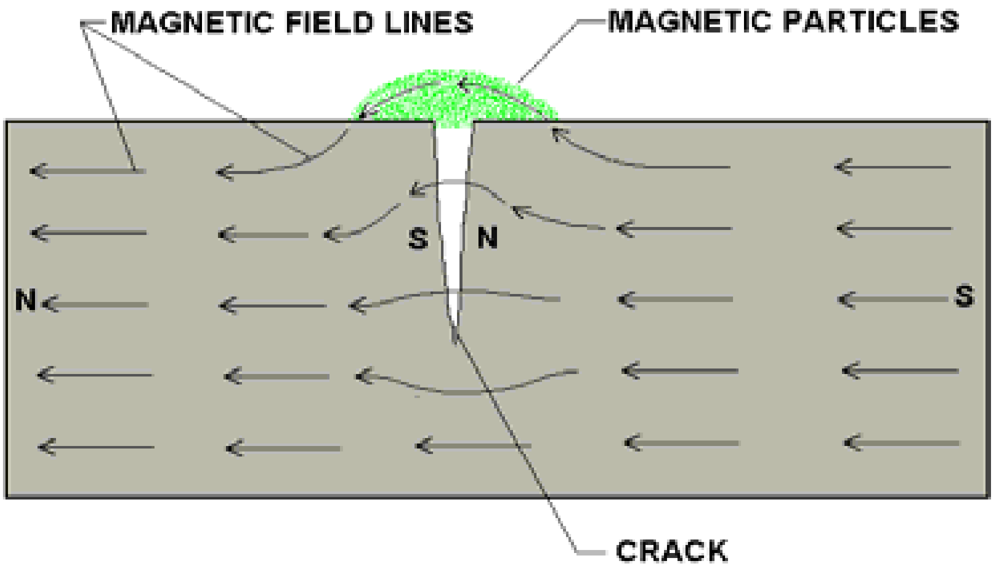

FIG. 5. Magnetic field lines and magnetic particles influenced by a crack.

Magnetic particle (MT) testing is used to locate surface and slight subsurface discontinuities or defects. MT is only applicable to magnetic materials. It can be used on metallic parts of civil engineering equipments.

Figure 6 shows a magnetic testing image of a gear.

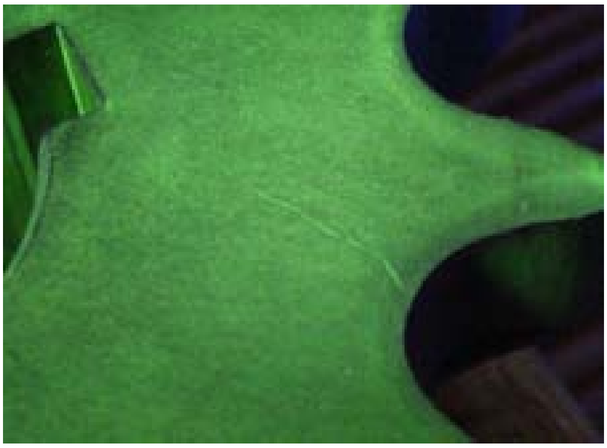

FIG. 6. Magnetic testing of a gear. Crack line is shown along left side of the gear.

There are many methods of magnetizing materials. The use of permanent magnet is one of the ways of magnetization. However, in many cases the use of electromagnet is considered as a more superior and effective way of magnetization. Another way of creating magnetic field in a material is by the use of coil carrying current.

In this way, a longitudinal magnetic field would be able to be established in long items such as bars and cylinders. Circular magnetic field on the other hand is produced by allowing current flowing along the cylindrical material. Induction of magnetic field into the material to be inspected can be achieved by the use of either alternating current (AC) or direct current (DC). In general the use of DC would produce magnetic field deeper below that surface that allow subsurface discontinuity to be detected.

Discontinuities can be best detected when the direction of magnetic field is perpendicular. The chance of detection reduces as the angle between the magnetic field and the plane of defect decreases.

When the angle between the magnetic field and the plane of defect is zero, i.e. the magnetic field is parallel with the plane of defect then the chance of detection becomes zero.

The application of MT involved the following sequence:

- Pre-cleaning
- Magnetization
- Application of magnetic powder
- Demagnetization

The advantages and limitations of using MT method are as follows:

Advantages
- Inexpensive
- Equipment are portable
- Equipment easy to operate
- Provide instantaneous results
- Sensitive to surface and subsurface discontinuities

Limitations
- Applicable only to ferromagnetic materials
- Insensitive to internal defects
- Require magnetization and demagnetization of materials to be inspected
- Require power supply for magnetization
- Coating may mask indication
- Material may be burned during magnetization

2.4. ELECTROMAGNETIC OR EDDY CURRENT TESTING

Eddy current (ET) testing method is based on applying an alternative current (AC) around the specimen by using a coil. Inducted current (so called Eddy current) is generated close to the surface of the specimen (Fig. 7). Monitoring the Eddy current by a sensitive galvanometer flaws and other discontinuities in the specimen can be detected. ET method can be used for verification of metallic tubular components of civil engineering equipments.

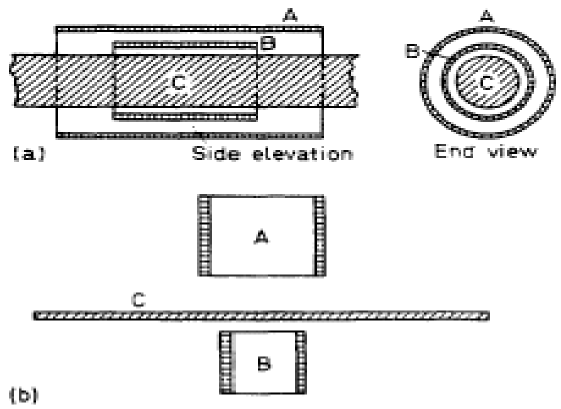

FIG. 7. Eddy current testing principle.

Eddy current is an electrical current having circular path induced in a conductor by a coil carrying an alternating current (AC). Thus eddy current testing (ET) is an NDT method that utilizes the interaction between eddy current and discontinuity. When alternating current flows through a coil, a magnetic field (H_p) will be produced whose direction will also change with time. If this coil is positioned close to a conductor, the magnetic field will continuously 'cut' the conductor, producing eddy current, which is also alternating in nature, whose plane is parallel with the plane of the coil (Fig. 8).

FIG. 8. A small surface probe is scanned over the part surface in an attempt to detect a crack.

Alternating eddy current in turn, will produce a secondary magnetic field (H_s) which is always in opposite direction with the primary magnetic field. Thus, the resultant magnetic field is H_p - H_s. When there is a discontinuity that obstructs the eddy current path, it will alter the value of H_s and consequently will affect the resultant magnetic field.

Changes in resultant magnetic field will cause changes in current, voltage and impedance of the circuit. In this way anything that affect secondary magnetic field (H_s) would be detected. Parameters that affect H_s include conductivity, permeability, heat treatment, and the presence of surface and subsurface discontinuity.

Several types of eddy current probes are available for generation of eddy current. The most common probe refers to as pencil probe, which is used for generating eddy current in a flat surface. Such probes are useful for detecting cracks in components having a flat surface such as turbine, plate, etc. Internal and external probes on the other hand are used to generate eddy current for the inspection of hollow tubes and solid cylinder respectively.

Eddy current density and phase change with distance from the surface of material. Such behavior can be capitalized to measure the depth of discontinuity from the surface. In tube inspection, by carefully analyzing the phase angle of eddy current signals and compare it with eddy signals obtained from a series of hole with different depth in a calibration tube, one would be able to estimate the amount of wall loss experienced by the tube.

Advantages and limitation of eddy current methods are as follows:

Advantages
- The results can be obtained instantaneously
- The inspection system can easily be automated
- It is non contact method
- Equipment are portable and suitable for field application
- Some equipment are made dedicated for specific measurement (e.g., conductivity, crack depth, etc)

Limitations
- Applicable only to conducting materials
- If it is to be used for ferromagnetic material, the item must be magnetically saturated to minimize effect from permeability
- Require highly skillful and experienced operator
- Applicable only for the detection of surface and subsurface discontinuity.

2.5. RADIOGRAPHIC TESTING

Radiography is an NDT method, which uses penetrating radiation. It is based on differential absorption of radiation by the part under inspection. In this inspection the source of radiation can be from radioactive sources, typically Irridium-192, Cobalt-60, Caesium-137, which emit gamma rays or from a specially built machine that can emit X rays. The former is known as gamma radiography whereas the latter is referred as X ray radiography. Table I presents major radioisotope sealed sources largely used in gamma radiographic testing.

There are many methods of NDT, but only a few of them examine the volume of a specimen; some only reveal surface-breaking defects. One of the best established and widely used NDT methods is radiography — the use of X rays and gamma rays to produce a radiograph of a specimen, showing any changes in thickness, defects (internal and external), assembly details etc.

Radiographic testing (RT) method can be used in civil engineering equipments notably to verify the integrity of pre-stressed wires in a pre-stressed concrete structure by using radioisotope sealed sources, X ray machines or linear accelerator. Table I presents the main radioisotope sealed sources used for gamma radiography. Figure 9 shows a typical set up in radiographic testing and figure 10 presents a radiographic image of a metallic structure.

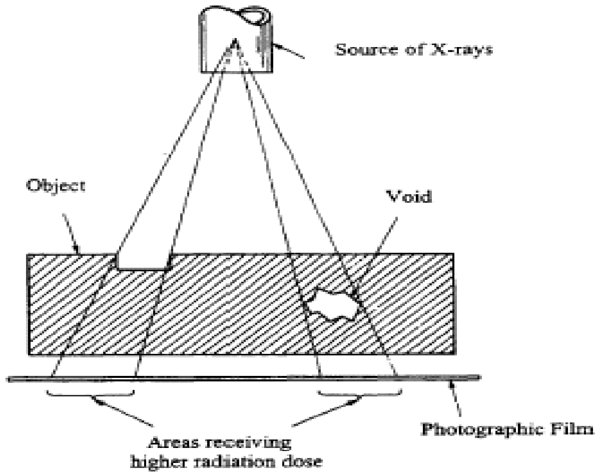

FIG. 9. Typical set up in radiographic testing.

TABLE I. TYPICAL GAMMA RAY SOURCES FOR GAMMA RADIOGRAPHY

Characteristics / Source	Half life	Gamma ray energies (MeV)	RHM value per curie	Optimum thickness range (mm of steel)	Half value layer (mm of lead)
Thulium-170	128 Days	0.87, 0.52	0.0025	2.5 to 12	-
Cobalt-60	5.3 Years	1.17, 1.33	1.33	50 to 150	13
Iridium-192	74.4 Days	0.31, 0.47, 0.64	0.5	10 to 70	2.8
Caesium-137	30 Years	0.66	0.37	20 to 100	8.4

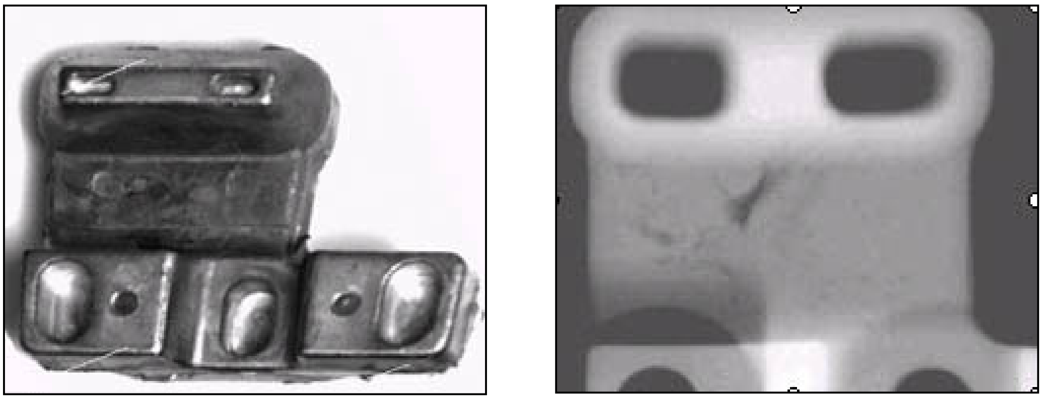

FIG. 10. Radiographic image of a metallic structure.

During the radiography X rays or gamma rays penetrate through material under inspection. While traversing through the material, these radiations experience modification by the internal structure of the material through absorption and scattering processes. If the internal structure is homogeneous, the absorption and scattering processes would be uniform throughout the material and radiations that escape from the material would be of uniform intensities.

These radiations are then recorded by a suitable recording medium, typically radiographic film. When the film is processed, a uniform dark image will appear on the film that indicates the homogeneity of the material tested. The situation is different for cases of materials containing discontinuities or different in thickness. In general, the absorption of radiation by a material depends on the effective thickness through which the radiations penetrate.

Discontinuities such as cracks, slag inclusions, porosity, lack of penetration and lack of fusion reduce the effective thickness of the material under test. Thus, the presence of such discontinuities causes radiations to experience less absorption as compared with those in areas with discontinuity. As a result, in areas containing discontinuities more radiations escape, recorded by the film and forming a dark image that represents the internal structure of the material.

The appearance of radiographic images depends on the type discontinuities encountered by the radiation. Cracks for example will produce a fine, dark and irregular line, whereas porosities produce dark round images of different sizes.

Some discontinuities that presence in a material such as tungsten inclusion in steel has a higher density than its surrounding. In this case, the effective thickness that needs to be traversed by radiation is somewhat greater. In other words, more radiation is absorbed in this area as compared with other areas. As a result the intensity of radiation that escaped after traversing this area will be lesser than that for other areas giving a lighter image bearing the shape of tungsten inclusion inside the material.

Radiography is widely used throughout the industry. Its capability to produce two-dimensional permanent images makes it as one of the most popular NDT methods for industrial application. However, radiation used for radiography presents a potential hazard to radiographers as well as members of public. Due to its hazardous nature, the use of radiation, including for industrial radiography is strictly controlled by Regulatory Authorities.

Almost all countries throughout the world have their own Regulatory Body that regulates the use of radiation. Requirements imposed by the Authority upon the use of this method make it as one of the most expensive NDT method.

Advantages and limitations of this method are as follows:

Advantages

- Applicable to almost all materials
- Produce permanent images that are readily retrievable for future reference
- Capable of detecting surface, subsurface and internal discontinuities
- Capable of exposing fabrication errors at different stages of fabrication
- Many equipment are portable

Limitations

- Radiation used is hazardous to workers and members of public
- Expensive method (cost of equipment and other accessories related to radiation safety are relatively expensive)
- Incapable of detecting laminar discontinuities
- Some equipment are bulky
- For X ray radiography, it needs electricity
- Require two sides accessibility (film side and source side)
- Results are not instantaneous. It requires film processing, interpretation and evaluation
- Require highly trained personnel in the subject of radiography as well as radiation safety.

Organizations applying this method need to be licensed and subjected to various rule and regulation.

2.6. ULTRASONIC TESTING

As the name implies, ultrasonic refers to an NDT method, which uses sounds having frequencies beyond those audible by human ears. Sounds having frequencies about 50 kHz to 100 kHz are commonly used for inspections of nonmetallic materials, whereas those with frequencies between 0.5 MHz up to 10 MHz are commonly used for inspections of metallic materials.

Ultrasonic testing (UT) method uses high frequency sound waves (ultrasounds) to measure geometric and physical properties in materials. Ultrasounds travel in different materials at different velocities. The ultrasound wave will continue to travel through the material at a given velocity and does not return back unless it hits a reflector. Reflector is considered any boundary between two different materials, or a flaw. The ultrasound generator (transducer) emits waves and in the same position receives reflected sounds (if any). Comparing both signals (emitted and reflected) the position of the defect and its size can be measured. The UT can be used on civil engineering equipments, outside metallic parts, to verify the granulation of road covering or of concrete.

High frequency sound waves are introduced into a material and they are reflected back from surfaces or flaws. Reflected sound energy is displayed versus time, and inspector can visualize a cross section of the specimen showing the depth of features that reflect sound (Fig. 11).

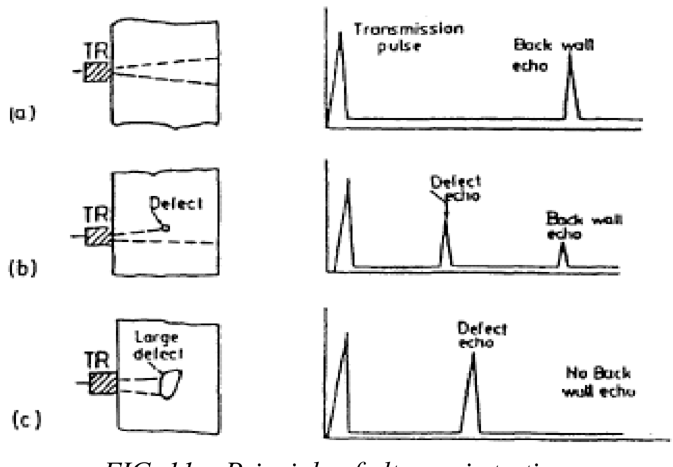

FIG. 11. Principle of ultrasonic testing.

(a) defect free specimen; (b) specimen with small defect; (c) specimen with large defect

As in the case of radiography, ultrasonic is an NDT method that is used for detecting internal discontinuity. In ultrasonic inspection, sounds are generated by the use transducers that are made of materials exhibiting piezoelectric effect. Materials exhibiting piezoelectric effect are capable of converting electrical energy into sound energy and vise versa. Typical example of such a material is quartz. When a quartz crystal is cut in certain orientation and thickness it is capable of generating sounds appropriates for ultrasonic inspections. Depending upon the orientation of crystal cutting, sounds generated by quartz can be of the longitudinal or transverse modes. Figure 10 shows ultrasonic testing in laboratory.

During the inspection, sound generated by a transducer is transmitted into the material to be inspected via couplant. This sound travels in the material with a speed that depends on the type of material. For example, longitudinal waves travel at speeds of 5960 m/s and 6400 m/s in steel and aluminum respectively. When there is no discontinuity in the material, sound continues to travel until it encounters the backwall of the material.

FIG. 12. Ultrasonic testing in laboratory.

At the backwall, sound is reflected and continues to travel until it reaches the transducer. At this transducer, piezoelectric converts sound energy into electrical pulse. The pulse is then amplified and presented on the screen as a backwall signal or backwall echo (Fig. 12).

However, if there is a discontinuity in the material, a portion of sound energy is reflected by this discontinuity whereas another portion continues to travel until it reaches backwall and reflected. Under these circumstances, a portion of sound that was reflected by the discontinuity reaches the transducer first and followed by those reflected by the backwall. In both cases sound energies are converted into electrical signals which then are displayed on the ultrasonic flaw detector screen as backwall signal and signal due to discontinuity. By properly calibrating the equipment, both the position of discontinuity with respect to the position of backwall and the size of discontinuity can be determined.

The fact that ultrasonic does not present any potential hazard to the operator makes this method as a good competitor for radiography method. However, highly skillful and experience operators are required to allow correct interpretation of the test results. Unlike in the case of radiography where the results are presented in the pictorial forms, results of ultrasonic inspections are purely in the form of electrical signal. Knowledge about the material, correct movement of the transducer and proper time base calibration is absolutely necessary for correct assessment of the test results.

More sophisticated ultrasonic equipment is currently available which allow results to be presented in 2D or 3D dimensions. This development provides greater strength to ultrasonic method in its rivalry against radiographic method.

The advantages and limitations of ultrasonic methods are as follows:

Advantages

- Requires only one side accessibility
- Capable of detecting internal defect
- Not hazardous
- Applicable for thickness measurement, detection of discontinuity, and determination of material properties
- Can provide the size of discontinuity detected
- Very sensitive to planar type discontinuity
- Suitable for automation
- Equipment are mostly portable and suitable for field inspection
- Applicable for thick materials

Limitations

- Not capable of detecting defect whose plane is parallel to the direction of sound beam
- Require the use of couplant to enhance sound transmission
- Require calibration blocks and reference standards
- Require highly skillful and experience operator
- Not so reliable for surface and subsurface discontinuity due to interference between initial pulse and signal due to discontinuity.

2.7. OTHER NDT TECHNIQUES

Thermal infrared testing

Thermal infrared testing method can be used on components of civil engineering equipments, mainly to verify thickness of parts or to detect lack in a wall. Infrared thermography is a NDT method that utilizes the fact that all objects above absolute zero emit infrared radiation. Infrared monitoring equipment has been developed which can detect infrared emission and visualize is as a visible image. The thermograms taken with an infrared camera measure or indicate the temperature distribution at the surface of the object at the time of test. Thus, the presence of discontinuity in engineering components or systems, including concretes that have an effect on the temperature distribution on the surface can be detected by using this technique. Leakages in plant components or short circuit that lead to overheating can easily be detected by this method. The advantages and limitations of the methods are as follows:

Advantages

- It provides results in the form of two-dimensional image of heat distribution on the test surface.
- Applicable to all situations as long as there is temperature differences exist on the surface of material.
- Infrared is not hazardous
- It provides area testing instead of point or line testing

Disadvantages

- Cannot determined the depth of void or other defect in materials including in concrete
- Equipment are expensive
- Require highly skillful and experience operator

Acoustic emission testing

Acoustic emission testing method can be used to inform of breaking risk of parts of civil engineering equipments, mainly metallic parts.

Acoustic emissions are microseismic activities originating from within the test specimen when subjected to an external load. Acoustic emission is caused by local disturbances such as microcracking, dislocation movement, irregular friction etc. In NDT, the acoustic emission is normally applied to for monitoring of cracks repeatedly subjected to external loads. Crack growth will be accompanied by an emission of high frequency sounds in various directions. By placing several sensors around the crack, monitoring the time of arrival of this signal to the sensor, observing the frequency of the emission and the amplitude of the event, the nature of the microcrack in the material can be quantified.

Acoustic emission sources are determined by calculating the difference in time taken for the wave to arrive at different sensors. The velocity of the waves in the specimen is determined using pulse velocity method. The most notable advantage of this technique is that it provides quantitative information regarding crack behavior and propagation rate. However, such a technique is considered as a very sophisticated method that requires highly qualified personnel.

Leak testing

Leak testing method concerns mostly some components of civil engineering equipments having to contain dangerous or lethal gas, but its use is uneasy. Leakage in engineering components can lead to a disastrous consequence. If it involved poisonous gas it may harm workers in plant. If it involved highly flammable gas, it could lead to fire. Thus leak testing constitutes one of the most important activities in plant life assessment.

There are many techniques used for leak testing. Tracer techniques that involved injection of radioactive tracer into the system and monitoring it by using a highly sensitive detector has been found successful for leak detection in heat exchangers and piping. Other techniques for leak detection include pressure test, hydrotest, and helium test.

Neutron radiography testing

Neutron radiography testing method, to be applied to the verification of hydrogenous components, can be used on some components of civil engineering equipments.

New NDT techniques are under development, such as:

- Back diffused radiations
- Ultrasonic or magnetic perturbations
- Barkhausen effect
- Mössbauer effect
- Mirage effect
- Nuclear magnetic resonance

3. DIGITAL RADIOSCOPY

Radiography is one of the most versatile NDT method used to identify various types of defect. Film is very sensitive sensor for measuring internal structure of inspected specimen. However, film radiography is a slow and rather expensive method, particularly for tube inspection where thousands of joints are to be inspected every day. Real Time Radioscopy (RTR) is the alternative to film radiography with considerable saving in running cost and processing time.

Digital (film-less) radioscopy is an on-line NDT method in which penetrating radiation (X or γ rays) is passed through an object to produce an image on a video monitor and the image is viewed in concurrent irradiation.

The arrangement of the source, object and radiation image detector is similar to the conventional film radiography. X or gamma ray image is converted into a digital image through a long chain, consisting of an X ray image intensifier, optical lens system between camera and intensifier, video camera and analog to digital converter electronics.

Radiation image detector (RID) is the sensor that measure the transmitted radiation and convert it to digital signals. Fig. 13 shows the digital radioscopy principle arrangement for industrial application, being very similar to the arrangement when using films.

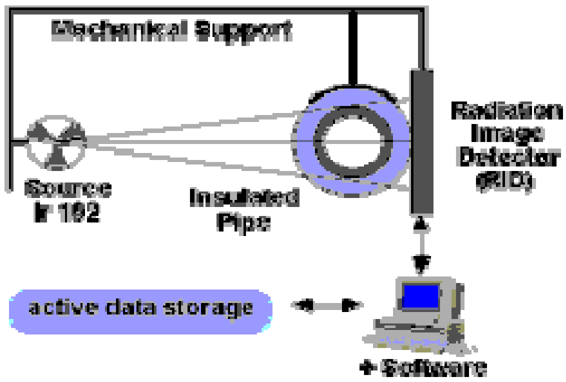

FIG. 13. Digital radiography setup for on-line wall-thickness measurement and corrosion monitoring at insulated pipes.

A typical radiation image detector (RID) has the size of 330 mm x 320 mm x 46 mm. The active imaging area is 204.8 mm x 204.8 mm and consists of 512 x 512 pixel-elements, each 0.4 mm x 0.4 mm. Each pixel consists of a scintillator, which transforms the rays into visible light and a light-sensitive semiconductor directly coupled to a TFT-transistor. The semiconductors can be considered as small capacitors, which are charged before the measurement and discharged by the emitted light from the scintillator. All pixels of the array are read out every 200 ms which leads to an image-refresh-rate of 5 Hz.

With an exposure time of only 200 ms one complete ray image is available on the PC-screen. By temporal averaging, the images noise can be reduced. Averaging of 25 images within 5 seconds leads to a sufficient signal-to-noise ratio. The image is stored on the PC hard disk and can be evaluated on-line or off-line by software.

New digital radiological techniques using different types of RID have been developing and replacing classical radiography techniques in medical and industrial radiology in recent years. The rapid development of proper application guidelines and minimum requirements promotes their safe and successful application in the industrial sector.

3.1. DIGITAL RADIOSCOPY METHOD

The use of X ray film carries with it a number of limitations, including the cost and shelf life of the film and chemicals needed to develop it. Darkrooms with processing tanks and tools are required to be near the inspection site and must be stocked and maintained. Film requires taking the exposure with a technique developed through trial and error. There is always a delay between the exposure and the viewing of results, often requiring a series of adjustments to the technique and several revisits to the location for reshooting the exposure.

Other conventional nondestructive methods have been developed to compete with X ray in some weld inspection applications. In particular, advances have been made in ultrasonic equipment and methods; however, X ray continues to offer advantages in that it can detect some types of weld defects that ultrasonics cannot.

In recent years, also, increased emphasis on environmental safety, including concerns for the effects of radiation on workers and the requirement for disposal of the chemicals used to process film, have contributed to the growing need to replace conventional X ray inspections involving long film exposures.

Radiation image detectors are fastly developed in recent years. In 1995 CMOS (complementary metal oxide semiconductors) detectors were used in digital cameras and X ray detection. X ray detectors using these new CMOS sensors have now been developed for the nondestructive examination industry, offering significant benefits over other nonfilm X ray technologies and avoiding many of the limitations of both film and non-film inspection systems. Digital X ray detectors have improved dramatically with regard to image resolution; they can now meet or exceed the resolution X ray film provides.

Most importantly, an industrial inspection system must be durable and, often, portable. These requirements have been hard to meet with nonfilm X ray systems until recently. CMOS detector chips are constructed from a metal oxide silicon material making them tolerant to mechanical shock and temperature changes. CMOS detectors take advantage of a new development in electronic chip architecture — thin film transistors (TFT). This TFT architecture means most of the electronics needed to support the detector are located on a microscopic level within the detector. Thus, TFT allows imaging systems made from CMOS to be much more compact and durable than were previous technologies.

Paralleling the advances that have been made in digital cameras, digital X ray detectors have improved dramatically in image resolution. In many cases, CMOS X ray imaging systems can now meet and exceed the resolution provided by X ray film. This increase in resolution overcomes a significant limitation of previous nonfilm systems. When needed, X ray sources with microfocus beams can now be used to discover defects of less than 10 microns in size.

Rather than using an optical magnifier to view film, the operator simply zooms in on the area of interest to any level desired on the computer display. Like a digital photo camera, the resolution of the X ray image can be selected by the operator, allowing the image file size to be no larger than necessary, and for the inspection speed to be optimized.

Cost savings from replacing film-based inspection processes with digital systems can be enormous because consumables are no longer required.

CMOS detectors are less expensive to produce than other detectors made from such materials as amorphous silicon or amorphous selenium, allowing the inspection system to cost less to manufacture and repair. The up-front cost is often recovered in less than six months through the avoidance of consumables alone. Additional savings are realized through the reduced time required to perform the inspection, lack of need for reshoots, and reduced personnel costs.

Radiation safety for the radiographer and other workers has also been improved through the use of digital X ray detectors. Because these digital sensors are far more efficient at capturing radiation than film, the exposure time required for most applications is shortened dramatically. Less exposure time means less radiation dosage to the personnel in the area, and faster inspection times. In some applications, CMOS detectors can be used to capture X ray images in just a fraction of a second, creating so little radiation exposure that it is virtually immeasurable using conventional radiation monitoring devices.

CMOS systems are now being applied to a broad range of X ray applications including inspection of pipeline welds during new construction, tubing welds, castings, agricultural products, medical devices, electronics assemblies, tires, wheels, and many other industrial uses. Because of the advances made in sensitivity, portability, format options, and resolution, these systems can now be used where film and nonfilm X ray were losing out to other inspection methods. Thanks to new development in detector technology the oldest method in NDT has found a new life in the future of industrial inspection. Fig. 14 shows the inspection of pipeweld with digital radioscopy.

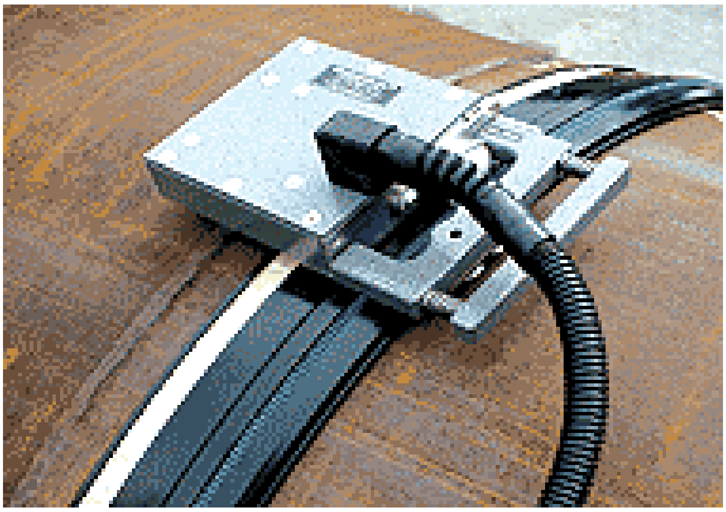

FIG. 14. Inspection of pipeline weld with digital radioscopy.

3.2. COMPARISON OF CLASSICAL AND DIGITAL INDUSTRIAL RADIOLOGY

New digital radiological techniques are compared with the potential of classical film radiography. The major parameters are spatial resolution, contrast sensitivity and optical density range. Derived from the properties of X ray NDT film systems and application ranges minimum requirements are defined. The concept of the standard is the classification of systems and the definition of minimum requirements to ensure a certain spatial resolution and contrast sensitivity, which shall be similar to those as defined by ISO5579 and EN444 for film radiography.

3.2.1. New standards on digital industrial radiology

There are no differences in physics between film and digital radiographies, but traditions and rules for radiography are quite different. Nevertheless, new developments in the field of industrial digital radiology (DIR) open the opportunity to bring up the discussion about harmonisation of standards on upcoming technologies. A new tendency of harmonisation can be observed in the field of qualification standards for old and new methods.

An example for harmonisation in the classical field of radiography is the new set of standards for classification of industrial X ray films. The basic difference in the testing philosophy cannot easily be overridden in the new field of DIR too. But in principle there exist no obstacles for harmonisation of the qualification and classification standards for the new methods and new digital equipment. The new digital detectors are world wide conquering NDT applications. Due to the industrial globalisation, there exists also a serious need for harmonized standards.

Unfortunately several countries started already own standardization activities. Also in USA and Europe different standard proposals were worked out. Since four years common discussions led to better harmonization.

3.2.2. Comparison of digital radioscopy with film radiography

Table II presents the cost comparison between digital radioscopy with film radiography. Of course this is a rough estimation example that depends on many factors, but gives an idea about the cost benefit value in both cases.

TABLE II. COMPARISON OF DIGITAL RADIOSCOPY WITH FILM RADIOGRAPHY

COMPARE COSTS	
Digital Radioscopy	Film Radiography
Space cost: (computer workstation) 10 sq. ft. US$ 20 /month	Space cost: (dark room, processor, illuminator, film storage, chemical storage, plumbing, electrical, janitorial) 300+ sq. ft. US$ 500 /month
Equipment: XY Mini system US$ 59,837 CD storage rack US$ 10 Equipment cost: US$ 59,847 Amortized over 3 years: US$ 1,662 /month	Equipment: Film processor……….…US$ 28 000 Film feeder……………....US$ 8 700 Dark room…………….…US$ 20 000 Tank set…………………..US$ 280 Silver recovery unit………US$ 2 000 Pump station…………..…US$ 900 Twin illuminator…………US$ 640 Film filing cabinet……..…US$ 900 Equipment cost:………US$ 61 420 Amortized over 3 years: US$ 1706 /month
Re-occurring costs per 1000 exposures: 1 CD-R disk.20 cents	Re-occurring costs per 1000 exposures: Film, chemicals, waste disposal, processor maintenance, and other consumables Re-occurring costs: US$ 6000

Then consider typical savings from going digital:

(1) no purchasing, receiving, or inventorying of consumables
(2) no loading or unloading of film cassettes
(3) no processing of film, handling chemicals, or equipment maintenance
(4) no clean up or hazardous waste disposal
(5) instant results / no returns to the job for re-shoots
(6) easy, on the spot measurement and annotation of indications or defects
(7) compact, inexpensive and permanent archive on CD's.

When switching from film to digital many users will recover their investment within four or five months, then the savings can begin at the rate of over US$10,000 per month per system.

4. APPLICATIONS OF NDT METHODS

4.1. NDT FOR PLANT LIFE ASSESSMENT

NDT technology as applied for plant life assessment (PLA) is a trend in many developed and developing countries. NDT for plant life assessment deals with application of NDT techniques to detect discontinuities in an industrial manufacturing process that can affect the mechanical strength of a product and may cause its premature failure. Plant life assessment in many cases means the remaining life assessment of a structure, component or product.

An industrial product is designed to perform a certain function for a certain period of time to the satisfaction of its user. In older design procedures, the presence of the discontinuities was taken care of by including a safety factor in the design of the product. But nowadays since high emphasis is being placed on the use of as little material as possible to reduce the cost and weight, the presence of discontinuities is no way tolerable.

The pace of change in the power generation and petrochemical industries has never been higher with a continuing move from principles of “engineering excellence” to a highly commercial management style aimed at maximizing company profits and minimizing corporate exposure. In this competitive arena, there is increased emphasis on maintaining plant and equipment in productive use well beyond its original design date. This must be achieved without increasing the risk to plant safety, personnel or the environment. Increasingly, run/repair decisions must be made for old, or even new, plant components containing service induced and design allowable defects, based on state of the art analysis and life assessment techniques.

Plant life assessment is applied to any kind of processing lines, structures, vessels or pipes which are designed to operate for a specific life time taking account the temperature, corrosion and material. To ensure extended life operation of processing lines beyond design life a policy of NDT routine inspections has to be outlined. To assess and monitor the quality of the product during its manufacturing and service life without interfering with service performance of the product the NDT techniques provide the best choice. On line and on-site NDT techniques are used for plant life assessment.

Assessing the condition and remaining life of power plant components operating at high temperatures and at high stresses is necessary to optimize inspection and maintenance schedules, to make “RUN, REPAIR, REPLACE” decisions and to avoid unplanned outages. While two different approaches are available for residual life assessment of power plant components, one using data analysis based on operational history and the other based on periodic examination of critical components, the latter method is widely adopted as it is more accurate since it does not rely on standard material data with their associated uncertainties and does not necessarily require knowledge of the operational stress-temperature data.

Any engineering component, when put in service, is designed to last for definite period referred to as “design life” of the component. There are many factors, which adversely affect the define life and lead to premature retirement of the component from service. Such factors include unanticipated stresses (residual services), operation outside designed limit (excessive temperature, load cycling), environmental effects, degradation of material properties in service etc. On the other hand, there can be some favorable factors, which result in lesser degradation of the component then expected in his design life.

Assessment of structural integrity requires three inputs:

(I) Material properties (e.g. yield strength, fracture toughness etc.)
(II) Flaw characteristics (type, location, size, shape, orientation) and
(III) Stresses (residual, service).

NDT has been traditionally used for flaw characterization and measurement of residual stress. In the last 10–15 years, extensive studies have been reported on material characterization by NDT. Combining these inputs many parameters, including mechanical properties, factor of safety in design, conservative operation of unit, inaccuracy in data extrapolation, overestimation of corrosion effects etc, can be assessed. Since constructing a new plant is always much more expensive than extending the life of existing plants these parameters are vital for plant maintenance and normal performance in long run. In this regard, NDT provides all the three vital inputs necessary for assessment of structural integrity of a plant.

Residual life assessment (RLA) and plant life extension (PLEX) are complementary terms to plant life assessment (PLA). Life extension of engineering components is based on the principle that flaw size at the end of extended life will be less than that the critical value, with appropriate safety factor, and it is economical to operate the flawed component safely. NDT methods selected for residual life assessment have high reliability and not necessarily high sensitivity. The concept of “How small a flaw can be detected?” is replaced by “How large a flaw can be missed?” The topic of RLA and PLEX is of national importance since many operating power, chemical and petrochemical plants are approaching their end of design life

As more and more power plant equipments are reaching their designed life, utility owners are forced to take vital decisions on “RUN, REPAIR, REPLACE” for different components. Innovative NDT techniques are developed continuously and, coupled with on-line monitoring and special computer programs, the decision making process has become more realistic and cost saving.

4.2. NDT INSPECTION OF METALIC STRUCTURES

NDT methods are largely used for inspection of metallic structures.

4.2.1. Pipework NDT inspection

Inspection of pipelines using NDT methods is crucial for oil and gas industry. A typical plant may contain several km of pipe work and the identification of features such as valves, bends, tee-pieces and welds can be difficult. In specifying and carrying out NDT work it is particularly important that the items to be inspected are clearly identified. An isometric drawing of the pipe work is essential and the various items should also be identified on the actual plant.

The inspections can be classified into manufacturing inspections, covering initial construction and subsequent repairs and modifications, and in-service inspections, looking for plant degradation.

Figure 15 shows NDT inspection of pipes during their manufacturing (manufacturing inspection).

FIG. 15. Pipe inspection with NDT techniques.

The majority of manufacturing inspections on pipe work involves the inspection of welds. The NDT methods used in this case are:

- RT of welds
- UT of welds
- MT/PT of welds

4.2.2. Radiography testing for measuring of corrosion and deposit in pipes

In-service inspection is related with pipe degradiation during operation. The corrosion and deposit are two typical important phenomena affecting the pipe and plant performance (Fig. 16). With the exception of some noble metals, all metals (and alloys) are subject to deterioration caused by corrosion. Corrosion is generally defined as a degradation of a material or its properties because of its reaction with environment. Corrosion reaction is electrochemical in nature, i.e. it involves transfer of electrons. It requires an anode, cathode and electrolyte.

It is always the anode that undergoes corrosion or oxidation reaction. Buildings, ships, machines, power plant equipment, oil and gas pipelines, bridges and automobiles are all subjected to attack by the environment. But while corrosion itself cannot be totally prevented, it can be controlled in order that problems do not reach the severity as shown in figure 16. Corrosion often renders pipes useless and ultimately they may have to be scrapped. Several estimations have arrived at the conclusion that the total annual corrosion costs in the industrialized countries amount to about 4.6% of gross national product.

A deposit is an accumulation of transported or corroded materials on the wall or pipe bottom. The interior of any section of piping can show a wide range of deposit characteristics — those characteristics and their severity being generally dependent on piping service, followed by physical orientation and location. Accumulated deposits may also create conditions favorable to extremely destructive microbiologically influenced corrosion, so-called deposit corrosion. Deposit corrosion is associated with stagnant areas (e.g. crevices), with the intrusion of foreign matter into environment, lack of drainage and difficulty of surface cleaning. Iron oxide and rust products are the main deposits. In its oxidized form, steel produces approximately 20 to 25 times it original volume in iron oxide or rust product. This by-product is often found in horizontal lines and at low flow areas, accumulating in sufficient volume to produce under-deposit corrosion, heat transfer loss, and flow rate problems. Examples of old condenser systems, having accumulation of rust deposits in horizontal distribution lines are shown in figure 16.

Piping degradation caused by corrosion and erosion are by far the most prevalent failure mechanisms in various process piping systems. Pipe degradation is usually caused by external corrosion under the insulation, internal corrosion caused by a variety of mechanisms, or internal erosion from the flowing product. A major inspection challenge facing the factory process industries is how to examine insulated piping for blockage and corrosion, especially for corrosion under the insulation and internal erosion. This problem is especially troublesome for the petrochemical, refining, utility, mining and paper industries.

The common methods for locating corrosion and deposit problems in piping involve radiography and ultrasonic thickness testing. Ultrasonic testing has two limitations. Firstly, it needs insulation to be removed for the measurement. Removal of insulation and refixing it requires a much longer time than the actual testing time. It thus adds to plant down-time. Secondly, even for a non-insulated pipe, the influence of the surface condition is very strong.

FIG. 16. Corrosion and deposit phenomena in piping system

Corrosion and deposit assessment using NDT methods is reflected in thickness monitoring. The most accurate technique for monitoring thickness and consequently corrosion and deposit is the tangential radiography technique, which is a variant of radiographic testing taking cordial projection of the radiographic image of the pipe. Figure 17 presents the principle of tangential radiography technique.

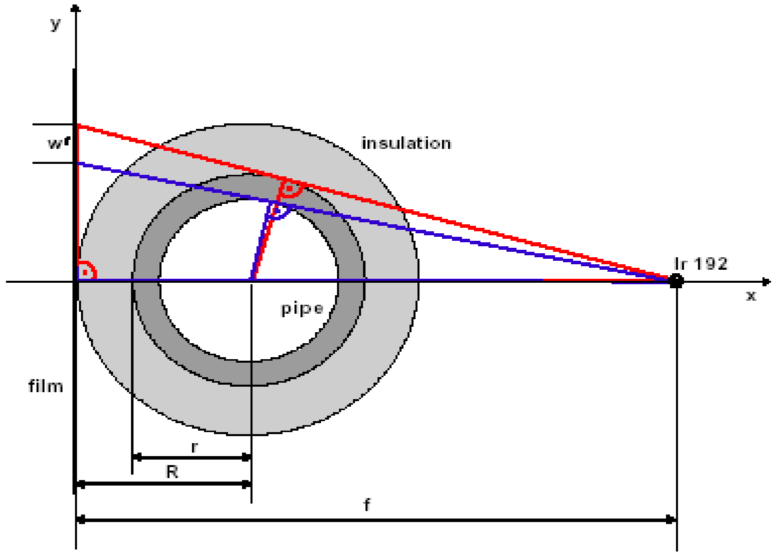

FIG. 17. Tangential radiography for measuring corrosion and deposit in cladded pipes.

According to the geometrical set-up of the tangential exposure technique (Fig. 17) there is a magnification factor inherent to this set-up. To consider this, a correction on the estimated wall thickness must be done. The following correction can be applied:

The true wall thickness is: $w = \dfrac{w' x (f - R)}{f}$

where

- w' is the apparent wall thickness,
- R is the pipe radius (including insulation),
- f is the source film distance.

The radiation source mostly used in tangential radiography is the radioisotope Ir-192, especially for small diameter pipes. For thicker pipes, or pipes with outer diameters (OD) greater than 250 mm, the radioisotope Co-60 is often used. Pipe tangential radiography is normally not carried out with X rays or Se-75 due to their soft energies. The tangential imaging requires harder gamma radiation, because the tangential configuration leads to greater material thickness to be penetrated by the rays.

4.2.3. NDT inspection of boilers & pressure vessels

Typical applications and techniques are:

- Hardness measurement – by using UT and ET
- Welds in construction – by using RT
- Welds in-service – by using UT

4.2.4. NDT inspection of heat exchangers & condensers

Typical applications and techniques are:

- Tube integrity – by using ET and UT
- Thickness measurement – UT (special probe)
- Thermography – infra-red – in-service inspection
- Leak testing

4.2.5. NDT inspection of turbines & other rotating plant

Typical applications and techniques are:

- Blade fixings – ET, UT phased arrays
- Shield erosion- UT

4.2.6. NDT inspection of bolts, studs

Typical applications and techniques are:

- Measurement of tightening torque by UT
- Cracks in threads – detected by UT

4.2.7. NDT inspection of storage tanks

- ET, UT magnetic flux leakage to detect corrosion on far surface – onshore, and offshore

4.2.8. NDT inspection of pipelines for transporting oil and gas

In the world, millions of miles of pipeline carrying everything from water to crude oil. The pipe is vulnerable to attack by internal and external corrosion, cracking, third party damage and manufacturing flaws. If pipeline carrying water springs a leak bursts, it can be a problem but it usually doesn't harm the environment. However, if a petroleum or chemical pipeline leaks, it can be an environmental disaster.

Inspection of oil transporting pipelines is an important problem in oil industry. The target inspections are mainly corrosion, deposit and welding. They may create leaks and danger situation for the pipe and plant, as well for environmental pollution.

Inspection of pipes for corrosion and welding is a preventive monitoring of the pipelines. There are several NDT techniques applied for preventive inspection of pipelines. The searching for leaks is more complicated, especially when the pipes are buried under the ground surface, which is the common case. The development of NDT techniques for pipe inspection is still ongoing process.

In an attempt to keep pipelines operating safely, periodic inspections are performed to find flaws and damage before they become cause for concern.

When a pipeline is built, inspection personnel may use visual, X ray, magnetic particle, ultrasonic and other inspection methods to evaluate the welds and ensure that they are of high quality.

Figure 18 shows two NDT technicians setting up equipment to perform an X ray inspection of a pipe weld.

FIG. 18. Radiography testing inspection of a pipe welds.

These inspections are performed as the pipeline is being constructed so gaining access the inspection area is not a problem. In some areas, sections of pipeline are left above ground like shown above, but in most areas they get buried. Once the pipe is buried, it is undesirable to dig it up for any reason.

Engineers have developed devices, called pigs (or intelligent pigs) that are sent through the buried pipe to perform inspections and clean the pipe. The pigs are about the same diameter of the pipe so they range in size from small to huge. The pigs are carried through the pipe by the flow of the liquid or gas and can travel and perform inspections over very large distances. They may be put into the pipe line on one end and taken out at the other. The pigs carry a small computer to collect, store and transmit the data for analysis. In 1997, a pig set a world record when it completed a continuous inspection of the Trans Alaska crude oil pipeline, covering a distance of 1,055 km in one run to check for corrosion in the pipeline.

The pig of 3.65 meter and 3.2 ton can withstand pressures of up to 100 bar (Fig. 19). It is equipped with sophisticated sensors, a computer, ultrasonic measuring equipment, a data recorder and other devices. During the Alaska inspection, the pig was propelled through the high-temperature, high-pressure pipeline by liquid flowing at a speed of 7 km per hour and collected high-resolution corrosion data along the way. The data collected during the one-week run amounted to 168.8 billion items. The recorded data was then retrieved for processing and analysis to produce a detailed inspection report.

FIG. 19. Ultrasonic testing pig used for corrosion inspection of buried oil pipeline.

Pigs use several nondestructive testing methods to perform the inspections. Most pigs use a magnetic flux leakage method but some also use ultrasound to perform the inspections.

The pig shown in Figure 20 uses magnetic flux leakage. A strong magnetic field is established in the pipe wall using either magnets or by injecting electrical current into the steel. Damaged areas of the pipe can not support as much magnetic flux as undamaged areas so magnetic flux leaks out of the pipe wall at the damaged areas. An array of sensor around the circumference of the pig detects the magnetic flux leakage and notes the area of damage.

On some pipelines it is easier to use remote visual inspection equipment to assess the condition of the pipe. Robotic crawlers of all shapes and sizes have been developed to navigate the pipe (Fig. 21). The video signal is typically fed to a truck where an operator reviews the images and controls the robot.

FIG. 20. Magnetic testing pig.

FIG. 21. Robotic crawler for remote visual inspection to assess the condition of the pipe.

Typical applications and techniques used for transporting pipe inspection are;

- Hydraulic test
- Leak test
- Girth weld inspection – RT using film or digital, automated UT
- Pigging
- Guided waves, long range ultrasonics – especially for buried pipelines

4.3. NDT INSPECTION OF CONCRETE STRUCTURES

According to applications, there are three general categories of NDT methods used for inspection of concrete structures and civil engineering constructions.

The first category includes the tests which estimate the in-situ strength indirectly, such as surface hardness, and directly, such as penetration resistance and pullout techniques.

The second category includes the tests which measure the material properties of concrete, such as moisture, density, compressive wave velocity, modulus of elasticity, thickness, and temperature. Ultrasonic, nuclear and electrical methods are in this category.

The third category includes the tests, which are used to detect and locate the defect areas within concrete structures and rock masses such as honeycombing, fractures, flaws and delaminations. Impact-echo, ground penetrating radar, pulse-echo, infrared thermography and acoustic emission methods are in this category.

Table III presents the main NDT techniques and applications as applied for concrete structures.

TABLE III. NDT TECHNIQUES FOR CONCRETE STRUCTURES

Items / NDT methods	Strength	Elastic Modulus	Thickness	Crack depth	Crack width	Crack distribution	Crack development	Honeycombing, voids	Lamination	Bar location	Bar size	Bar corrosion
1- Rebound hammer	●											
2- Penetration resistance	●											
3- Pull-out	●											
4- Ultrasonic	●	●	●	●				●	●	●		
5- Radar								●	●	●		
6- Thermagraphy						●		●	●			
7- Radiography			●					●		●	●	●
8- Acoustic emission							●					
9- Magnetic or eddy current										●	●	●
10- Half-cell Potential												●
11- Photography					●	●						

The NDT techniques presented in Table III are largely used by the concrete industry and some of them have been recognized by the standard committees of the professional associations such as American Concrete Institute (ACI) and American Society for Testing and Materials (ASTM).

Figure 22 shows inspection of bridges using NDT methods.

FIG. 22. Inspection of bridges.

4.3.1. Overall review of available NDT methods for concrete structures

The techniques presented below are the most common that are used by the concrete industry.

4.3.1.1 Mechanical methods

Some of the mechanical devices, that are currently available, can be used to measure strength or hardness of materials. Other types of mechanical devices are used to detect defects or properties of materials by use of stress wave propagation techniques. Mechanical methods are divided into six major techniques:

(a) Surface hardness equipment

Available equipment is capable of estimating the concrete hardness by impacting the surface and measuring the indentation or rebound value. The Schmidt hammer testing system and the Equitip hardness tester are the two most widely used concrete hardness testing equipment. The performance of both devices is based on the rebound of their impact body as it comes in contact with the concrete surface. The new Schmidt hammer is equipped with digital displays, which enhance data collection (Fig. 23).

For both the Schmidt hammer and the Equitip hardness tester, the hardness values must be corrected if the impact direction is different from the vertical direction. Conversion tables are used for this purpose. The other factors that may influence the results for concrete are: the moisture content, surface conditions, and aggregate size and type. Although the use of surface hardness testing equipment is simple and straightforward, the accuracy of the results is highly dependent on the correct positioning of the devices on the specimen surface.

FIG. 23. DIGI SCHMIDT by Proceq (Switzerland).

(b) Penetration resistance and pullout systems

Both systems are semi-destructive, but since in some literature they are classified as non-destructive techniques they will be briefly discussed.

The penetration technique essentially uses a powder-actuated gun or driver which fires a hardened alloy probe into the concrete. The Windsor probe testing system is the most widely known penetration resistance device available for both laboratory and in situ measurements (24). A steel rod is placed in the concrete at the time of construction. When it is pulled, a dynamometer measures and registers the force (Fig. 25). The pullout test is mainly used during the early construction phase in order to estimate the in-situ strength of concrete.

The main drawback to this technique is that the tests cannot be repeated and the steel rods have to be pre-planted. The maximum size and shape of the coarse aggregates has a large influence on the final results (Malhotra, 1984).

Both penetration and pullout methods are techniques for measuring compressive strength at early stages of concrete curing.

FIG. 24. Windsor probe system by James NDT Product (USA).

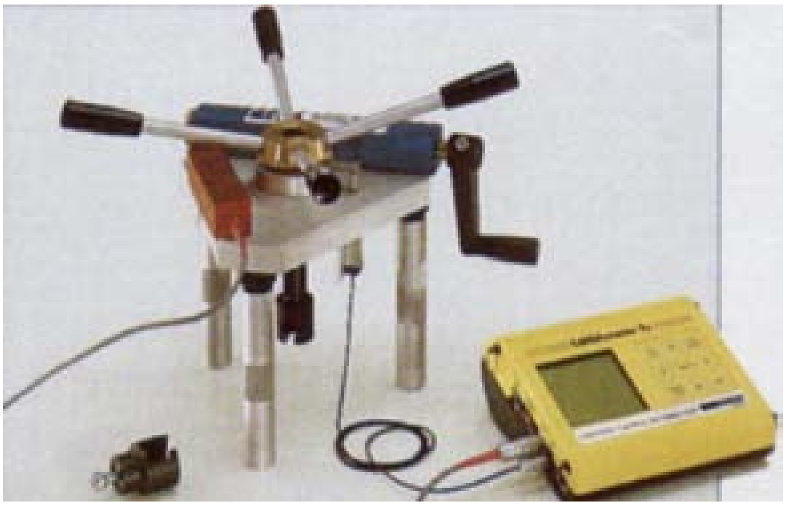

FIG. 25. Pull-out test system by Proceq (Switzerland).

(c) Impact-echo technique

Impact-echo is a technique developed for thickness measurement and delamination location in concrete. The system is based on a high resolution seismic reflection survey on concrete structures using an impact source, a broad band unidirectional receiver and a waveform analyzer.

The mechanical impact generates stress pulses in the structure (Fig. 26). The stress pulses undergo multiple reflections between the top and the bottom concrete layer. The surface displacements are recorded and the frequency of the successive arrivals of the reflected pulses is determined. Wave reflections are used for detection of discontinuities and voids in concrete structures. Discontinuities, defects and reinforcements could be identified in the resulting frequency spectra, as the wave reflects from their surfaces. Thus, knowing the thickness of a given layer, together with the derived frequencies, compression and shear wave velocities can be calculated. If, on the other hand, the thickness is unknown, the time-distance graph of the primary surface stress wave is used to calculate the thickness.

Recent studies show that impact-echo technique can be used for concrete early strength gain estimation and evaluation of micro-cracking and chemical attacks in concrete structures.

FIG. 26. Field impact-echo system by Andec (Canada).

(d) Impulse-response technique

The impulse-response method follows a principle similar to that of the impact-echo. A stress pulse is generated by a mechanical impact on the surface of the object. The force-time function of the hammer is recorded. A transducer records the vibration response of the surface as the reflected waves arrive. The processing of the recorded waveforms of the force and the arriving reflected waveforms reveals information about the condition of the structure. The impulse response of the structure is calculated by dividing the Fourier transform of the reflected wave by the Fourier transform of the force-time function of the impact.

The technique is used to evaluate the dynamic stiffness of the concrete piles. Discontinuities, voids and the base material affect the impulse-response evaluation. The main drawback of the system is the size and shape limitation of the structure undergoing testing.

(e) Spectral analysis of surface waves (SASW) technique

The SASW method uses the Raleigh wave (R-wave) to determine the stiffness profile and layer thickness of thin concrete layers. The SASW system includes an impact device, two receiving transducers, and a two-channel waveform analyzer. The characteristics of the impact device and the relative positioning of the transducers are determined by the stiffness and thickness of the layers.

The R-wave produced by impact contains a range of frequencies, or components of different wavelengths. This range depends on the contact time of impact; the shorter the contact time, the broader the range of frequencies or wavelengths. The velocity of the individual frequency components is called phase velocity. For the component frequency of the impacts, a plot of phase velocity versus wavelength is obtained. This curve is used to calculate the stiffness profile of the test object. The experimental results are compared with theoretical curves until the results match.

The main drawbacks of SASW are the limitation on the maximum layer thickness of the two media, and the matching of theoretical and experimental data.

4.3.1.2. Penetrability methods

Many of the degradation mechanisms in concrete involve the penetration of aggressive materials, such as sulfates, carbon dioxide, and chloride ions. In most cases, water is also required to sustain the degradation mechanisms. As a result, concrete that has a surface zone that is highly resistant to the ingress of water will generally be durable. To assess the potential durability of in-situ concrete, it is necessary to focus on methods that assess the ability of the surface zone to restrict the passage of external agents that may lead to direct deterioration of the concrete or to depassivation and corrosion of embedded reinforcement.

Based on three principals mechanisms external agents can penetrate into concrete: (a) absorption, ingress of liquids due to capillary forces; (b) permeation, flow of liquid under action of pressure head; and (c) diffusion, movement of ionic or molecular substances from regions of high concentration to regions of lower concentration of the substances. The penetrability tests and equipment are developed to assess the durability potential of concrete surface.

4.3.1.3. Ultrasonic methods

Ultrasonic equipment is constructed to operate based on two different principles: resonant frequency and pulse velocity method. Almost all of the field and laboratory instruments for concrete and rock evaluation make use of pulse velocity systems. This method operates by measuring the average time taken for the ultrasonic wave to travel between the source and the receiver. The distance between the two points is divided by the travel time, which gives the average velocity of compressive wave propagation in the material. This method is used for measuring uniformity and in some cases the compressive strength.

In addition to quality evaluation, ultrasonic waves can be used for determining fractures and voids within structures. This is known as the pulse-echo technique, which makes use of reflected waveforms from the interfaces to locate defects or measure thickness from only one direction.

Ultrasonic equipment (pulse velocity) is capable of locating discontinuities, of quality evaluation and of thickness measurements. Pundit and V-Meter are the most commonly used ultrasonic instrument utilized for both field and laboratory testing. In recent years, Andec Mfg Ltd. has developed a more sophisticated high-power digital system called Soniscope. Soniscope’s 4000 volts pulsar and digital signal processing package allows the user to pass through thick concrete monoliths and produce tomographic images based on ultrasonic wave velocity variations.

For ultrasonic systems, the main drawbacks are problems caused by wave scattering, poor coupling of sensors to medium and unwanted noise, which are mainly due to the heterogeneous nature of concrete elements.

The principle of the resonant frequency method is based on the relation between the natural frequency of vibration of an elastic medium and its dynamic elastic properties. For a vibrating beam of known dimensions, the natural frequency of vibration is related to the elastic properties and the density of the medium. Therefore, the dynamic elastic modulus of the material can be calculated by measuring the natural frequency of vibration of the samples.

In addition to the dynamic elastic properties of the concrete, moisture content and the strength of the samples could also be evaluated by using the mathematical relationships between the damping constant and the physical properties of the specimen. This is mainly a laboratory testing procedure and representative samples from the structures are tested for quality control purposes. However, field tests have been recorded on concrete columns.

FIG. 27. Digital ultrasonic system by Andec (Canada).

4.3.1.4. Electrical methods

The change in the electrical properties of the concrete such as electrical resistance, dielectric constant and polarization resistance can be monitored in order to evaluate thickness, moisture content, density and temperature variations.

Electrical resistivity has been used to measure concrete thickness by applying the dialectic difference between the concrete and the base material. A change in the slope of the resistivity versus depth curve is used to estimate the depth of a concrete slab. The dielectric constant of concrete increases with any increase in the moisture content. Capacitance instruments are used to measure the in-situ moisture content of the concrete. Linear polarization is used to calculate the corrosion rate of steel reinforcement bars in concrete slabs and pavements. Problems may occur due to variability of moisture content and temperature in the concrete.

The Half-Cell potential instruments are used to determine corrosion in reinforcement bars based on the anomalies in the electrical field generated by the instrument on the surface of the concrete structure. The main drawback of the electrical methods is the assumption that the resistivity of each layer is constant and varies slightly with depth, which is far from reality.

FIG. 28. Half-Cell Potential instrument for corrosion measurements by Proceq (Switzerland).

4.3.1.5. Magnetic methods

Magnetic devices are available for detecting ferromagnetic materials. For concrete structures these devices are used for detecting the position of the reinforcing bars, pre-stressing tendons, and metal ducts within the concrete, and can also be used for identification of the corrosion of the bars.

Three main techniques using different magnetic principles are available for NDT purposes:

(a) Magnetic Induction,
(b) Flux Leakage Theory, and
(c) Nuclear Magnetic Resonance (NMR).

(a) The Magnetic Induction systems operate based on the fact that steel rods or any other ferromagnetic objects within the specimen affect and in fact distort the primary field generated by the instrument. The instrument consists of a U-shaped magnetic core with two mounted coils. An alternating current is passed through one coil and the induced current is measured in the other coil. The presence and distance of steel reinforcement bars and ferromagnetic mineralized zones can be located by their effect on the induced current.

(b) Other magnetic devices use the Flux Leakage methodology. These instruments are sensitive to changes in magnetic lines of force (flux) flowing through the materials. When a ferromagnetic material is magnetized, magnetic flux flows through and completes a path between the poles. However, if the pathway is disturbed by a crack or discontinuity, its magnetic permeability will be disturbed and this results in a flux leakage. The intensity of flux leakage can be used to characterize the various discontinuities and their shapes.

(c) Nuclear Magnetic Resonance (NMR) systems use the interaction between nuclear magnetic dipole moments and a magnetic field. This interaction can be used to measure the moisture content of the material by detecting the signals from the hydrogen nuclei present in water molecules. The main drawback of these systems is that they cannot be used in heavily reinforced concrete elements or in tunnels with steel culvert supports, since the effect of a secondary field cannot be eliminated as a result of the intense presence of ferromagnetic alloys and detection and positioning of the targets is very difficult.

FIG. 29. NMR instrument for moisture content in concrete.

4.3.1.6. Electromagnetic methods

Short-pulse or Ground Penetration (or Probing) Radar (GPR) is an electromagnetic equivalent of ultrasonic and stress-wave reflection techniques. An antenna transmits the EM pulses into the object. The energy travels through different materials with different velocities. This variation of velocity has a direct relationship to the material quality, which is controlled by the material's dielectric properties. A change in the material's dielectric constant, which occurs at interfaces such as concrete and air, or between two different rock types, causes a change in wave shape.

The reflected signals are received by the receiving antenna, separate from the transmitting antenna, or in the same casing. Signals are positive when they are traveling from a lower to a higher dielectric material (e.g. air to concrete) and are negative when they are traveling from higher to lower dialectical material (e.g. concrete to air). Electromagnetic waves are also known as microwaves or centimeter waves. An EM wave, which has a range of wavelengths between 0.3 and 30 cm corresponds to frequencies in the range of 1 GHz to 100 MHz. The commercially available GPR systems operate with the frequencies ranging from 20 MHz to 2 GHz.

The radar system operates by a transmitting antenna and a receiving antenna that collects the reflected waveforms. The control unit controls the functions of the GPR system such as scanning speed, signal filters, amplifications and time measurements. Ground Penetrating Radar could be used for detection of delaminations, cracks, voids, and reinforcing steel bars within the concrete with reasonable accuracy (Fig. 30). The GPR has been demonstrated to be an effective tool in measuring the thickness and geometry of pillar structures, in addition to locating faults and shear zones in underground coal, salt and gold mines.

The resolution of the survey can be accurately set by using various antenna-signal frequency combinations. The GPR could be used for inspection of underground concrete linings, shafts and dams. The system could also be used to map the cavities and fracture patterns behind the linings, particularly in the case of shafts and subway tunnels.

FIG. 30. Ground Penetrating Radars for detection of delaminations, cracks, voids, and reinforcing steel bars in concrete structures.

4.3.1.7. Infrared thermographic methods

Infrared thermography, or infrared scanning, is a technique which operates based on the capability of various materials to absorb heat. Solar radiation is the main source of heat for surface structures. As the solar ray flows through a structure, air voids and fracture openings absorb a larger percentage of heat than the surrounding material. This can be monitored and registered by an infrared camera. The same principle holds for steel reinforcement but at a different intensity.

Using infrared thermography, it is possible to locate voids, delaminations, fractures and steel reinforcing bars. However, it is not possible to locate their exact position. Test results are highly affected by the surrounding conditions such as time of day or seasonal changes. Moisture content of the concrete or rocks also affects the readings. As for the underground openings and shaft linings, an artificial primary source of heat is needed. In the tunnels, a convectional heating of the air and lining surfaces can be achieved with diesel or gas machinery exhaust. The release of toxic fumes as a result of engine exhaust is the main drawback and it is not practical to use an infrared thermography system in a closed environment.

4.3.1.8. Acoustic emission methods

Acoustic emission or stress emission is a general term used for any transient waveform released from a solid, which is under stress. In concrete structures, the main source of wave emission would be crack development or the slip between the concrete and the reinforcing bars. On the concrete surface a number of transducers receive and later register these low amplitude stress waves. The variation of arrival time of waveforms registered by each transducer is used to locate the source. Later interpretations can be performed using the intensity of wave emission. An increase in wave emission in a structure could be analyzed as an unsafe condition; however, this is not considered as a satisfactory deduction.

4.3.1.9. Radioactive methods

Radioactive methods are mainly used in the concrete industry. Radioactive systems are classified into two main subgroups:

(a) Radiography Technique

Using a radioactive source, this technique provides a photographic image of the concrete which makes it possible to locate the reinforcement bars, voids, fractures, and honeycombing. High costs associated with the source, dangerous high voltage equipment, and safety factors make this technique undesirable for field use.

(b) Radiometry Technique

Because gamma rays are capable of passing through concrete, various types of radioisotopes are used and pre-planted within the structures at the time of construction. Using calibrated charts the thickness, moisture content, and density of concrete can be measured. This can be done as a result of change in the emerging intensity of gamma rays, which are collected with the aid of a scintillation or Geiger counters. Similarly, high operational costs and safety factors have limited the use of radiometry in the field of NDT.

4.3.2. Conclusion

In situ NDT techniques provide a great deal of information about maintenance and support of concrete structures at relatively low cost. In case, extra information is needed about the quality of a structure or if the damaged areas are not visible, NDT becomes a useful tool for the field engineers. One appealing factor about the NDT methods is that the tests could be repeated in situ for the same area, for a majority of the cases. A number of reliable NDT techniques exist for measuring material properties and strength of concrete and rock. Some other NDT methods have been used to detect and measure the delaminating, voids and thickness.

5. PERSONNEL CERTIFICATION IN NDT

The personnel certification (PCN) scheme is dealing with:

- Magnetic Particle Inspection
- Liquid Penetrant Inspection
- Ultrasonic Inspection
- Radiographic Inspection
- Eddy Current Inspection
- PCN Level 3.

The PCN scheme, an internationally recognized scheme, for the certification competence of NDT personnel, is accredited as meeting the requirements of European Standards EN 45013, EN 473 and international standard ISO 9712. Entry to PCN examinations require training and experience in accordance with published guidelines.

The personnel certification scheme offers three levels of certification specific to industry sectors and NDT methods (Table IV).

TABLE IV. THREE LEVELS IN NDT QUALIFICATION AND CERTIFICATION

Level 1 An individual certificated to Level 1:

- is qualified to carry out NDT operations according to a written instruction and under the supervision of Level 2 or 3 personnel.
- has demonstrated the competence to set up equipment, carry out the test, record and classify the results in terms of written criteria, and report on the results

Level 2 An individual certificated to Level 2:

- prepares written instructions
- is qualified to perform and direct NDT according to established procedures
- has demonstrated competence in the choice of test method and technique to be used, and in the assessment, characterisation and interpretation of test results.

Level 3 An individual certificated to Level 3:

- is qualified to direct any operation for which he is certificated
- has demonstrated a competence to interpret and evaluate test results according to applicable standards, codes and specifications
- possesses the required level of knowledge to enable the selection of methods and techniques and to assist in the establishment of test criteria where non are otherwise available
- has also the ability to guide personnel below Level 3
- can establish and validate NDT instructions and procedures

PCN certification is also available in a number of sectors:

- tube and pipe
- aerospace
- welds
- castings
- wrought products (forgings)
- general engineering products (includes welds, castings and wrought products)
- railway

To be eligible for Level 1 and Level 2 examination, candidates must have successfully completed, prior to making application for examination, a PCN approved course of structured training to the relevant PCN syllabus and satisfy relevant work experience requirements.

To successfully complete examinations the candidate shall obtain a grade of at least 70% in each examination part and an overall composite grade (N) of at least 80%.

Certificates

PCN certificates are valid for a period of 5 years and can be renewed by examination or documentation.

6. QUALITY CONTROL AND ACCREDITATION IN NDT

6.1. BACKGROUND ON QUALITY CONTROL AND ACCREDITATION SYSTEMS

Quality assurance and quality control (QA/QC) of products and services is need of the day. The product manufacturers and service providers have to follow certain prescribed procedures and protocols to provide quality products and services to consumers and clients. To meet this requirement they need authentic certification that they follow acceptable national/international standards. Standards contribute to making the development, manufacturing and supply of products and services more efficient, safer and competitive. Standards also make trade between countries easier.

The credibility of a laboratory, which should be one of the major concerns of any laboratory management, is increasingly dependent on the documented evidence of quality assurance and quality control (QA/QC) implementation according to the international conventions and standards. The more customers request these conditions and the more contracts are relying on its demonstrated evidence, the more laboratories will be convinced that, in order to compete, appropriate QA/QC implementation is indispensable for the survival of a lab in the long run. Laboratory managers will appreciate this easily. Their strong support for a comprehensive effort in this direction will be mandatory to cope with the requirements of setting up a complete quality system in a particular area of a NDT laboratory.

Accreditation is defined as being:

- formal recognition by
- an authoritative body that
- an organization is competent.

Accreditation is a confirmation procedure of the competence of the service provider laboratories to carry out their specific tasks. In order to be accredited, a NDT laboratory should demonstrate its technical and organisational competence in its areas of application. Accreditation can be achieved through implementation of a quality management system.

The ISO 9000:2000 Quality Management System has been successful in helping organizations to deliver quality products or services. NDT laboratories have been introducing the ISO systems for their product and services to industrial end-users. Accreditation to ISO 9001:2000 regarding the Quality Management System (or management aspects) is in process in many countries.

However, it should be noted that ISO 9000 series addressed only the management aspects of an organization. For laboratories providing calibration and testing services, there are loopholes that are not covered by this system. For this reason, standard known as ISO 17025 was introduced. In this standard, not only the management aspects of the organization were addressed, the technical aspects were also given a comprehensive coverage to ensure that an accredited laboratory would be able to deliver quality products or services.

ISO 17025 International Standard has been produced as the result of extensive experience in the implementation of ISO/IEC Guide 25 and EN 45001, both of which it now replace. It contains all of the requirements that testing and calibration laboratories have to meet if they wish to demonstrate that they operate a quality system, are technically competent, and are able to generate technically valid results. Now the NDT laboratories are reshaping all activities related to industrial inspection, calibration and testing services to be accredited to a quality system based on the ISO 17025.

QA/QC is a continuous process, not a goal to be achieved once and forever. No doubt, increased efficiency and effectiveness, a lower rate of false results, higher grade of transparency of procedures will definitely foster the confidence of co-workers, enhance their productivity and identification with the unit they are working for and ultimately help to improve the reputation of a laboratory towards its clients.

6.2. ISO 9001:2000 QUALITY MANAGEMENT SYSTEM

The growth in use of quality management systems generally has increased the need to ensure that laboratories offering services which form part of larger organizations can operate to a quality system that is seen as compliant with ISO 9001 or ISO 9002.

What are ISO 9000 and ISO 9001? They are International Standards for Quality Management Systems.

ISO 9000 is a set of standards for quality management systems that is accepted around the world. Currently more than 90 countries have adopted ISO 9000 as national standards. When you purchase a product or service from an organization that is registered to the appropriate ISO 9000 standard, you have important assurances that the quality of what you receive will be as you expect. In addition, with the year 2000 revision of the standard, quality objectives, continual improvement, and monitoring of customer satisfaction provide the customer with increased assurances that their needs and expectations will be met.

The standard intended for quality management system assessment and registration is ISO 9001. The standards apply uniformly to organizations of any size or description. Accreditation against ISO 9001 and ISO 9002 does not of itself demonstrate the competence of the laboratory to produce technically valid data and results. The acceptance of testing and calibration results between countries should be facilitated not only if laboratories comply with this ISO but also if they obtain accreditation from bodies which have entered into mutual recognition agreements with equivalent bodies in other countries using International Standards.

Standard Operating Procedures (SOP) need to be formulated to demonstrate the competence of a laboratory to produce technically valid data and results. Laboratory staff may wish to create their own written instructions for particular procedures frequently encountered in daily work without being imbedded into a formal QA/QC system. Only it should be noted that such instructions most probably will not be comprehensive as common understanding and agreements between currently involved staff members will rarely be described in sufficient detail. Though such records can be used as a basis to establish a protocol or a Standard Operating Procedure (SOP) the human factor may preclude the comprehensive treatment on such an improvised basis. The call for a more formal approach on QA/QC will definitely come from the experience with such offhand attempts.

Particularly in laboratories with frequently changing personnel transfer of specific experience is hampered and every new member is trying to create his own working sequences. If results are depending on the cooperation of several staff members such a situation can easily cause chaos and heavy friction between the co-workers. Such situations can be greatly resolved, and the demand to do so might emerge from the person(s) affected, to provide them with detailed written procedures to clarify responsibilities and demands to be fulfilled by each individual.

As part of a QA/QC system such procedures assure some level of continuity even when personal experience is lost due to shift or exchange of personnel.

What are the requirements of the ISO 9001:2000 Standard?
The major requirements of the ISO 9001:2000 are organized into the following five sections:

- Section 4: Quality Management System
- Section 5: Management Responsibility
- Section 6: Resource Management
- Section 7: Product Realization
- Section 8: Measurement, analysis and improvement.

How to prepare a Quality Management System according to ISO 9000 series?
ISO 9000 series are prepared as a general standard for all types of testing and calibration activities. For this reason their requirements might need some supporting explanation and guidance for specific areas such as radioisotope methodology and technology. The preparation of Standard Operating Procedures, quality manuals and other technical, managerial, structural and administrative documents is part of quality management system. Also important are technical articles from scientific journals describing a state of the art of relevant laboratory activities.

Illustration of a process-based Quality Management System is given in Figure 31. It is a common approach for many radioisotope applications in industry. It represents a logical program structure; other formats may also be acceptable provided that the information meets the following criteria:

- Communicates specifications efficiently;
- Demonstrates that all aspects which required control are indeed in control; and
- Permits regular assessment of program effectiveness by the licensee, the operator and the regulatory body.

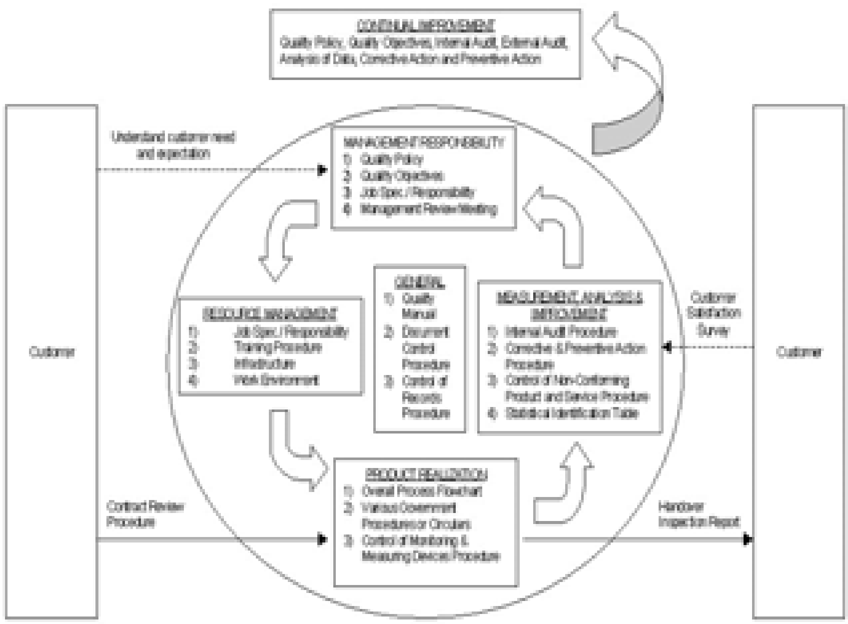

FIG. 31. Illustration of a process-based Quality Management System.

The model recognizes the fact that customers and other interested parties play a significant role during the process of defining input requirements. Process management is then implemented for all processes involved in manufacturing of a product and/or provision of services.

The process outputs shall be verified. Customer satisfaction assessment and evaluation of other relevant interested parties are used as a guide to evaluate and validate whether customer requirements have been achieved.

6.3. ACCREDITATION OF NDT LABORATORIES TO ISO 17025

ISO 17025 is the evolution of the ISO/IEC Guide 25, a joint partnership between the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). This document is called "The General Requirements for the Competence of Calibration and Testing Laboratories".

ISO/IEC 17025 is a recently introduced standard from the International Organization for Standardization and the International Electrotechnical Commission. "ISO17025", as it has become known, replaces a number of older standards and guides including ISO/IEC Guide 25 and EN45001 (in Europe) and ANSI/NCSL-Z540 (in North America).

It is a global standard for the technical competence of calibration and testing laboratories. In addition to establishing quality system, documentation and personnel requirements, it directs calibration labs to:

- analyze the uncertainty of each measurement
- incorporate the uncertainty into the test procedure and/or test limits
- provide the uncertainties with the calibration certificate and results.

This standard was developed specifically to give guidance to lab managers on both quality management and the technical requirements for the proper operation of a laboratory. Thus, ISO 17025 can be thought of as the technical compliment to ISO 9000. As a matter of fact, any organization who meets the requirements for ISO 17025 automatically is ISO 9000 compliant (but the converse is not true).

ISO 17025 is to provide a third-party demonstration to customers that the laboratory has the technical and managerial capabilities to perform specific tests, measurements, or calibrations, to stated standards or to customized procedures within their bounds of stated accuracies, chosen test methods & equipment. One of the attractive aspects for achieving this standard is that the fee is dependant on the number of tests for which the lab is seeking accreditation. Therefore, for smaller labs one can have as few or as many tests accredited as they wish.

While the ISO 9000 requirements are generic and can be used by any type of organization, the ISO 17025 requirements are specific to laboratory functions. This standard addresses issues such as: the technical competence of personnel, ethical behavior of staff, use of well-defined test & calibration procedures, participation in proficiency testing (i.e.: interlaboratory comparisons and/or reference materials), and provide guidance on the contents of test reports & certificates generated. As such, this standard fits nicely within the framework of the new ISO 9000 (2000) and the Good Laboratory Practice (GLP) standards.

Another difference between ISO 9000 and ISO 17025 (ISO/IEC Guide 25) is the accreditation audit. The latter requires an assessor who must have technical expertise in the testing procedures and equipment being inspected.

What are the benefits to implementing ISO 17025?

- Provides valid test data that the customer (whether internal or external) can trust;
- Strong quality control, qualified processes and demonstrations of staff competence provide a greater degree of data defensibility;
- Provide excellent third-party recognition to the customers;

- Should lead to fewer re-analysis of samples;
- Clear definition of roles, responsibilities, and authority, provide for greater efficiency in operation of the laboratory;
- Audit and assessment activity by laboratory customers can be reduced through third party recognition;
- Increased efficiency will lead to a reduction in operating costs;
- Increased efficiency will result in less re-analysis of samples. This too, effects the cost of operations in a positive way;
- Increased efficiency and reduction of re-analysis will decrease customer complaints and should contribute to decreased turnaround time for analyses; and
- Increased efficiency should also free up capacity to increase throughput and provide for increased business.

What are areas where ISO 17025 has been implemented?

In the European Union (EU), it is almost an unwritten rule that companies within their economic community have this accreditation to freely market their product or service. In contrast, North America is only starting to grasp its importance. Surprisingly the leaders are not the Private sector. Within the Private sector, the environmental analytical labs appear to be the present leader.

As one can see, this standard can be implemented for anyone who performs testing, measuring, or calibrating. Just a few more examples include:

- measuring physical properties such as: mass, length, time, electricity, radiation, power, pressure, temperature, humidity;
- environmental monitoring of air, water, soil for quality;
- electrical product safety and properties;
- mineral assays;
- analyses of chemicals, pharmaceuticals, cosmetics, oilfield & refinery products;
- construction and pipeline materials &integrity;
- communication equipment & electrical appliances.

What are some of the requirements for this Standard?

This standard can generally be sub-divided into two main categories:

(a) Management system requirements and
(b) Technical requirements.

In addition to the usual ISO 9000 requirements, just a few of the requirements unique to ISO 17025 are outlined below.

Management System Requirements: The laboratory shall:

- be legally identifiable;
- identify its approved signatories;
- identify its' scope of calibrations and/or tests;
- have arrangements to ensure that its personnel are free from any commercial, financial, and other pressures which might adversely affect the quality of their work;
- have a ratio of supervisory to non-supervisory personnel such as to provide adequate supervision;
- where relevant, have documented policy and procedures to ensure the protection of clients' confidential information and proprietary rights;

- where appropriate, participate in interlaboratory comparisons and proficiency testing programmes, use reference materials, or other internal Q.C. protocols;
- ensure the quality of results provided to clients by implementing checks (using internal Q.C. protocols, replicate testing, etc.);
- have sufficient personnel with the necessary education, training, technical knowledge and experience for their assigned functions;
- advise and seek the approval of the client in writing when it intends to sub-contract specific tests or calibrations to another laboratory;
- afford clients the right to monitor the performance of the laboratory in relation to the work performed;
- ensure that adequate records are retained in case of the need for future dispute resolution;
- have procedures to protect data held on computers at all times and to prevent unauthorized access to or amendment of data on computers; and
- have periodic Management Reviews which include the results of any inter-laboratory comparisons, or proficiency tests, and any changes in the volume & type of work undertaken.

Technical Requirements: The laboratory shall:

- ensure that personnel who make professional judgments are competent and have the applicable theoretical and practical backgrounds. They must also have integrity and a good reputation;
- maintain records of the relevant competence, educational and professional qualification of all technical personnel;
- define and control access to and the use of all areas affecting the quality of the testing and/or calibration activities;
- include procedures for the sampling, handling, transport, storage, and preparation of items to be tested and/or calibrated;
- include the identity of the personnel responsible for the sampling, performance of each test and/or calibration and checking of results;
- use test and/or calibration methods which preferably are those published as international or national standards;
- inform the client when the method proposed by the client is considered to be inappropriate or out-of-date;
- validate their methods to confirm that they are suitable for their intended use;
- be able to estimate measurement uncertainties when this is a customer requirement;
- perform appropriate checks on calculations and data transfers;
- establish calibration programmes for key instruments; and establish equipment maintenance procedures and schedules.

Reporting the uncertainty qualifies the accuracy of the measurement and aids understanding when results from different labs are compared. The ratio of specification-to-calibration uncertainty is one way that equipment users gauge their confidence in a product's performance.

ISO17025 is the single most important metrology standard for test and measurement products. Nearly all national standards bodies and accreditation agencies around the world have adopted it. A growing number of companies require it and some industries have even incorporated it into sector-specific standards.

The quality systems based on ISO 17025 “General requirements for the competence of testing and calibration laboratories” contains all of the requirements that testing and calibration laboratories have to meet if they wish to demonstrate that they operate a quality system, are technically competent, and are able to generate technically valid results.

NDT laboratories provide services, calibrations, testing and inspection, so part of their activities (products and services) are covered by ISO 9000:2000 Quality Management System, while calibration and testing services are covered by ISO 17025.

ISO 17025 (under Section 4.1.3) states: "The laboratory management system shall cover works carried out in the laboratory's permanent facilities, at sites away from its permanents facilities or is associated temporary or mobiles facilities."

Until few years ago there was question mark about the applicability of ISO 17025 for accreditation of NDT laboratories. Many individuals, especially those involved in providing services at industrial process plants away from their premises, were of the opinion that such a standard is only applicable for laboratories and not for field conditions (testing or inspection activities performed at sites). But ISO 17025 statements makes clear that field radioisotope applications are part of it.

How to establish a quality management system and how to obtain accreditation of radioisotope application laboratories, in accordance with ISO 17025?

The procedure is more or less the same as in ISO 9000 series. Accreditation is defined as a confirmation procedure of the competence of a laboratory to carry out their specific tasks. In order to be accredited, a laboratory should demonstrate its technical and organisational competence in its areas of applications. The paper work and requests for accreditation under both ISO 9000 series and 17025 are similar. Institutions that have experience in establishing quality management system according to ISO 9000 series can easy comply with the ISO 17025.

The quality system of a laboratory must be adequate to the type, range, and volume of the work performed. The elements of the system should be documented in a quality manual that is available by the laboratory personnel.

Radioisotope application laboratories should demonstrate their competences in following fields:

- Technical competence (use of radioisotope methods based on knowledge and experience; development, modification, and updating of techniques; qualification of personnel; use of suitable equipment)
- Organisational competence (assurance of the overall traceability of testing procedures and supporting processes in the review of contract, and method validation; regarding technical and personnel realisation).
- Areas of application (availability of complete verifiable documentation and of processes under operational conditions).

After establishing the quality system, the accreditation procedure consists of four stages:

- application,
- assessment,
- accreditation, and
- surveillance (inter-laboratory comparisons, proficiency tests, documentation; re-accreditation after five years).

Quality System

The Centre where a NDT laboratory is part, should guarantee that its organisational and technical activities are planned, supervised and controlled. The staff members of the laboratories and all units of the Centre, which are directly or indirectly involved, are bound to carry out the tasks in accordance with the quality policy stated in the quality manual. All the staff has the right to detect deviations and inadequacies in the quality system, to request corrections and to make suggestions for the improvement of the quality level.

The laboratory has documented instructions on the use and operation of all relevant radioisotope related equipment, on the handling and preparation of test items, and on standard testing techniques. All instructions, standards, manuals and reference data are maintained up-to-date and are readily available to the personnel.

The laboratory is furnished with equipment required for correct performance of the tests. Where the laboratory is obliged to use outside equipment, it should ensure the fitness of that equipment.

Reliability is the basic principle of the quality system. Internal audits, corrective actions, preparation of documents, revision of present documents are carried out in accordance with the procedures and instructions written in the quality manual.

The director of the centre coordinates on his behalf the planning, execution and review of quality system in the centre. He is responsible for the preparation, maintenance and control of the centre's quality manual. A quality manager is authorized for the quality issues.

The documentation structure of the centre consists of the quality manual, quality procedures, instructions, and forms.

Quality Manual

The quality manual describes the structure of the Centre and process organisation as regards quality assurance in the services rendered by it. This is the main unit that has specific and general topics. For the detailed information on any subject, it refers to the annexes, procedures or instructions.

The content of typical quality manual is summarized below.

First chapter includes definitions related to the quality system and specific to the Centre, abbreviations, and the coding system used for forms and instructions. In the second chapter, the objective and the field of application, and legal identity of the centre is explained.

The impartiality, independence and integrity statement is also involved such that "The Centre and its personnel are free from any commercial, financial and other pressures which might influence their technical judgement. Any influence on the results of tests and examinations exercised by persons or organisations external to the Centre shall be excluded. The Centre shall not engage in any activities that may endanger the trust in its independence of judgement and integrity in relation to its testing activities. The re-numeration of the personnel engaged in testing activities shall not depend on the results of tests. When products are tested by bodies, who have been concerned with their design, manufacture or sale, provision for a clear separation of different responsibilities and appropriate statement shall be made". Then, the statement on the confidentiality of test results is written.

Third chapter includes the quality policy of the centre.

Organisation: The general organisation of the Centre is given in a chart (Table I). The name of the personnel responsible for each position is given in annex. Information about the functioning of the organisation system is given in the quality system procedure.

Personnel, duties and responsibilities: Personnel files are kept by the section head. New personnel attend to an orientation program that is planned by the respective section head. This program includes understanding of the quality system and the documents. All staff works according to their duties and responsibilities, which are explained in the annex, under control of the section heads. In the case of temporary absence of any personnel due to various reasons his/her duties and responsibilities are transferred to another who is authorised by the section head.

Qualification and training of the staff: All staff has the necessary education, training, technical knowledge and experience for the assigned functions. The laboratory management ensures that the training of the personnel is kept up to date. All the activities, such as training, to improve the quality level of the services given by the centre are carried out according to the training procedure.

All activities within this frame are planned and realised annually by the section heads by filling the related form. Written procedures are of prime importance in a quality management system.

Table IV provides general contents of a quality manual of a radioisotope service application.

TABLE V. CONTENTS OF A QUALITY MANUAL OF A RADIOISOTOPE APPLICATION SERVICE

1	Definitions
2	Identification of the Centre
3	Management
4	Quality system
5	Premises and environment
6	Equipment
7	Handling of Industrial Jobs
8	Handling of complaints
9	Recording and filing system
	ANNEX
A.0	Distribution List of Quality Manual
A.1	Organisation Charts
A.2	Duties and responsibilities
A.3	Premises
A.4	Environment
A.5	Sample of Contract
A.6	Sample Test Reports
A.7	Check Lists for Application of radioisotope technique
A.8	Radiation Protection Rules
A.9	Declarations for impartiality and independence of the Centre
	QUALITY PROCEDURES
P.1	Quality Procedure
P.2	Quality System Procedure
P.3	Training Procedure
P.4	New Document Preparation and Revision Procedure
P.5	Internal Audit Procedure
P.6	Maintenance-Repair Procedure
P.7	Calibration Procedure
P.8	Purchasing Procedure
P.9	Instruction Preparation Procedure
	INSTRUCTIONS
OI	List of Operating Instructions
MI	List of Maintenance Instructions
CI	List of Calibration/Calibration Control Instructions
TI	List of Test Instructions/Standards
	LIST OF FORMS

6.4. ISO 9712:1999 NDT— QUALIFICATION AND CERTIFICATION OF PERSONNEL

ISO 9712 qualification and certification are widely recognized as having a number of advantages:

- Complies with an internationally agreed ISO Standard which is increasingly being adopted worldwide
- Utilises an internationally developed training syllabus
- Examinations (theory and practical) are provided by independent central examination centres under the control of independent Certification Bodies (most of which are linked to national NDT societies)
- Increasing numbers of Certification Bodies are themselves independently accredited.
- Provides a harmonized standard for training, qualification and certification for NDT personnel and can be used as the base level for more specific employer-based or third party certification relevant to particular products or installations
- The latest version of ISO9712 gives more detailed requirements for practical examinations (including details of test pieces and references) to determine the performance level of the candidate.
- The latest version of ISO 9712 gives guidance on the definition of industrial and product sectors to aid international harmonization.

The certification of NDT personnel is one part of the process of quality assurance in NDT. To avoid unnecessary cost and demotivation of NDT personnel, harmonization and mutual recognition of qualifications is desirable.

Company based certification versus third party central certification.

There is long-standing debate between the proponents of the two types of scheme. Company-based certification is especially favoured in the USA and is used world wide in business areas which employ American codes and standards. Third party independent central certification is employed in the rest of the world and is particularly favoured in Europe, parts of Asia, Canada etc. This type of certification has been standardized at European and International level through EN473 and ISO9712.

Proponents of company-based certification argue the benefits of training and certification being directed closely at the needs of the particular company's NDT business. Those who favour third party central certification argue the benefits of standardisation, harmonisation, and independence.

There is a gradual coming together of the central independent and company-based approaches. The former are increasingly aware of the need for the central certification to be used in the correct way — as part of an organisation's quality systems for NDT - and the standards for company-based certification are bringing in requirements for external assessment eg. independently certified Level 3s.

Competition between EN 473 versus ISO 9712 standards

These standards for third party certification had the same roots in the International Committee for NDT (ICNDT) Recommendations for Training but diverged during the development stage. The differences are relatively minor but are a cause of confusion. ICNDT strongly supports the convergence of the two standards as soon as possible. In practice in the meantime, it is realistic for a personnel certification scheme to meet the minimum requirements of both standards and this is the case for many schemes in Europe.

Competition between Personnel Certification schemes

In most countries in the world there is competition between the different NDT personnel certification schemes. For example, throughout Europe there exist accredited national third party independent certification schemes which are linked to the national NDT societies. In some countries (e.g. Russian Federation, Sweden) there are several such schemes. These schemes, which offer EN473/ISO9712 certification, operate in competition with providers of ASNT Certification to SNT-TC-1A. ASNT conducts Level 3 examinations to its own standard in several European countries. There is also competition from schemes operated by welding societies. In the USA, ASNT faces competition from the welding societies.

There are both advantages and disadvantages from this competition. Arguably it keeps costs/prices of individual schemes down and it keeps certification providers closely focused on the needs of the customer. However the competition also has disadvantages. It inhibits any desire to raise quality standards and the existence of multiple certifications causes additional costs. Individuals who carry one type of certification frequently have to be retrained and re-examined to gain a second or third type of certificate.

ICNDT/ISO

Cooperation in the area of training and certification of NDT personnel began in ICNDT. In 1985, ICNDT published its Recommendation ICNDT WH 15-85 "Basic Requirements for National Personnel Qualification and Certification Schemes" which had been prepared by a Working Group on Harmonisation of Training and Qualification of NDT Personnel. This document, which was re-published in the ICNDT Journal No.2 April 1999, set down the key principles to be followed in the establishment of national independent third party central certification schemes. ICNDT also published a Training Syllabus for each method (ICNT WH 16-85 to 22-85). These principles and most of the details were embodied in the International Standard (ISO9712) and the European Standard (EN473).

The IAEA has been cooperating with international bodies to achieve the harmonisation of international NDT practices especially in the field of training and certification of NDT personnel. The IAEA has already published a number of training materials in support of ISO9712 standard. The IAEA TECDOC 628/Rev.1 Training Guidelines in Non-Destructive Testing Techniques has played an important role in qualification of NDT specialists worldwide, in particular in developing countries.

The ISO Technical Committees are working continuously to define new guidelines with the intention to better establish and maintain the general standard of training of non-destructive testing (NDT) personnel for industrial needs. Two recent proposals are submitted for approval:

- ISO/TC135 N278: prCEN/TR 15107:2004: Non-destructive testing — Training syllabuses for NDT personnel
- ISO/TC135 N279: prCEN/TR 15108: 2004: Non-destructive testing — Guidelines for NDT personnel training organizations

These publications are prepared by the International Standard Organization ISO/TC 135 and European Committee for Standardization CEN/TC 138 working groups to promote harmonisation and mutual recognition of minimum requirements of the different existing certification schemes. They update the ISO 9712 in the light of new development in NDT technology. Simplifying the training, qualification and certification services is the main objective of new standards in NDT.

7. STANDARDS AND SPECIFIC REFERENCES

ACI REPORTS

201.1R	Guide for Making a Condition Survey of Concrete in Service
207.3R	Practices for Evaluation of Concrete in Existing Massive Structures for Service Conditions
222R	Corrosion of Metals in Concrete
224.1R	Causes, Evaluation and Repair of Cracks in Concrete Structures
228.1R	In-Place Methods to Estimate Concrete Strength
228.2R	Nondestructive Test Methods for Evaluation of Concrete in Structures
362R	State-of-the-Art Report on Parking Structures
437R	Strength Evaluation of Existing Concrete Buildings
503R	Standard Specification for Bonding Hardened Concrete, Steel, Wood, Brick, and Other Materials to Hardened Concrete with a Multi-Component Epoxy Adhesive

ASTM STANDARDS

ASTM C 39	Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 42	Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C 215	Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens
ASTM C 294	Descriptive Nomenclature for Constituents of Natural Mineral Aggregates
ASTM C 295	Guide for Petrographic Examination of Aggregates for Concrete
ASTM C 341	Test Method for Length Change of Drilled or Sawed Specimens of Hydraulic-Cement Mortar and Concrete
ASTM C 457	Test Method for Microscopical Determination of the Air-Void System in Hardened Concrete
ASTM C 469	Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
ASTM C 496	Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C 597	Test Method for Pulse Velocity through Concrete
ASTM C 642	Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete
ASTM C 805	Test Method for Rebound Number in Concrete
ASTM C 803	Test Method for Penetration Resistance of Hardened Concrete
ASTM C 823	Practices for Examination and Sampling of Hardened Concrete in Constructions
ASTM C 856	Practices for Petrographic Examination of Hardened Concrete
ASTM C 876	Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete
ASTM C 1040	Test Methods for Density of Unhardened and Hardened Concrete in Place by Nuclear Methods
ASTM C 1084	Test Method for Portland-Cement Content of Hardened Hydraulic-Cement Concrete
ASTM C 1152	Test Method for Acid-Soluble Chloride in Mortar and Concrete
ASTM C 1202	Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
ASTM C 1218	Test Method for Water-Soluble Chloride in Mortar and Concrete
ASTM C 1383	Test Method for Measuring P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method
ASTM D 4748	Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar
ASTM D 4580	Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding

ASTM D 4748	Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar
ASTM D 4788	Test Method for Deflecting Delaminations in bridge Decks Using Infrared Thermography
ASTM E 105	Practices for Probability Sampling of Materials
ASTM E 122	Practices for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process
ASTM G 15	Terminology Relating to Corrosion and Corrosion Testing

AASHTO STANDARD

AASHTO T 259	Method of Test for Resistance of Concrete to Chloride Ion Penetration

BRITISH STANDARD

BS 1881 Part 204	Recommendations on the Use of Electromagnetic Covermeters
BS 1881 Part 205	Recommendations for Radiography of Concrete
BS 1881 Part 207	Recommendations for the Assessment of Concrete Strength by Near-to-surface Tests
BS 1881 Part 5	Methods of Testing Concrete for Other than Strength

CSA STANDARDS

CSA-A23.2-M94	Methods of Test for Concrete

The above publications may be obtained from the following organizations:

American Concrete Institute (ACI)
P.O. Box 9094
Farmington Hills, Mich. 48331-9094,
USA

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, Penn. 19428-2959,
USA

American Association of State Highway and Transportation Officials (AASHTO)
444 N. Capitol St., NW
Washington, D.C. 20001,
USA

Canadien Standards Association (CSA)
178 Rexdale Boulevard
Rexdale, Ontario M9W 1R3
Canada

British Standards Institution (BS)
2 Park Street
London W1A 2BS
England

ISO NON-DESTRUCTIVE TESTING

- ISO/TTA 3, Polycrystalline materials — Determination of residual stresses by neutron diffraction.
- ISO 1027, Radiographic image quality indicators for non-destructive testing — Principles and identification.
- ISO 3057, Non-destructive testing — Metallographic replica techniques of surface examination.
- ISO 3058, Non-destructive testing — Aids to visual inspection — Selection of low-power magnifiers.
- ISO 3059, Non-destructive testing — Penetrant testing and magnetic particle testing — Viewing conditions.
- ISO 3452, Non-destructive testing — Penetrant inspection —General principles.
- ISO 3452-2, Non-destructive testing — Penetrant testing — Part 2: Testing of penetrant materials.
- ISO 3452-3, Non-destructive testing — Penetrant testing — Part 3: Reference test blocks.
- ISO 3452-4, Non-destructive testing — Penetrant testing — Part 4: Equipment.
- ISO 3453, Non-destructive testing — Liquid penetrant inspection — Means of verification.
- ISO 3999, Apparatus for gamma radiography — Specification.
- ISO 3999-1, Radiation protection — Apparatus for industrial gamma radiography — Part 1: Specifications for performance, design and tests.
- ISO 5576, Non-destructive testing —Industrial X ray and gamma-ray radiology — Vocabulary.
- ISO 5577, Non-destructive testing — Ultrasonic inspection — Vocabulary.
- ISO 5580, Non-destructive testing — Industrial radiographic illuminators — Minimum requirements.
- ISO 9712, Non-destructive testing — Qualification and certification of personnel.
- ISO 9934-1, Non-destructive testing — Magnetic particle testing — Part 1: General principles.
- ISO 9934-3, Non-destructive testing — Magnetic particle testing — Part 3: Equipment.
- ISO 9935, Non-destructive testing — Penetrant flaw detectors — General technical requirements.
- ISO 10375, Non-destructive testing — Ultrasonic inspection — Characterization of search unit and sound field.
- ISO 11537, Non-destructive testing — Thermal neutron radiographic testing — General principles and basic rules.
- ISO 12706, Non-destructive testing — Terminology — Terms used in penetrant testing.
- ISO 12710, Non-destructive testing — Ultrasonic inspection —Evaluating electronic characteristics of ultrasonic test instruments.
- ISO 12713, Non-destructive testing — Acoustic emission inspection —- Primary calibration of transducers.

- ISO 12714, Non-destructive testing — Acoustic emission inspection — Secondary calibration of acoustic emission sensors.
- ISO 12715, Ultrasonic non-destructive testing — Reference blocks and test procedures for the characterization of contact search unit beam profiles.
- ISO 12716, Non-destructive testing — Acoustic emission inspection — Vocabulary.
- ISO 12721, Non-destructive testing — Thermal neutron radiographic testing — Determination of beam L/D ratio.
- ISO 15708-1, Non-destructive testing — Radiation methods — Computed tomography — Part 1: Principles.
- ISO 15708-2, Non-destructive testing — Radiation methods — Computed tomography — Part 2: Examination practices.

ISO RADIOGRAPHIC FILMS.

- ISO 11699-1, Non-destructive testing — Industrial radiographic films — Part 1: Classification of film systems for industrial radiography.
- ISO 11699-2, Non-destructive testing — Industrial radiographic films — Part 2: Control of film processing by means of reference values.

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- ISO 4987, Steel castings — Penetrant inspection.
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- ISO 5948, Railway rolling stock material — Ultrasonic acceptance testing.
- ISO 6933, Railway rolling stock material — Magnetic particle acceptance testing.
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- ISO 9303, Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes — Full peripheral ultrasonic testing for the detection of longitudinal imperfections.
- ISO 9304, Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes — Eddy current testing for the detection of imperfections.
- ISO 9305, Seamless steel tubes for pressure purposes — Full peripheral ultrasonic testing for the detection of transverse imperfections.
- ISO 9402, Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes — Full peripheral magnetic transducer/flux leakage testing of ferromagnetic steel tubes for the detection of longitudinal imperfections.

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- ISO 10543, Seamless and hot-stretch-reduced welded steel tubes for pressure purposes — Full peripheral ultrasonic thickness testing.
- ISO 11484, Steel tubes for pressure purposes — Qualification and certification of non-destructive testing (NDT) personnel.
- ISO 11496, Seamless and welded steel tubes for pressure purposes — Ultrasonic testing of tube ends for the detection of laminar imperfections.
- ISO 11971, Visual examination of surface quality of steel castings.
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- ISO 12095, Seamless and welded steel tubes for pressure purposes — Liquid penetrant testing.
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- ISO 1106-2, Recommended practice for radiographic examination of fusion welded joints — Part 2: Fusion welded butt joints in steel plates thicker than 50 mm and up to and including 200 mm in thickness.
- ISO 1106-3, Recommended practice for radiographic examination of fusion welded joints — Part 3: Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness.
- ISO 2400, Welds in steel — Reference block for the calibration of equipment for ultrasonic examination.
- ISO 2437, Recommended practice for the X ray inspection of fusion welded butt joints for aluminum and its alloys and magnesium and its alloys 5 to 50 mm thick.
- ISO 2504, Radiography of welds and viewing conditions for films — Utilization of recommended patterns of image quality indicators (I.Q.I.).
- ISO 5817, Arc-welded joints in steel — Guidance on quality levels for imperfections.

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